

**EVALUATION OF THE MORPHOLOGICAL AND GENETIC
DIVERSITY OF BAMBARA GROUNDNUT (*Vigna subterranea* [L.] Verdc)
USING MICROSATELLITE MARKERS**

BY

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DECLARATION

I, Amaefule, Comfort Chioma with Registration Number: GBT/Ph.D/15/001 hereby declare that this thesis on “Evaluation of the morphological and genetic diversity of bambara groundnut (*Vigna subterranea*) using microsatellite markers” is the product of my research effort under the supervision of Prof. Ene-Obong Efiom Ene-Obong and Prof. Edak A. Uyoh and has not been presented elsewhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that this thesis titled “**Evaluation of the Morphological and Genetic Diversity of Bambara Groundnut (*Vigna subterranean (L.) verdc*) using Microsatellite Markers.**” carried out by **Amaefule, Comfort Chioma** with Registration number **GBT/Ph.D/15/001** has been examined and found worthy for the award of the degree of Doctor of Philosophy in Genetics and Biotechnology (Plant Biotechnology).

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ABSTRACT

The high nutritional value of bambara groundnut (*Vigna subterranea* [L.] Verdc.) has placed a tremendous demand on it in the face of low supply due to neglect and continuous use of poor cultivars with low genetic base. Information on the genetic variability and adaptation of this crop has remained scanty and minimal. This study focused on the evaluation of the morphological and genetic diversity of bambara groundnut for a possible adaptation to Calabar South-South ecological zone. Thirty eight accessions sourced from local farmers and the International Institute of Tropical Agriculture (IITA), Ibadan Nigeria were studied. The field experiment was laid out in a randomized complete block design (RCBD) with three replications while the molecular work was done using seven microsatellite markers specific for bambara groundnut. Thirty characters, representing 20 quantitative and 10 qualitative traits were studied. Data collated were subjected to analysis of variance (ANOVA), principal component analysis (PCA) as well as heritability computations. Significant differences were observed among the accessions for most of the traits studied ($P < 0.05$) indicating enormous morphological diversity. Principal component analysis (PCA) revealed that plant height, leaflet number, leaf area, seed weight, seed yield per plot, pod fresh weight, pod dry weight, terminal leaflet width and length, petiole and internode lengths contributed most of the variations observed among the accessions. Broad sense heritability estimates were high in many of the traits but was at its peak in pod fresh weight suggesting that many of these traits may have genetic bases. Correlation and regression coefficients showed that number of pods per plant, pod fresh weight, pod dry weight and seeds per plant associated positively and significantly with yield. Thus, selection for these traits would help in the improvement of yield in bambara groundnut. The study also revealed a moderate level of genetic diversity in the accessions (mean of 0.53). The dendrogram generated from the morphological data grouped the 38 accessions into three major clusters, with several sub-clusters. Grouping of accessions into sub-clusters indicated some level of intra-landrace polymorphism, suggesting that accessions existed in various forms which could be harnessed for the improvement of bambara crops. The principal coordinate analysis (PCoA) from the morphological data grouped the accessions based mainly on their origin and source of collection. There was a slightly similar grouping pattern between SSR markers and morphological parameters in the accessions. This was shown by the grouping together of the highest yielding accessions as obtained in

this study on the P-2 axis of the PCoA for SSR markers and cluster two of the dendrogram generated from the morphological data. The highest yielding accessions in this study (NG/BG/2/1-A3 with 9.38g, NG/BG/1-A2 with 8.16g; NG/BG/2/2-A4 with 8.13g and NG/BG/4-A5 with 7.74g) were the locally sourced ones, they performed better in yield than the improved varieties from IITA. These 4 varieties are therefore recommended for growth in the Calabar region of Nigeria. In conclusion, although the yield recorded in this work is lower than records from the Middle Belt and Northern Nigeria as well as some African countries, the present study has shown that the crop could also have a good yield in Calabar agro-ecology if properly managed. In addition, the observed genetic variability would aid further selection for improved traits. (Word count: 485)

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Plant proteins provide nearly 65% of the world's need of protein for humans in the ratio of 50:15 from legumes and cereals, respectively (Oiiimelukwe, 1992). Food legumes have been part of meals that are low in price around the globe. They have a major role to play in the fight against malnutrition and to contribute to food security (Borget, 1992; Brink *et al.*, 2006; Aliyu *et al.*, 2016). One example of such legume is the Bambara groundnut (*Vigna subterranean* [L] Verdc.) which is an underutilized crop species. Bambara groundnut is an indigenous African legume which represents the third most important pulse of sub-saharan Africa after groundnut (*Arachis hypogea*) and cowpea (*Vigna unguiculata*) (Odongo *et al.*, 2015). The crop is a herbaceous indeterminate annual plant, with creeping stems at ground level. It grows to a height of 0.30-0.35m with compound leaves of three leaflets (Bamshaiye *et al.*, 2011).

Vigna subterranea (L) Verdc, belongs to the family Fabaceae which is morphologically diverse and includes a number of trees and some aquatic plants. It is the third largest family of flowering plants, consisting of about 650 genera and 180,000 species (Doyle and Luckow, 2003). The family Fabaceae has an important socio-economic role in the tropical zone, especially in Africa where they are part of tradition in culinary habits (Massawe *et al.*, 2005). It serves as an important source of protein in the diets of a large percentage of the population in Africa (Odongo *et al.*, 2015), particularly the poor people who cannot afford expensive animal protein. The crop has natural agronomic advantages including nutritional values, drought tolerance and the ability to thrive in soils that are considered insufficiently fertile. It is primarily

cultivated for its seeds which are highly nutritious and are used for both human and animal consumptions (Baryeh, 2001; Olukolu *et al.*, 2012).

Research into the production and improvement of bambara groundnut has been neglected for many years. Although, farmers have an important role to play as custodians of this crop (Hillocks *et al.*, 2012), the responsibility of its propagation and improvement should not be saddled with them alone. There should be governmental interventions as well as support from the private sectors which might serve as possible bridge between farmers and consumers (Atoyebi *et al.*, 2017).

1.2 Justification

Legumes are the most important sources of plant-based proteins for human and animals. Their high nutritional values have placed a tremendous demand on them in the face of low supply due to neglect and continuous use of poor cultivars with low genetic base. Bambara nut is a promising commodity whose potentials are largely unexploited. Its cultivation in Nigeria presently is mainly limited to the middle belt as well as the northern part of the country. It is no longer widely cultivated in the South-East of the country as was the case previously as a result of low yield and is sparsely grown in the South-South region. Information on genetic variability and adaptation of this crop has remained scanty as the crop has been largely neglected by modern researchers. Hence, there is need to focus first and foremost on a proper characterization of available germplasm as well as morpho-agronomic studies for its adaptability to the South-South zone of Nigeria, which is what the present study did. This would help in the selection of landraces that would enhance the performance of the crop in this zone.

1.3 Aim and objectives of the study

The aim of the research was to study the genetic variability of bambara groundnut as well as its adaptability to South-South ecological zone of Nigeria.

The objectives were:

- i. To evaluate the morphological traits and adaptability of 38 accessions of bambara groundnut to Calabar in the South-South ecological zone of Nigeria
- ii. To evaluate yield and yield-related traits in the accessions studied
- iii. To identify traits that contribute most significantly to variation in these accessions using principal component analysis (PCA)
- iv. To document the genetic variability existing within 38 accessions of bambara groundnut using SSR marker.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of bambara groundnut

Investigations into the origin of Bambara groundnut revealed that it originated from the African continent; that it was actually found by Dalziel in its wild state in 1901 around the Jos Plateau and Yola in Nigeria. There was another report that same year about Ledermann who also found Bambara groundnut (wild species) near Garoua in Northern Cameroon (Dalziel, 1937). Generally, Nigeria and Cameroon have been accepted as the putative centres/origins of domestication of *V. subterranea* (Hepper, 1963; Harlan, 1977; Goli, 1995).

Many other authors as well as scientists have carried out some studies in order to ascertain this claim. Begemann (1988) undertook a detailed analysis of seed diversity in a collection of bambara groundnut from the international Institute of Tropical Agriculture (IITA). He found out that samples collected within 200km of the putative centre (Yola/Cameroon) showed greater diversity than accessions and samples collected from other regions. Similarly, Olukolu *et al.* (2012) using both diversity array technology (DArT) molecular markers and phenotypic descriptors on 40 and 124 accessions respectively, provided evidence that pointed out Nigeria and Cameroon as the putative areas of origin of bambara groundnut. These regions showed a higher phenotypic diversity for both quantitative and qualitative characters compared to other regions. In contrast to the above claim, Somta *et al.* (2011) studied diversity in a collection of 240 bambara groundnut accessions using 22 simple sequence repeat (SSR) markers and found highest diversity in West Africa (excluding Cameroon and Nigeria). Based on the above results, Odongo *et al.* (2015) maintained that the centre of diversity and origin of Bambara groundnut is still inconclusive as more evidence is needed to elucidate them. However, Rungnoi *et al.* (2012) suggested that the contrasting results

reported by Somta *et al.* (2011) might have stemmed from the different DNA markers, number of loci and germplasm used. They maintained that the centre of origin of Bambara groundnut is West Africa (including Cameroon and Nigeria), having analyzed a set of 363 bambara groundnut accessions from five geographical region using inter simple sequence repeat (ISSR) and random amplified polymorphic DNA (RAPD). Molosiwa *et al.* (2015) and Aliyu *et al.* (2016) independently raised the possibility of the Southern African region as a secondary centre of domestication or diversity for the bambara groundnut and suggested a call for re-evaluation of the current domestication theory and hypothesis of *V. subterranea*, based on emerging new data.

Today, *V. subterranea* is widely cultivated throughout tropical Africa, Indonesia, Malaysia, India, Srilanka, Philippines, South Pacific, parts of northern Australia, Papua New Guinea, Central and South Thailand and America (Brink *et al.*, 2006; Temagne *et al.*, 2018). The crop is believed to have been brought first to East Africa and Madagascar, then to South East Asia and with the slave trade to Suriname, Brazil and later to the New World (Hamelt, 2001). In 2001, FAO published a global mapping account of the earth pea in which crop modelling was used for the first time to predict areas of production as well as potential yields. Azam-Ali *et al.* (2001) reported that countries with a Mediterranean climate such as Lebanon, Israel and some European countries including Italy, Portugal, Spain and Greece are potential areas for the cultivation of bambara groundnut.

2.2 Nomenclature and taxonomy

The genus *Vigna* is an important legume taxon. It comprises about 90 described species of which seven are cultivated as economic crops in various regions whilst several others are planted as minor crops. Some widely grown ones are harvested for food and feed (Rungnoi *et al.*, 2012; Odongo *et al.*, 2015).

In 1763, Linnaeus (the father of botanical/scientific names) described the bambara groundnut in species *Plantarum* and named it *Glycine subterranea* in accordance with his naming system. Thereafter, Du Petit-Thouars (1806) located the crop in Madagascar (already called by the local people as “Voanjo”) and named it *Voandzeia subterranea* (L.) Thouars. This name was widely used by researchers for more than one hundred years. Then, Marechal *et al.* (1978) undertook detailed botanical studies on bambara groundnut and found great similarities between this crop and plant species of the genus, *Vigna*. This research was in line with the studies done by Verdcourt, who in 1980 proposed the current name: *Vigna subterranea* (L.) Verdc (Goli, 1995). The species *Vigna subterranea* is further divided into two groups: var.*spontanea*, comprising the wild type and var.*subterranea* consisting of the cultivated forms (Basu *et al.*, 2007). The chromosome number in both var.*spontanea* and var.*subterranea* is $2n=2x=22$ (Forni-Martins, 1986; Heller *et al.*, 1997). The wild types of the grain legume landraces usually have a spreading growth habit, compared to the compact type of the cultivated landraces (Swanevelder, 1997). The two types also differ in pod size, with domesticated landraces having bigger seeds which do not wrinkle upon drying unlike the wild types (Pasquet, 2003; Basu *et al.*, 2007). Several African varieties differ in the shape and size of the leaves, as well as the colour, size and hardness of the seeds (Purseglove, 1992). There might be no named cultivar of bambara groundnut yet, but genotypes are differentiated based on seed characteristics (colour, size, hardness) and growth habit (bunch, semi-bunch or spreading). Sometimes, crops are named on the basis of the location where the seeds are collected (Brink *et al.*, 2006).

Different names are associated with bambara groundnut. In French language, it is called Voandzou, “pois bambara” or “Pois de terre”. The generally acceptable common name – ‘bambara groundnut’ is linguistically linked to the Bambara tribe, near Timbuktu (a derivative of the Mande group of people) whose descendants now live

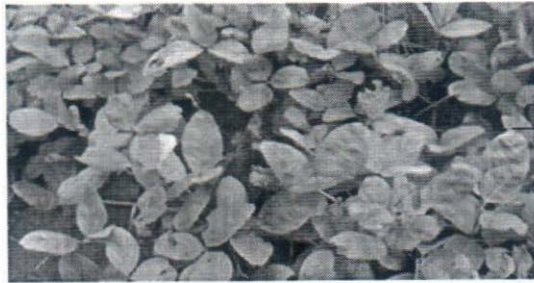
mainly in modern day Mali (Holm and Marloth, 1940; Aliyu *et al.*, 2016). However, the tribe has no claim to the plant, only that wild forms might have been located near Senegal (Dimakatso, 2006; Temegne *et al.*, 2018). Other English names include: bambara pea, bambara nut, hog-peanut, bambara bean, Congo goober, earth pea and ground bean. The bambara nut is also known as jugo beans (South Africa) ntoyo ciBemba (Republic of Zambia), nyimo beans (Zimbabwe), matob (Douala-Cameroon). In Nigeria, it is known by the major ethnic groups as okpa (Igbo), gurjiya or kwaruru (Hausa) and eparoro by the Yorubas (Bamshaiye *et al.*, 2011).

2.3 Morphology of bambara groundnut

Bambara groundnut generally takes the appearance of bunched leaves arising from branched stems which form a crown on the soil surface (Goli, 1995) (Plate 1). The leaves with erect petiole are alternate and trifoliate. The plant is considered to be autogamous (Baudoin and Mergaei, 2001). It has a taproot surrounded by lateral profuse roots which grow from the nodes at each stem. The roots bear nitrogen-fixing nodules (Heuze *et al.*, 2016). The peduncles are auxiliary, elongating from the stem nodes. During pollination and fertilization, the peduncle stretches to bring ovaries at the soil level. After fertilization, the pedicels grow downwards into the soil to form pods with either one or two seeds (Dimakatso, 2006). It might not require complete coverage with soil for pods to develop.

2.3.1 Growth and development of bambara nut

The emergence of seedling takes place within five to twenty one (5-21) days after planting. Flowering starts 30 – 55 days after sowing and may continue until the plant dies (Brink *et al.*, 2000). Pods reach maximum size at about 30 days (after fertilization) and during the following 10 days, the seeds expand and reach full maturity (Linnemann and Azam-Ali, 1993).



leaflet



Flowers



Pods

PLATE 1: Morphology of bambara groundnut

The duration of the crop cycle is between 100 - 180 days (Baudoin and Mergeai, 2001); although some records of reduced growth cycle landraces of approximately 90 days have been recorded in Ghana (Berchie *et al.*, 2010). Plants are hand weeded (about 1 – 3 times) and covered up with soil during flowering to encourage development of the pods or to improve yield respectively Tweneboah (2000).

Bambara groundnut is a short day plant. Fruit development has been observed and reported to be influenced by photoperiod (Linneman and Azam-Ali, 1993). Long photoperiods delay or even prevent fruit-set in some genotypes (the shorter the photoperiod, the higher the number of pods). In most genotypes; the onset of flowering is not affected by photoperiod (Nishitani *et al.*, 1988; Brink, 1997). Generally, photoperiod usually has a stronger effect on the onset of podding than on the onset of flowering (Linnemann and Cruafurd, 1994). Maturity of pod is delayed under long photoperiods. Vegetative growth might occur in spring and early summer while the pods may set in late summer (Linnemann *et al.*, 1995).

2.3.2 Propagation and planting of bambara groundnuts

Sowing dates for bambara groundnuts may vary with locations and depends on the rainfall pattern. Swanevelder (1997) reported that early or late planting of the crop may affect its pod formation. He advocates the importance of knowing the correct planting date to encourage higher yield production in a well-adapted environment. He noted that bambara groundnut produces good yields when planted between October and November. In Zambia and Botswana, sowing takes place from November to February (Brink *et al.*, 2006). In the dried savanna zone of Ghana, two cropping seasons are possible, May – June and October respectively. In the other regions of Ghana, planting is done between August/September and September/November when rainfall is reliable

moisture is scarce, this strategy enables a greater volume to be exploited for available water. The ground pea uses the available water frugally through slow leaf development, thereby conserving water for the crop to thrive during the reproductive stage in order to produce good yield. The crop needs an average annual rainfall of 600-700mm during the growing season and dry period for harvesting (Heller *et al.*, 1997; Swanevelder, 1997). It requires cool and warm temperatures and does not tolerate freezing temperature at any stage of growth. Cool temperatures are conducive to longer seed filling periods and as a result help in the increase in yield (Wych *et al.*, 1982). An average day temperature for the Bambara groundnut development ranges between 20°C to 28°C. Extreme temperatures may bring about dryness of leaves, resulting in yield reduction. (Heller *et al.*, 1997; Swanevelder, 1997). Karikari (1971) suggested that the dry season would be more favourable for the cultivation of bambara nut than the wet seasons. He observed that the fertility coefficient (the pod: flower ratio) was higher during the dry than in wet season.

2.4 Yield, production and marketing of bambara groundnut

Yields of bambara groundnut vary with the genotype planted (Heller *et al.*, 1997; Swanevelder, 1997). The landraces can produce good yield in controlled environment and field experiments. Yields as high as 4t/ha (4000kg) were obtained in an experiment carried out at the University of Nottingham's tropical Crop Research (TCRU) under controlled environment (Molosiwa, 2012). Kouassi and Zoro (2009) equally recorded the same yield (4t/ha) in a field experiment in Cote d'Ivoire. Average yields are 300-800kg/ha but yields of less than 100kg/ha are also reported (Brink *et al.*, 2006). Average yield of bambara groundnut is low and unstable compared to other cultivated *Vigna* crops. This is because there are no improved cultivars, thus local genotypes and landraces are mostly used for planting. Other factors include: poor seed

storage which may result in low seed germination, difficulty of breeding cultivars through hybridization due to the small nature of the flowers as well as the production environment which may be characterized by various abiotic and biotic stresses. If these landraces are further developed to produce cultivars and varieties, they could possibly produce even greater yield with improved stability (Dimakatso, 2006; Odongo *et al.*, 2015). It is reported that number of pods per plant is an important component of seed yield in bambara groundnut and that yield could be improved through selection of that component (Mayes *et al.*, 2019). It is important therefore to select genotypes that are high yielding and stable in different agro-ecological conditions. This is possible after the effects of individual components on yield and yield stability have been established (Heller *et al.*, 1997; Swanevelder, 1997).

The major producers are Burkina Faso, Chad, Cote d'Ivoire, Ghana, Mali, Niger, Nigeria, Cameroun and Zambia with Burkina Faso, Chad, Mali and Niger as the key exporters. They make their sales in Benin, Ghana, Nigeria and Togo (Brink *et al.*, 2006). Cameroon has been recorded as the second world's largest producer of bambara groundnut after Burkina Faso which is the leading country. Its production in Cameroon increased from 6,800 tons in 1996 to 42,041 tons in 2016 (Temegne *et al.*, 2018).

2.5 Pests and diseases

Bambara groundnut is considered to be generally less affected by pests and diseases than peanuts or cowpea but some diseases and pests have been identified as causing damage to the crop. Such diseases include: leaf spot and blight caused by *Phoma exigua var. exigua*, *Cercospora* leaf spot caused by *Cercospora spp*, powdery mildew caused by *Erysiphe polygoni*, *Fusarium* wilt caused by *Fusarium solani* and *F. oxysporium*, root rot caused by *Pythium parocandrum* (Brink *et al.*, 2006; Magagula *et al.*, 2003). *Fusarium wilt* disease attacks young seedlings and limits yields of the

grain. *Cercospora* is one of the major diseases that attack the crop (foliage) usually under irrigation. It reduces the quality of the fodder. Powdery mildew is a widely spread disease observed on leaflets in form of white powder (Dimaktoso, 2006). Some examples of pests include: Root knot nematode (*Meloidogyne javanica* and *M. incognita*) which attacks roots of crops in the soil; moth beetle (*Piezotrachelus ugandum*) which damages the young and developing pods of bambara groundnut. Others are aphids which spread rosette viral diseases and groundnut plant hopper (*Hilda patruelis*) which feeds on pods of the crop. There are also attacks on the pods by termites in dry weather (Mkandamire, 2007; Goli, 1995). In storage, the seeds are prone to attack by bruchids (*Callosobruchus maculatus*) (Munthali and Ramoranthudi, 2003).

2.6 Nutritional contents of bambara groundnut

Bambara groundnut has been described as a complete food because the seed contains sufficient quantities of protein, carbohydrate and fat (Goli, 1995; Bamshaiye *et al.*, 2011). The seeds contain an average of 15 – 20% protein, 50 – 65% carbohydrate, 4.5-7.4% fat, 2% mineral, 3.2-4.4% ash, 10% water and 3-5% fibre (Baudoin and Mergeai, 2001; Murevanhema and Jideani, 2013). Brink *et al.* (2006) reported that dried leaves for fodder contain 15.9% crude protein, 31.7% crude fibre, 7.5% ash and 1.8% fat. Minerals from the seed include calcium, potassium, iron and nitrogen while vitamins include vitamin E ($3.18 \pm 0.15 \text{mg}/100\text{g}$), vitamin C ($1.17 \pm 0.20 \text{mg}/100\text{g}$) and vitamin A ($26.05 \pm 0.14 \text{mg}/100\text{g}$) (Jideani and Diedericks, 2014; Brink *et al.*, 2006). The crop equally contains kaempferol, an antioxidant polyphenol which reduces the risk of many chronic diseases such as cancer (Jideani and Diedericks, 2014). It has high content of essential amino acids like methionine (1.3%) and lysine (6.8%) (Ella and Singh, 2008). Bamshaiye *et al.* (2011) reported that, bambara groundnut seeds are

richer than peanuts in the above mentioned essential amino acids. This is important as bambara groundnut can be used to complement foods lacking in these essential amino acids (Minka and Bruneteau, 2000). The high nutritional value of this crop provides a cheap source of protein to poorly resourced farmers in semi-arid areas (Borough and Azam-Ali, 1992; Amarteifio *et al.*, 2006). Its fat and protein contents are low when compared to other grain legumes such as soybean (protein-35%) and cowpea (protein-30%) (Heller *et al.*, 1997) but the gross energy value is greater than cowpea lentil and pigeon pea (FAO, 1982). Although *Vigna subterranea* is an important source of protein in developing countries, research has revealed the presence of anti-nutritional factors such as condensed tannins (0.2 to 6.2 mg/g), phytic acid phosphate (1.4 to 4.9 mg/g) and polyphenol (0.4 mg/g) (Unigwe *et al.*, 2017). However, Akaninwor and Okechukwu (2004) observed that these anti-nutritional contents in bambara groundnut can be lowered by approximately 50% through processing techniques such as soaking, dehulling, drying and autoclaving.

2.7 Uses of *Vigna subterranea*

Various parts of the plant are useful. The leaves are used as fodder because they are rich in nitrogen and phosphorus (Dimaktso, 2006; Bamshaiye *et al.*, 2011). The haulms are palatable and serve as an important source of livestock feed during the dry season (Tibe *et al.*, 2007). The roots are sometimes used as an aphrodisiac. Leaf preparations/extracts are used in Senegal to treat abscesses, infected wounds, as well as epilepsy (Brink *et al.*, 2006).

The seeds are used in many types of foods. In general, both the immature and mature bambara nut seeds are consumed. The mature seeds are hard and should be soaked before they could be boiled (Gibbon and Pain, 1985). The immature seeds can be eaten fresh, grilled or boiled, shelled or unshelled. In Ghana, the nuts are boiled with

pepper and salt in preparation of their local food “Aboboi” which could be served with “garri” or “tatare” (mashed fried ripe plantain) to make a very delicious meal (Doku and Karikari, 1970). Also, in Ghana and Zimbabwe, the canning of the bambara seeds in sauce has been reported (Baudoin and Mergeai, 2001; Makanda *et al.*, 2009). Bambara milk is processed from seed in ways similar to that of soymilk and is often used as weaning milk in many African countries. It has been reported that bambara groundnut milk (BGNM) is rated higher in acceptability compared to other legume-based milks such as soybean and cowpea (Murevanhema and Jideani, 2013).

The dry seeds are usually pounded or ground into fine powder to obtain flour that may be used in different recipes. In South Eastern Nigeria, particularly in Enugu State, the dried bambara seeds are ground into powder (flour) and made into “Okpa”. Here, the flour is mixed with palm oil, pepper, salt, water and ground “uziza” seeds. It is traditionally wrapped with banana leaf, tied at both ends. This banana leaf is usually smoked or put over fire to soften it, and then the mid-rib is removed for proper and easy wrapping (personal communication). In Enugu Ezike (still in Enugu State), the flour could also be mixed with cold water and cooked. After much stirring and when it solidifies, under controlled environment could be eaten with special soup prepared with maize. The dried bambara seeds can be fried and eaten as snacks with coconut or palm kernel (in Nigeria). In Indonesia, it is equally fried and eaten as snacks called “Kacang bogor”. In Cameroon, the seeds are ground into flour to make ‘koki’(Temegne *et al.*, 2018). In East Africa, the seeds are roasted then pulverized and used to make soup with or without other ingredients. Bread made from bambara groundnut flour has been reported in Zambia (Linnemann, 1990). The bambara seeds can be used as animal feed. Seeds have been used to feed chicks (Bamashaiye *et al.*, 2011).

Bambara groundnut seeds appear in different colours: black, cream-white, brown, red, mottled and purple (Stephens, 2003; Ocran *et al.*, 1998). There is a preference for cream- white landraces with large seed size mostly in Africa (Berchie *et al.*, 2010; Akpalu *et al.*, 2013) where as in south East Asia black and red landraces are preferred. The cream-white landraces are usually chosen over red/brown ones because they are less bitter and take less time to cook. Darker coloured seeds are not favoured due to the high tannin. The white seeds can be mixed with guinea fowl meat as treatment for diarrhoea while black seeds may be mixed with water to treat skin rashes and cataract. It can also be chewed to alleviate swollen jaw diseases (Akpalu *et al.*, 2013). Other uses include: stimulation of milk production in breast-feeding women. It is equally given to women after childbirth to heal their wounds (Temegne *et al.*, 2018). Like other legume plants, bambara groundnut is a good soil fertilizer and a fine rotation crop. It contributes to the soil fertility through biological nitrogen fixation (Karikari, 1971).

2.8 Available gene banks for Bambara groundnuts

Genetic resources for crop breeding are derived from populations of genotypes collected from various places. Plant genetic resources are the backbone of agriculture and play an important role in development of new cultivars (Malik and Singh, 2006). Various landraces and wild type accessions of bambara groundnut are held in trust on behalf of the international community by a number of organizations. The International Institute of Tropical Agriculture (IITA) has about 1,973 accessions in its collection in Nigeria (Atoyebi *et al.*, 2017). The Institute of Research for Development (IRD), based in France has about 1000 accessions also in its bank (Aliyu *et al.*, 2016; Temegne *et al.*, 2018). Another gene bank of bambara groundnut located in Zambia, was established

in 1988 by 15 member countries of Southern Africa Development Community (SADC) (Molosiwa, 2012).

2.9 Morphological descriptors and diversity evaluations in selected pulses

The study of agro-morphological parameters has been an essential method in exploiting the diversity of crops. Morphological evaluation is the oldest means and has been considered as the first step in description and classification of germplasm (Hedrick, 2005). It is found to be direct, cheap, simple and requiring little skill. Nevertheless, it is more dependent on the environment (Li *et al.*, 2009) but its agricultural relevance makes it an important tool in germplasm evaluation studies (Molosiwa, 2012).

The standard descriptors for bambara groundnut [International Plant Genetic Resources Institute/International Institute of Tropical Agriculture/The International Bambara groundnut Network (IPGRI/IITA/BAMNET 2000)] have always been used in the phenotypic characterization exercises. Qualitatively, the guidelines represent the following indices: growth habit, terminal leaflet shape, colour of fully expanded terminal leaflet, stem hairiness, photoperiodic reaction, dark pigmentation on wings and banner, pod shape, pod colour, pod texture, seed shape and seed colour/pattern. Similarly, the following quantitative characters are listed: days to emergence, days to 50 % flowering, number of leaves per plant, plant spread, leaflet length, leaflet width, leaf area, plant height, internode length, petiole length, petiole-internode ratio, petiolule length, peduncle length, number of stems, days to maturity, shoot dry weight, number of pods per plant, pod dry weight, pod length, pod width, seeds per plant, seed length, seed width and seed weight (Molosiwa, 2012; Aliyu *et al.*, 2016).

Analysis of diversity in landrace collections of bambara groundnut using morphological descriptors have been reported by Goli, (1995); Ntundu *et al.* (2006); Abu and Buah, (2011); Molosiwa *et al.* (2012); Olukolu *et al.*(2012); Aliyu and

Massawe, (2013); Molosiwa *et al.*(2015) and Atoyebi *et al.* (2017). Goli (1995) characterized approximately 1400 bambara groundnut accessions at the International Institute of Tropical Agriculture (IITA) in Nigeria based on 38 characters for qualitative and quantitative traits. Ntundu *et al.* (2006) in Tanzania evaluated qualitative and quantitative characters among the 100 accessions of bambara nuts. The result of the principal component analysis (PCA) showed that some vegetative traits, namely, terminal leaflet width/length, petiole length, plant spread, plant height, pod width/length and number of pods per plant that had prominent loadings in PCA were useful in distinguishing bambara groundnut landraces. Shegro *et al.* (2013) assessed the level of phenotypic variability among 20 ground pea accessions using eighteen phenotypic markers. Analysis of variance for the phenotypic traits revealed that differences among accessions were highly significant for all traits. The results of the principal component analysis showed that the first seven principal components contributed 83 % of the variability among the accessions evaluated. Leaf area index, pod mass and dry weight were highly associated with the first principal component, whereas estimated leaf area, actual leaf area, number of pods and fresh weight contributed more to the second principal component. Molosiwa *et al.* (2015) studied 35 genotypes derived from landraces of bambara groundnut in Botswana and scored them for 37 phenotypic traits. The 35 individual genotypes were ranked for agronomic performance based on yield components and other traits. Five genotypes with good yield potential and adaptability were recommended. Also, morphological characterization of selected African accessions of bambara groundnut was carried out by Atoyebi *et al.* (2017). Three hundred (300) accessions of bambara nut among 1,973 accessions maintained in the global repository at the IITA Nigeria were selected for this study. Thirty-seven (37) agro-morphological parameters representing 28 quantitative and 9 qualitative traits were studied on each plant (IPGRI, 2002). The results revealed lines that had high yield potentials.

Similarly, morphological markers have equally been used for phenotypic studies in other Pulses like mungbean (*Vigna radiata*) (Ghafoor *et al.*, 2001), peanut (*Arachis hypogaea*) (Swamy *et al.*, 2003) and cowpea (*Vigna unguiculata*) (Omoigui *et al.*, 2006). Abdulkareem *et al.*, (2015) evaluated the degree of diversity in twelve accessions of African yam bean (*Sphenostylis stenocarpa* HOCHST EXA.RICH) collected from IITA in Nigeria using quantitative and qualitative variables. Some characters such as length and width of terminal leaf, petiole length, number of leaves among others, were significantly different among the accessions. Strilova *et al.* (2013) analyzed the morphological variation of 15 Portuguese and 15 Bulgarian landraces of common bean (*Phaseolus vulgaris* L.) in different environmental conditions (in Bulgaria and Portugal). The landraces were evaluated for 16 morphological characteristics and a considerable morphological variation was found among the genotypes. Majority of the landraces had cream seed colours but some also had red and purple colours. The geographical site of the trials (Portugal and Bulgaria) determined the cluster pattern of majority of accessions. In Portugal, the plants required more days to reach the flowering and maturity phases and had higher biological yield. In both environments, the components that mainly determined yield were the number of pods and the number of seeds per plant.

2.10 Biochemical markers and diversity studies in *Vigna* species

Biochemical markers or isozymes are protein molecules with different charges that can be separated by gel electrophoresis based on their molecular sizes, weight and electrical charges (Hedrick, 2005). Isozyme analysis, the first technique used in the estimate of genetic variance was developed in 1966 by Lewinton and Hubby (Molosiwa, 2012). Biochemical markers are co-dominant, easy to use and cost effective, no DNA or sequence information required, primers and expensive PCR machines are not needed (Spooner *et al.*, 2005). The main disadvantage is that they are

few in number and detect less polymorphism. Isozyme analysis is affected by various extraction methodologies as well as different plant growth stages (Mondini *et al.*, 2009). Also, different tissues in the same plant can reveal different isozyme variation (Molosiwa, 2012).

Biochemical markers have been successfully applied in the detection of genetic diversity, population structure, gene flow and population division. The earliest report of genetic diversity analysis in bambara nut includes the work done by Pasquet *et al.* (1999) using 79 domesticated landraces of bambara groundnut and 29 wild relatives at 41 isozymes loci. They concluded that the wild relative is the progenitor of the former based on the high level of genetic similarities. Pasquet *et al.* (1999) confirmed the report of Howell (1990) that the overall level of isozyme diversity in bambara plant is low. Despite the low heterozygosity among both wild and domesticated landraces, intra population genetic diversity among the domesticated landraces is high. This may be attributed to the autogamous breeding system of the crop (Aliyu *et al.*, 2016). Biochemical markers are not widely applied because of the advent of higher molecular tools (Molosiwa, 2012).

2.11 Molecular markers and diversity study in bambara nuts

Molecular markers are fixed marks in the genome, found at specific locations. They are used to identify specific genetic differences (Semagn *et al.*, 2006). An ideal marker should be co-dominant, evenly distributed throughout the genome, highly reproducible and having ability to detect higher level of polymorphism (Nadeem *et al.*, 2017). Several markers are available to choose for genetic diversity studies and some factors influencing the choice of molecular markers may include: the objectives of the study, availability of organism's specific sequences, equipment and technical resources, biological features of the species, cost, level of polymorphism,

reproducibility and genomic abundance (Garcia *et al.*, 2004). Examples of molecular markers include: Random Fragment Length Polymorphism (RFLP), Amplified Fragment Length Polymorphism (AFLP), Random Amplified Polymorphic DNA (RAPD), Simple Sequence Repeat (SSR), Single Nucleotide Polymorphism (SNP), Variable Number Tandem Repeat (VNTR), Short Tandem Repeat (STR) and Diversity Array Technology (DArT) (Gupta *et al.*, 1999; Nadeem *et al.*, 2017).

Molecular markers have emerged as powerful tools in the assessment of genetic variability (Agarwal *et al.*, 2008). Some of these have been used to generate genetic diversity data from bambara groundnut (Molosiwa *et al.*, 2015) as discussed briefly here.

2.11.1 Random amplified polymorphic DNA (RAPD)

RAPD markers are based on PCR amplification of random DNA segment using typically short primers of arbitrary nucleotide sequence (William *et al.*, 1990). The use of RAPD marker technique is simple and inexpensive. However, it has a problem of reproducibility and its dominant nature does not differentiate between homozygosity and heterozygosity. These problems make the RAPD markers unsuitable to transfer results (Molosiwa, 2012). A set of 363 bambara nut accessions from five geographical regions (Cameroon/Nigeria, other West African regions, Central Africa, East Africa, Southeast Asia) and an unknown origin was evaluated with 65 loci generated from RAPD markers to provide more information on genetic diversity. A higher percentage of polymorphic DNA bands and gene diversity were found in accessions from Cameroon/Nigeria than those from other West African Regions. The result of the principal coordinate analysis showed that accessions from Cameroon/Nigeria and other West African regions were separated into two groups. A dendrogram generated by the unweighted pair group method with arithmetic means (UPGMA) failed to illustrate

clear pattern of germplasm groups. In most cases, accessions from different regions clustered with one another (Rungnoi *et al.*, 2012).

2.11.2 Amplified fragment length polymorphism (AFLP)

AFLP technique is based on the selective PCR amplification of restriction fragments. In AFLPs, two restriction enzymes (could be a frequent cutter and a rare cutter) are used for the cutting of DNA (Vos *et al.*, 1995; Nadeem *et al.*, 2017). They produce higher levels of polymorphism than RFLP and better reproducibility than RAPD. However, AFLPS require greater technical and heavy equipment. They equally have the problem of dominance hence not informative for heterozygosity (Molosiwa *et al.*, 2015). AFLP markers have been used in the genetic diversity analysis of common bean (Maciel *et al.*, 2003) as well as in cowpeas (*Vigna unguiculata*) (Coulbaly *et al.*, 2002). Massawe *et al.* (2002) employed seven AFLP markers to determine the genetic diversity among 16 bambara groundnut landraces. The result of the analysis showed polymorphism ranging from 68 to 98% with an average of 83%. The dendrogram generated grouped the 16 landraces into three clusters according to their geographic origin. AFLP technique was also used to assess the genetic diversity of 100 accessions of bambara nuts obtained from a diverse geographic area of Tanzania. Eleven AFLP primers used generated a total of 49 polymorphic fragments. The result of the cluster analysis revealed that the accessions formed two major groups based on their areas of collection (Ntundu *et al.*, 2004).

2.11.3 Simple sequence repeats (SSRs)

Simple sequence repeats (SSRs) also called microsatellite markers are DNA stretches consisting of tandemly repeated short nucleotide units (1-5 bases per unit). Such repeats are distributed throughout the genomes of all eukaryotic species. The

occurrence of SSRs may be due to the slippage of single-stranded DNA, recombination of double-stranded DNA, transfer of mobile elements and mismatches (Nadeem *et al.*, 2017).

Simple sequence repeats (SSRs) have appeared as a marker of choice for plant genetic studies because of their abundance in the genome, co-dominant nature and reproducibility (Collard *et al.*, 2005). They are highly informative and polymorphic among related species. The major problem with microsatellites is that they need to be developed *de novo* for each species (Ellis and Burke, 2007).

Genetic relationship among 105 bambara groundnuts accessions from Kenya were assessed using twelve microsatellite markers. A total of 24 alleles were revealed with a mean of two alleles per locus. The polymorphic information content and gene diversity values averaged 0.28 and 0.38 respectively, indicating low genetic diversity among the evaluated bambara nut germplasm (Odongo *et al.*, 2015). In the same vein, Molosiwa *et al.* (2015) assessed the level of genetic diversity in 24 collections of bambara nut landraces in Botswana using 68 polymorphic SSR markers. Polymorphic information content (PIC) ranged from 0.08 to 0.89 with an average of 0.42 across all SSR polymorphic markers with observed (H_o) and expected (H_e) heterozygosity of 0.01 and 0.5 respectively. Based on these, a subset of 35 genotypes derived from the landraces were advanced for field trials in Botswana and scored for 37 phenotypic traits. These 35 individual genotypes were ranked for agronomic performance based on yield component factors and other qualitative after-field evaluation. Five genotypes with good yield potential and adaptability were recommended as potential varieties for Botswana agro-ecology.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sites of experiment

The bambara groundnut plants were grown at the Convent Farm of the Handmaids of the Holy Child Jesus (HHCJ), 130 Calabar road, Calabar, Cross River State Nigeria while the molecular work was carried out at the Molecular Biology Laboratory of the Department of Genetics and Biotechnology, Faculty of Biological Sciences, University of Calabar, Calabar, Nigeria.

3.2 Plant material

A total of thirty eight accessions of bambara groundnut were used in this study. Sixteen accessions were sourced from local farmers across some areas and states in Nigeria whereas the other twenty two were obtained from the Genetic Resources Centre-International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria (Table 1).

3.3 Experimental design and field layout

The field experiment (Plate 2) was laid out in a randomized complete block design (RCBD) in three replications and each bambara groundnut accession was assigned randomly to the 38 plots per block. Six seeds were planted per plot; one seed per hole and no thinning was carried out. Two hundred and twenty eight (228) seeds were sown per block. Each block measured 12 m² (6 m x 2 m) with 0.5 m between plots at 30cm x 40cm planting distance. The planting period was between December 9, 2017- April 14, 2019. The crops were watered twice daily for the first two months. The seeds were observed for germination and other morphological and yield characteristics.

TABLE I

List of 38 accessions of bambara groundnut studied and their sources

SN	ACCESSION	AREA/COUNTRY OF ORIGIN	SOURCE	GPS INFORMATION
1	NG/BG/1/1- A2	GOMBE	FARMERS	Lat:10°17'22.88"N; Long:11°10'2.24"E; 380m
2	NGBG2/1-A3	JOS	FARMERS	Lat:9°55'42.56"N; Long:8°53'31.63"E; 1,238m
3	NG/BG/2/2-A4	PLATEAU	FARMERS	Lat:9°10'0.01"N; Long:9°45'0.00"E; 1,280m
4	NG/BG/2/3-A9	JOS	FARMERS	Lat:9°55'42.56"N; Long:8°53'31.63"E; 1,238m
5	NG/BG/2/4-A10	PLATEAU	FARMERS	Lat:9°10'0.01"N; Long:9°45'0.00"E; 1,280m
6	NG/BG2/5-A14	JOS	FARMERS	Lat:9°55'42.56"N; Long:8°53'31.63"E; 1,238m
7	NG/BG/3/1 -A5	BORNO	FARMERS	Lat:10°13'50"N; Long:11°13'45"E; 354m
8	NG/BG/4/1 -A7	ADAMAWA	FARMERS	Lat:10°16'6.89"N; Long:13°16'1.24"E; 560m
9	NGBG/5/1 A8	KANO	FARMERS	Lat:12°00'0.43"N; Long:8°31'0.19"E; 488m
10	NG/BG/6/1 -A13	NSUKKA	FARMERS	Lat:6°51'28.19"N; Long:7°23'44.77"E; 396m
11	NG/BG/6/2 -A17	ENUGU	FARMERS	Lat:6°26'28.75"N; Long:7°29'55.79"E; 240m
12	NG/BG/6/3-A20	NSUKKA	FARMERS	Lat:6°51'28.19"N; Long:7°23'44.77"E; 396m
13	NG/BG/6/4-A21	NSUKKA	FARMERS	Lat:6°51'28.19"N; Long:7°23'44.77"E; 396m
14	NG/BG/7/1 -A15	SOKOTO	FARMERS	Lat:13°03'45.68"N; Long:5°14'35.59"E; 450m
15	NG/BG/7/2 -A18	SOKOTO	FARMERS	Lat:13°03'45.68"N; Long:5°14'35.59"E; 450m
16	NG/BG/8/1-A23	OGOJA	FARMERS	Lat:6°39'30.24"N; Long:8°47'57.23"E; 96m
17	TUSU 214	GHANA	IITA	-
18	TVSU 238	GHANA	IITA	-
19	TVSU 261	NIGERIA	IITA	-
20	TVSU 305	BURKINA FASO	IITA	-
21	TVSU 329	NIGERIA	IITA	-
22	TVSU 368	NIGERIA	IITA	-
23	TVSU 401	CAMEROUN	IITA	-
24	TVSU 424	CAMEROUN	IITA	-
25	TVSU 465	CAMEROUN	IITA	-
26	TVSU 524	CAMEROUN	IITA	-
27	TVSU534	CAMEROUN	IITA	-
28	TVSU 562	CAMEROUN	IITA	-
29	TVSU689	ZAMBIA	IITA	-
30	TVSU733	ZAMBIA	IITA	-
31	TVSU 1202	BURKINA FASO	IITA	-
32	TVSU 1243	NIGERIA	IITA	-
33	TVSU 1258	NIGERIA	IITA	-
34	TVSU 1260	NIGERIA	IITA	-
35	TVSU 1419	TOGO	IITA	-
36	TVSU 1543	-	IITA	-
37	TVSU 1573	-	IITA	-
38	TVSU1606	TOGO	IITA	-

GPS= Global positioning system



PLATE 2: Field layout of bambara crops

Two hundred and twenty eight (228) seeds were sown per block. Each block measured 12 m² (6 m x 2 m) with 0.5 m between plots at 30cm x 40cm planting distance. The planting period was between December 9, 2017-April 14, 2019. The crops were watered twice daily for the first two months. The seeds were observed for germination and other morphological and yield characteristics.

3.4 Morphological studies

The accessions were evaluated for quantitative and qualitative traits based on the bambara groundnut descriptor list (IPGRI/IITA/BAMNET 2000). The following quantitative vegetative characters: plant height (cm), terminal leaflet length (cm), terminal leaflet width (cm), leaf area (cm²), leaf area index, number of leaves/plant, internode length (cm), petiole length (cm) and number of petiole were measured after eight weeks of sowing. Data for morphological traits were collected from four plants. Days to seedling emergence as well as percentage germination were also estimated. Similarly, the following reproductive traits: Days to fifty percent (50 %) flowering, days to maturity, number of pods per plant, pod fresh weight (g), pod dry weight (g), seed size (one hundred seed weight), yield per plot (g), yield per hectare (t/ha) and number of seeds per plant were scored during the period of flowering and after harvesting. In the same vein, pod colour, pod texture, pod shape, eye pattern, testa pattern, testa colour, terminal leaflet colour, seed shape, leaf shape and growth habit (all qualitative characters) were also determined.

Plant height - This was measured from ground level to the tip using a meter rule

Petiole length – This was measured from the node of the stem to the junction of the leaflets using a meter rule

Number of leaves and Petiole number - These were counted manually and recorded.

Terminal Leaflet length/Width - The length/width of the terminal median leaflet was measured using a meter rule

Internode length – This was measured by the use of a meter rule

Leaf area – This was assessed as follows:

$$\text{Leaf Area} = 0.74 \times 3 \times \text{leaflet length} \times \text{leaflet width}$$

This formula was developed by Deswarte (2001) and was applied in field experiment in Swaziland by Edjie and Sesay (2003). It was thereafter confirmed by Cornelissen (2004) using the leaf area meter (LI-COR 3000) (Molosiwa, 2012).

Leaf area index (LAI) -This was calculated as the ratio of the total leaf area to the total land area available to the plants. $\text{LAI} = \text{Total leaf area} / \text{Total land area}$.

Days to seedling emergence – These were counted from the number of days after sowing to the time the first leaves were seen on the surface of the soil.

Days to 50 % flowering – This was scored as number of days after sowing to the period the first flowers showed up on 50 % of plants per plot.

Days to maturity - The number of days from sowing to maturity

Number of pods per plant – This was counted manually immediately after harvest

Pod fresh weight - Pods were weighed immediately after harvest using a weighing balance (Sartorius BS 323 S).

Pod dry weight - Pods were sun-dried for seven consecutive days after harvest. Then, they were weighed using a weighing balance (Sartorius BS 323 S).

Seed size - One hundred seeds were counted per accession and weighed.

Percentage germination - $\text{Number of germinated seeds} \times 100 / \text{total number of seeds planted}$.

3.5 Data analysis for morphological studies

Data for all quantitative parameters were collated and subjected to analysis of variance (ANOVA) using the Genstat version 10.0. Means that showed significant differences were separated using the Fisher's least significant difference (LSD) test at 5 % probability. The Genstat software was also used to run the principal component analysis (PCA). Correlation, regression and path coefficients analysis were estimated using the Microsoft Excel workbook software. Components of variance and broad sense heritability were estimated based on the output from the ANOVA using the formulae given by Allard (1960); Singh and Chaudhary (1985) and Molosiwa *et al.* (2015) as follows:

$$H^2b = \delta^2g/\delta^2p$$
$$= Vg/Ve+Vg = Vg/Vp$$

Where $Vg = \frac{MSG-MSE}{r}$ (from ANOVA)

The genotypic coefficient of variation (GCV) was calculated as follows:

$$\frac{\sqrt{\delta^2g}}{\bar{x}} \times 100$$

Similarly the phenotypic coefficient of variation (PCV) was obtained

$$\frac{\sqrt{\delta^2p}}{\bar{x}} \times 100$$

NOTE: H^2b = Broad sense heritability; δ^2p or Vp = Phenotypic variance

δ^2g or Vg = Genotypic variance; Ve = Environmental variance

MSG = Genotype mean square (from ANOVA)

MSE = Error mean square

r = Number of replication

\bar{x} = Mean of each character

The cluster analysis for morphological parameters was done based on the unweighted pair group method with arithmetic means (UPGMA) using the Darwin software version 5.0.

3.6 Molecular analysis using simple sequence repeat (SSR) markers

3.6.1 DNA extraction

Genomic DNA was extracted from healthy leaf samples (three weeks old) of bambara groundnut using the modified Cetyl Trimethyl Ammonium Bromide (CTAB) method. (Appendix II) Leaf samples were collected from the garden and put into a 2.0 ml Eppendorf tube containing Zirconia beads. They were kept in a -80°C freezer (U410-HEF New Brunswick) overnight. The samples were then ground in a crushing machine (Retsch MM400, Germany) at 2500rpm for 3 minutes. The beads, thereafter, were removed with the aid of a magnet. Five hundred micro litre (500 µl) of CTAB extraction buffer was then added to the ground tissues. This was vortexed for a short time, using a Digital Vortex Mixer (230v, USA) and thereafter, incubated at 65°C for one hour on an Eppendorf Thermo mixer (F1.5). The mixture was then centrifuged (Eppendorf Centrifuge 5424R) for 10 minutes at 15000rpm and the aqueous phase pipetted and transferred into fresh tubes. Approximately 500 µl of Chloroform:Isoamyl (24:1) was added and mixed thoroughly by inversion. The mixture was centrifuged at 15000rpm for 10 minutes and the aqueous phase extracted and transferred again into clean tubes. Thereafter, 350 µl of 2-propanol was added and mixed gently by inverting the tube before centrifuging at 15000rpm for 10 minutes. A clear white pellet was seen at the base of the tube. The upper phase was then decanted carefully in order to preserve the pellet. This was followed by the addition of 500 µl of 70 % ethanol to the tube containing the pellet and a gentle hit with fingers to lift the pellet off the bottom of the tube; then centrifuged for 10 minutes at 15000rpm. The upper phase was decanted again

and pellet (DNA) allowed to dry for 30 minutes in open air. Then 30 μ l of Tris EDTA (TE) buffer was added to the DNA and stored in a -20°C freezer (Liebherr Mediline).

3.6.2 DNA quantification

The DNA concentration was determined using a Nano-drop Spectrophotometer (Jenway Genova Nano, UK). About 1.5 μ l of the DNA was tested on the Nano System using 1.5 μ l of TE buffer as a blank. The concentration was modified by diluting the DNA with TE buffer to bring to a 250 ng/ μ l final concentration.

3.6.3 Primer dilution and preparation of working solution

Eleven (11) simple sequence repeat (SSR) primers (Molosiwa, 2012) (Table 2) were screened for this study but seven primers (primers 1, 3, 4, 7, 16, 19 and 23) produced polymorphic bands and were used for the analysis. The primers were centrifuged briefly and then diluted with nuclease free water in order to obtain the stock solution. This was done in accordance with the specifications of the manufacturers.

TABLE 2

SSR markers screened for the study

S/N	NAME OF MARKER	SEQUENCE
1	PRIMER 1F PRIMER 1R	AGGCAAAAACGTTTCAGTTC TTCATGAAGGTTGAGTTTGTC
2	PRIMER 2F PRIMER 2R	AGGAGCAGAAGCTGAAGCAG CCAATGCTTTGAACCAACA
3	PRIMER 3F PRIMER 3R	TTCACCTGAACCCCTTAACC AGGCTTCACTCACGGGTATG
4	PRIMER 4F PRIMER 4R	ACGCTTCTTCCCTCATCAGA TATGAATCCAGTGCGTCTGA
5	PRIMER 5F PRIMER 5R	TCAGTGCTTCAACCATCAGC GACCAAACCATTGCCAAACT
6	PRIMER 7F PRIMER 7R	GTAGGCCCAACACCACAGTT GGAGGTTGTTCGATGGAAAA
7	PRIMER 15F PRIMER 15R	AGGAGCAGAAGCTGAAGCAG CCAATGCTTTTGAACCAACA
8	PRIMER 16F PRIMER 16R	CCGGAACAGAAAACAACAAC CGTCGATGACAAAGAGCTTG
9	PRIMER 19F PRIMER 19R	AGGCAAAAACGTTTCAGTTC TTCATGAAGGTTGAGTTTGTC
10	PRIMER 23F PRIMER 23 R	CAGTAGCCATAATTTGCTATGAA CGAATCACCATTCAATACGC
11	PRIMER 33F PRIMER 33R	ACGCTTCTTCCCTCATCAGA TATGAATCCAGTGCGTGTGA

TABLE 3

Polymerase chain reaction (PCR) cocktail for 25 μ l reaction amplification

Component	Volume/reaction	Final vol. for 40 samples
10 x Taq reaction buffer	2.5 μ l	100
dNTPs	0.5 μ l	20
Forward primer	0.5 μ l	20
Reverse primer	0.5 μ l	20
Template DNA	1.0 μ l	-
Taq polymerase	0.125 μ l	5
Nuclease-free water	19.875 μ l	795
Total	25μl	

Then, 1.5 μ l of loading dye was added to the amplified PCR product. The mixture was vortexed, prior to being loaded onto the wells, inside the tank. Also, 6 μ l of DNA ladder was loaded on the first well (starting well) and the setting allowed to run at 80 volts for 80 minutes. The gel was then transferred to a UV Transilluminator (UVP, UK) where it was viewed with safety goggle and the picture taken with a Canon camera (EOS 1200 D, Taiwan).

3.6.6 Molecular data analysis

The amplified DNA fragments were carefully scored on a presence and absence matrix with one (1) representing present and zero (0) for absent. The genetic diversity indices were analyzed using the Microsoft excel workbook software for polymorphic information content (PIC), number of allele (AN), marker index (MI) and heterozygosity. The principal coordinate analysis (PCoA) was done based on the unweighted pair group method with arithmetic means (UPGMA) using the Darwin software version 6.0.

CHAPTER FOUR

RESULTS

4.1 Morphological traits of 38 bambara groundnut accessions

4.1.1 Days to seedling emergence and percentage germination

Data on percentage germination and days to seedling emergence are given in Table 4. Analysis of variance results showed that days to seedling emergence did not differ significantly ($P > 0.05$) among the evaluated accessions (Table 5) but ranged from 7 to 9 days with the highest and lowest mean values recorded in accessions TVSU 689 (9.00 ± 0.577) and NG/BG/4-A7 (7.00 ± 0.00), respectively (Table 4). Percentage germination differed significantly ($P < 0.05$) among the accessions and ranged from 16.66 % in accession TVSU 238 to 94.44 % in accession NG/BG/3/1 – A5 (Table 4).

4.1.2 Days to 50 % flowering and days to maturity

Days to 50% flowering differed significantly ($P < 0.05$) among the evaluated accessions (Table 6) and ranged from 33 to 44 with accessions TVSU 1543 having the highest mean value of 44.00 ± 0.0 while the least mean value (33.33 ± 0.33) was recorded in accessions NG/BG/6/3 –A20; NG/BG/6/4- A21; NG/BG/7/1-A15 and NG/BG/7/2 –A18 (Table 7). Results reveal that days to maturity did not differ significantly ($P > 0.05$) among the accessions (Table 5) but ranged from 93 – 140.

Accessions NG/BG/6/3 – A 20; NG/BG/6/4 –A 21; NG/BG/7/ 1 -A15 and NG/BG/7/2 A-18 were the earliest to reach maturity (93.33 ± 0.33) while accession TVSU 1543 was the last to mature with 140.33 ± 0.00 days (Table 7).

TABLE 4

Percentage germination and days to seedling emergence in 38 accessions of bambara nuts

S/N	Accessions	Percentage germination (%)	Days to seedling emergence \square + S.E
1	NG/BG/1/1- A2	61.11f	8.66a \pm 0.881
2	NGBG2/1-A3	66.66e	8.00ab \pm 0.587
3	NG/BG/2/2-A4	66.66e	8.00ab \pm 0.587
4	NG/BG/2/3-A9	61.11f	8.00ab \pm 0.587
5	NG/BG/2/4-A10	66.66e	7.66ab \pm 1.7732
6	NG/BG2/5-A14	88.88b	8.66a \pm 0.882
7	NG/BG/3/1 -A5	94.44a	8.00ab \pm 0.587
8	NG/BG/4/1 -A7	66.66e	7.00b \pm 0.00
9	NGBG/5/1 A8	44.44i	7.66ab \pm 0.34
10	NG/BG/6/1 -A13	72.22d	8.00ab \pm 0.587
11	NG/BG/6/2 -A17	33.33k	8.00ab \pm 0.587
12	NG/BG/6/3-A20	72.22d	8.00ab \pm 0.587
13	NG/BG/6/4-A21	44.44i	8.00ab \pm 0.587
14	NG/BG/7/1 -A15	88.88b	8.00ab \pm 0.587
15	NG/BG/7/2 -A18	66.66e	8.00ab \pm 0.587
16	NG/BG/8/-A23	83.33c	8.00ab \pm 0.587
17	TVSU 214	38.88j	8.66a \pm 0.882
18	TVSU 238	16.66m	8.66a \pm 0.882
19	TVSU 261	66.66e	7.66ab \pm 1.732
20	TVSU 305	44.44i	8.66a \pm 0.882
21	TVSU 329	33.33k	8.50ab \pm 2.84
22	TVSU 368	38.88j	8.66a \pm 0.882
23	TVSU 401	50.00h	7.66ab \pm 1.732
24	TVSU 424	33.33k	8.66a \pm 0.882
25	TVSU 465	50.00h	8.66a \pm 0.882
26	TVSU 524	61.11f	7.66ab \pm 1.732
27	TVSU534	44.44i	7.66ab \pm 1.732
28	TVSU 562	38.88j	7.66ab \pm 1.732
29	TVSU 689	50h	9.00a \pm 0.577
30	TVSU733	61.11f	8.00ab \pm 0.578
31	TVSU 1202	55.55g	7.66ab \pm 1.732
32	TVSU 1243	50h	7.66ab \pm 1.732
33	TVSU 1258	50h	8.00ab \pm 0.578
34	TVSU 1260	22.22i	8.66a \pm 0.882
35	TVSU 1419	22.22i	7.66ab \pm 1.732
36	TVSU 1543	22.22i	8.66a \pm 0.882
37	TVSU 1573	33.33k	8.00ab \pm 0.578
38	TVSU1606	44.44i	8.00ab \pm 0.578
LSD (0.05)		1.37	1.35

TABLE 5

Analysis of variance (ANOVA) results for morphological traits among 38 accessions of bambara nuts

Parameters	SOV	DF	SS	MS	Fcal	Ftab.
Plant height	Genotype	37	546.698	14.783	4.321*	1.56
	Block	2	231.453	115.726	33.828*	3.13
	Error	74	260.000	3.421		
	Total	113	1038.421			
Leaf area	Genotype	37	1001.579	27.067	7.329*	1.56
	Block	2	509650	254.825	69.002*	3.13
	Error	74	273.317	3.693		
	Total	113	1784.546			
Leaf area index	Genotype	37	3.343	0.090	2.647*	1.56
	Block	2	2.015	1.000	29.412*	3.13
	Error	74	2.488	0.034		
	Total	113	7.846			
Terminal leaflet width	Genotype	37	567.330	15.330	27.277*	1.56
	Block	2	328.451	164.225	292.21*	3.13
	Error	74	41.611	0.562		
	Total	113	937.392			
Terminal leaflet length	Genotype	37	81.288	2.197	8.450*	1.56
	Block	2	67.619	33.910	130.036*	3.13
	Error	74	19.100	0.260		
	Total	113	168.005			
Internode length	Genotype	37	518.779	14.021	6.917*	1.56
	Block	2	265.225	132.610	65.421*	3.13
	Error	74	150.071	2.027		
	Total	113	934.075			
Petiole length	Genotype	37	595.487	16.094	7.325*	1.56
	Block	2	332.412	166.206	75.650*	3.13
	Error	74	167.008	2.197		
	Total	113	1094.907			
Petiole number	Genotype	37	977.74	26.425	39.617*	1.56
	Block	2	364.55	182.275	273.275*	3.13
	Error	74	49.422	0.667		
	Total	113	1391.711			
Number of leaves	Genotype	37	4985.044	134.731	5.538*	1.56
	Block	2	79	39.500	1.623 NS	3.13
	Error	74	1800.132	24.326		
	Total	113	6864.176			
Percentage germination	Genotype	37	155.026	4.190	4.124*	1.56
	Block	2	66.76	33.380	32.854*	3.13
	Error	74	45.24	1.016		
	Total	113	261.026			
Days to seedling emergence	Genotype	37	37.193	1.005	1.016 NS	1.56
	Block	2	77.43	38.715	39.145*	3.13
	Error	74	43.237	0.989		
	Total	113	157.86			
Days to 50% flowering	Genotype	37	554.098	14.975	5.329*	1.56
	Block	2	137.598	63.799	22.700*	3.13
	Error	74	208	2.810		
	Total	113	1024.5			
Days to maturity	Genotype	37	797536.09	2155.57	0.768 NS	1.56
	Block	2	218714.92	10935.7	3.898*	3.13
	Error	74	207554.32	2804.79		
	Total	113	1223805.3			
Pod fresh weight	Genotype	37	23784.748	642.831	113.574*	1.56
	Block	2	15543.782	777.189	137.310*	3.13
	Error	74	419.363	5.66		
	Total	113	39746.893			
Pod dry weight	Genotype	37	8295.446	224.201	82.700*	1.56
	Block	2	6785.987	339.299	125.150*	3.13
	Error	74	200616	2.711		
	Total	113	15282.049			
Number of seeds/plant	Genotype	37	10102.589	273.042	64.351*	1.56
	Block	2	7896.543	3948.27	930.537*	3.13
	Error	74	314	4.243		
	Total	113	18313.132			
Number of pods/plant	Genotype	37	10814.109	29227	95.638*	1.56
	Block	2	5987.65	2993.82	979.653*	3.13
	Error	74	226.166	3.056		
	Total	113	17027.925			
100 seed weight	Genotype	37	24675.231	666.898	16.802*	1.56
	Block	2	23887.543	11943.8	300.926*	3.13
	Error	74	2937.133	39.69		
	Total	113	51499.907			
Seed yield/plot	Genotype	37	397.433	10.741	7.851*	1.56
	Block	2	332.112	166.056	121.385*	3.13
	Error	74	100.892	1.368		
	Total	113	830.437			

*=Significant at $P < 0.05$ SOV=Source of variation

TABLE 6
Means and standard errors ($\bar{x} \pm SE$) of vegetative attributes in 38 accessions of bambara groundnut (*Vigna subterranea*)

Accessions	Leaf width (cm)	Plant height (cm)	Petiole number Per plant	Leaf Area Index	Leaf Area (cm ²)	Leaf length (cm)	Leaf number	Internode Length (cm)	Petiole length (cm)
NG/BG/1A2	2.40 ± 0.32	27.00 ± 0.21	18.00 ± 0.58	1.15 ± 0.33	13.88 ± 0.58	7.82 ± 0.58	24.00 ± 0.33	5.06 ± 0.32	14.09 ± 0.01
NG/BG/2/1-A3	2.25 ± 0.10	23.00 ± 0.52	5.67 ± 0.33	1.20 ± 0.33	14.51 ± 0.33	8.72 ± 0.33	18.00 ± 0.33	6.45 ± 0.11	10.20 ± 0.30
NG/BG/2/2-A4	2.01 ± 0.23	26.00 ± 0.03	8.00 ± 0.58	0.92 ± 0.16	11.16 ± 0.67	7.50 ± 0.58	14.67 ± 0.58	3.55 ± 0.03	7.08 ± 0.62
NG/BG/2/3-A9	2.18 ± 0.33	22.00 ± 0.12	3.00 ± 0.58	1.14 ± 0.31	13.77 ± 0.33	9.04 ± 0.67	27.33 ± 0.33	7.56 ± 0.62	14.12 ± 0.33
NG/BG/2/4-A10	1.88 ± 0.33	22.00 ± 0.01	3.33 ± 0.33	0.81 ± 0.53	9.73 ± 0.33	7.00 ± 0.33	24.33 ± 0.67	6.98 ± 0.03	12.24 ± 0.33
NG/BG/2/5-A14	2.62 ± 0.15	28.00 ± 0.02	1.67 ± 0.33	1.28 ± 0.97	15.50 ± 0.58	8.02 ± 0.33	16.33 ± 0.58	8.32 ± 1.12	13.33 ± 0.02
NG/BG/3-A5	2.50 ± 0.37	29.67 ± 0.80	2.67 ± 0.33	1.38 ± 0.05	16.72 ± 0.58	7.00 ± 0.67	26.00 ± 0.10	10.12 ± 0.40	16.54 ± 0.33
NG/BG/4-A7	1.96 ± 0.03	45.00 ± 0.67	3.00 ± 0.58	0.82 ± 0.42	9.95 ± 0.67	6.86 ± 0.58	19.66 ± 0.03	7.65 ± 0.82	13.23 ± 0.00
NG/BG/5-A8	2.24 ± 0.14	24.00 ± 0.32	1.67 ± 0.33	1.16 ± 0.03	14.08 ± 0.88	8.50 ± 0.33	17.66 ± 0.33	6.99 ± 1.14	13.62 ± 0.33
NG/BG/6/1-A13	2.04 ± 0.32	25.00 ± 0.11	1.67 ± 0.33	1.02 ± 0.23	12.30 ± 0.33	8.15 ± 0.58	29.00 ± 0.58	7.30 ± 0.23	17.24 ± 0.00
NG/BG/6/2-A17	2.44 ± 0.58	23.00 ± 0.12	2.00 ± 0.00	1.36 ± 0.10	16.46 ± 2.40	9.12 ± 0.33	28.33 ± 1.00	10.14 ± 0.72	15.12 ± 0.13
NG/BG/6/3-A20	2.64 ± 0.34	23.00 ± 0.31	5.00 ± 0.00	1.37 ± 0.03	16.64 ± 0.58	8.52 ± 0.33	21.66 ± 0.33	8.76 ± 0.44	14.40 ± 0.30
NG/BG/6/4-A21	2.36 ± 0.11	27.67 ± 0.02	2.00 ± 0.58	1.01 ± 0.05	12.25 ± 0.58	7.02 ± 0.30	17.00 ± 1.33	7.55 ± 0.33	12.55 ± 0.33
NG/BG/7/1-A15	2.40 ± 0.24	12.33 ± 0.02	2.00 ± 0.00	1.07 ± 0.32	12.99 ± 0.33	7.44 ± 0.33	25.00 ± 0.33	11.64 ± 0.60	12.30 ± 0.33
NG/BG/7/2-A18	2.66 ± 0.05	29.67 ± 0.01	3.67 ± 0.00	1.26 ± 0.12	15.31 ± 0.33	8.62 ± 0.33	21.33 ± 0.33	9.02 ± 0.03	14.90 ± 0.00
NG/BG/8-A23	4.24 ± 0.53	48.00 ± 0.02	3.00 ± 0.33	2.49 ± 1.21	30.12 ± 0.33	9.60 ± 0.23	19.00 ± 0.58	12.50 ± 1.03	18.69 ± 0.00
TVSU/214	2.60 ± 0.12	14.00 ± 0.50	5.00 ± 0.33	1.46 ± 0.31	17.73 ± 0.04	9.22 ± 0.58	26.66 ± 0.67	8.76 ± 0.26	16.23 ± 0.33
TVSU/238	2.31 ± 0.17	28.00 ± 0.23	7.00 ± 0.58	1.16 ± 0.03	14.01 ± 0.31	8.20 ± 0.58	18.66 ± 0.58	10.99 ± 2.03	15.75 ± 0.20
TVSU/261	2.40 ± 0.03	14.33 ± 0.12	4.67 ± 0.58	1.06 ± 0.13	12.85 ± 0.30	7.24 ± 0.58	26.33 ± 0.00	7.86 ± 0.33	13.33 ± 0.03
TVSU/305	1.62 ± 0.22	15.67 ± 1.45	2.30 ± 0.33	0.79 ± 0.02	9.61 ± 0.67	8.02 ± 0.88	23.66 ± 0.58	6.98 ± 0.12	9.20 ± 0.30
TVSU/329	1.58 ± 0.08	16.67 ± 1.20	15.33 ± 0.58	0.71 ± 0.10	8.66 ± 1.07	7.41 ± 0.58	21.33 ± 0.33	8.61 ± 0.03	11.60 ± 0.20
TVSU/368	2.22 ± 0.23	17.00 ± 0.01	8.00 ± 0.58	1.06 ± 0.33	12.84 ± 0.58	7.82 ± 0.58	15.00 ± 0.33	7.20 ± 0.03	8.00 ± 0.03
TVSU/401	2.34 ± 0.13	16.00 ± 0.32	8.00 ± 0.58	1.19 ± 0.06	14.42 ± 0.67	8.33 ± 0.58	13.33 ± 0.58	3.30 ± 0.06	12.00 ± 0.01
TVSU/424	2.40 ± 0.60	22.00 ± 0.23	3.00 ± 0.58	1.30 ± 0.24	15.73 ± 0.33	8.86 ± 0.33	16.33 ± 0.33	4.30 ± 0.40	11.67 ± 0.33
TVSU/465	2.82 ± 0.03	32.00 ± 0.06	3.33 ± 0.33	1.51 ± 0.32	18.19 ± 0.33	8.72 ± 0.33	15.33 ± 0.67	6.30 ± 0.67	12.67 ± 0.33
TVSU/524	2.52 ± 0.33	19.67 ± 0.03	2.67 ± 0.33	1.20 ± 0.12	14.58 ± 0.58	7.86 ± 0.67	16.33 ± 0.30	3.40 ± 0.33	9.67 ± 0.33
TVSU/534	2.63 ± 0.12	18.00 ± 0.02	3.00 ± 0.58	1.57 ± 0.02	18.99 ± 0.67	9.20 ± 0.58	12.33 ± 0.24	5.70 ± 0.03	10.00 ± 0.01
TVSU/562	1.82 ± 0.16	15.00 ± 0.21	1.67 ± 0.33	0.81 ± 0.03	9.75 ± 0.33	7.24 ± 0.58	11.00 ± 0.58	4.40 ± 0.10	7.00 ± 0.03
TVSU/689	2.04 ± 0.06	23.00 ± 0.23	2.00 ± 0.01	1.01 ± 0.03	12.09 ± 0.67	8.01 ± 0.33	10.33 ± 1.03	3.50 ± 0.01	12.67 ± 0.33
TVSU/733	2.02 ± 0.72	13.00 ± 0.22	5.00 ± 0.23	0.91 ± 0.03	11.06 ± 0.58	7.40 ± 0.33	12.33 ± 0.33	2.30 ± 0.23	14.67 ± 0.33
TVSU/1202	1.56 ± 0.34	25.00 ± 0.01	2.00 ± 0.03	0.80 ± 0.60	9.69 ± 0.33	8.40 ± 0.33	13.00 ± 0.33	7.30 ± 0.65	9.67 ± 0.06
TVSU/1243	2.42 ± 0.06	29.67 ± 0.02	3.67 ± 0.03	1.03 ± 0.67	12.53 ± 0.33	7.00 ± 0.33	14.33 ± 0.33	3.20 ± 0.20	10.00 ± 0.60
TVSU/1258	1.84 ± 0.33	17.67 ± 0.02	3.00 ± 0.33	0.90 ± 0.03	10.89 ± 0.67	8.00 ± 0.67	14.00 ± 0.58	4.10 ± 0.33	11.00 ± 0.33
TVSU/1260	1.72 ± 0.21	18.67 ± 0.10	2.33 ± 1.03	0.79 ± 0.06	9.54 ± 0.58	7.50 ± 0.36	11.33 ± 0.33	3.60 ± 0.67	14.67 ± 0.33
TVSU/1419	2.26 ± 0.12	18.67 ± 0.30	3.00 ± 0.58	1.27 ± 0.03	15.38 ± 2.23	9.20 ± 0.58	10.33 ± 0.58	11.30 ± 0.33	9.00 ± 0.33
TVSU/1543	2.25 ± 0.32	22.33 ± 0.67	7.00 ± 0.58	1.24 ± 0.12	15.00 ± 2.13	9.01 ± 0.58	17.33 ± 0.58	4.40 ± 0.28	8.40 ± 0.03
TVSU/1573	2.24 ± 0.22	25.33 ± 0.88	4.67 ± 0.58	1.08 ± 0.04	13.02 ± 2.03	7.86 ± 0.58	10.00 ± 0.13	7.30 ± 0.54	12.00 ± 0.02
TVSU/1606	2.10 ± 0.03	24.67 ± 1.05	2.30 ± 0.33	1.11 ± 0.23	13.44 ± 0.67	8.65 ± 0.88	14.04 ± 0.58	6.20 ± 0.06	9.00 ± 0.04
LSD (0.05)	1.02	3.15	2.12	0.25	3.02	1.02	2.14	1.55	2.01

TABLE 7

Means and Standard Errors ($\bar{x} \pm SE$) of reproductive attributes in 38 accessions of bambara groundnut (*Vigna subterranea*)

Accessions	Days to 50% Flowering	No. of pods Per plant	Fresh weight of pods(g)/plant	Dry weight of pod(g)/plant	Days to Maturity	Seed Yield per Plot (g)	100 seed Weight per plot	Number of seeds per plant	Yield per Hectare (t/ha)
NG/BG/1A2	36.00 ± 0.03	39.60 ± 1.58	70.40 ± 0.58	41.00 ± 0.33	100.33 ± 0.58	8.16 ± 0.58	80.02 ± 0.33	40.00 ± 1.33	0.081 ± 0.01
NG/BG/2/1A3	37.00 ± 0.67	44.66 ± 2.32	68.66 ± 0.33	36.83 ± 0.03	101.13 ± 0.33	9.38 ± 0.33	70.00 ± 0.33	46.00 ± 1.67	0.093 ± 0.0
NG/BG/2/2A4	38.00 ± 0.33	38.33 ± 0.12	57.00 ± 0.03	34.66 ± 0.30	105.50 ± 0.67	8.13 ± 0.58	65.00 ± 0.28	40.00 ± 1.33	0.081 ± 0.10
NG/BG/2/3A9	37.00 ± 0.33	21.83 ± 0.02	35.33 ± 0.21	18.33 ± 0.33	101.10 ± 0.33	4.49 ± 0.33	67.01 ± 0.33	22.00 ± 0.67	0.044 ± 0.33
NG/BG/2/4A10	35.00 ± 0.33	28.20 ± 1.20	34.60 ± 0.03	19.40 ± 0.03	100.30 ± 0.33	5.92 ± 0.33	53.00 ± 0.67	29.00 ± 0.33	0.059 ± 0.23
NG/BG/2/5A14	38.00 ± 0.67	17.00 ± 1.21	29.83 ± 0.02	17.83 ± 1.20	106.00 ± 0.58	3.47 ± 0.33	75.03 ± 0.58	17.00 ± 0.03	0.034 ± 0.30
NG/BG/3A5	35.33 ± 0.24	36.83 ± 0.88	72.33 ± 0.33	42.33 ± 0.40	100.33 ± 0.58	7.76 ± 0.67	76.20 ± 1.20	38.00 ± 0.01	0.077 ± 0.33
NG/BG/4A7	37.00 ± 0.33	7.00 ± 0.01	5.00 ± 0.52	3.00 ± 0.01	102.43 ± 0.67	2.04 ± 0.58	27.04 ± 0.30	10.00 ± 0.34	0.020 ± 0.30
NG/BG/5A8	36.00 ± 0.54	30.00 ± 0.03	19.00 ± 0.33	15.00 ± 0.33	100.45 ± 0.88	6.30 ± 0.33	49.00 ± 0.33	31.00 ± 0.67	0.063 ± 0.13
NG/BG/6/1A13	35.66 ± 0.67	17.33 ± 1.32	10.33 ± 0.33	7.66 ± 0.10	102.01 ± 0.33	3.68 ± 0.58	40.00 ± 0.21	18.00 ± 1.24	0.036 ± 0.10
NG/BG/6/2A17	34.33 ± 0.67	32.00 ± 0.48	20.00 ± 0.10	17.00 ± 0.03	100.21 ± 0.00	6.92 ± 0.33	30.20 ± 1.00	34.00 ± 0.33	0.069 ± 0.30
NG/BG/6/3A20	33.33 ± 0.67	14.60 ± 1.02	7.00 ± 0.30	6.20 ± 0.41	93.33 ± 0.58	3.28 ± 0.33	34.00 ± 0.33	16.00 ± 0.67	0.032 ± 0.33
NG/BG/6/4A21	33.33 ± 0.67	16.20 ± 0.58	7.40 ± 0.12	6.00 ± 0.20	93.33 ± 0.58	3.07 ± 0.33	40.00 ± 0.03	15.00 ± 0.54	0.030 ± 0.33
NG/BG/7/1A15	33.66 ± 0.67	20.00 ± 0.01	16.33 ± 0.33	12.33 ± 1.23	93.33 ± 0.33	4.90 ± 0.33	63.00 ± 0.23	24.00 ± 0.28	0.049 ± 0.10
NG/BG/7/2A18	33.33 ± 0.67	23.00 ± 0.18	21.66 ± 0.20	16.33 ± 0.15	93.33 ± 0.33	5.30 ± 0.33	58.00 ± 0.10	26.00 ± 0.33	0.053 ± 0.10
NG/BG/8A23	38.00 ± 0.54	22.83 ± 0.02	40.83 ± 0.33	23.16 ± 0.30	108.22 ± 0.67	5.31 ± 0.67	67.06 ± 0.18	25.00 ± 0.67	0.053 ± 0.33
TVSU/214	43.00 ± 0.34	6.00 ± 0.01	7.81 ± 0.33	2.10 ± 0.30	120.99 ± 0.00	1.43 ± 0.58	22.67 ± 0.30	7.00 ± 0.03	0.014 ± 0.33
TVSU/238	43.00 ± 0.28	5.00 ± 0.67	7.48 ± 0.52	1.50 ± 0.03	114.00 ± 0.00	1.02 ± 0.58	9.50 ± 0.58	5.00 ± 0.01	0.010 ± 0.31
TVSU/261	37.00 ± 0.03	26.00 ± 0.28	23.40 ± 0.38	10.00 ± 0.20	125.43 ± 0.00	5.30 ± 0.58	49.00 ± 0.67	26.00 ± 0.60	0.053 ± 0.31
TVSU/305	38.00 ± 0.33	3.00 ± 1.45	7.97 ± 0.33	2.00 ± 0.30	112.66 ± 0.67	0.93 ± 0.08	32.33 ± 0.58	5.00 ± 0.43	0.009 ± 0.01
TVSU/329	39.00 ± 0.67	2.00 ± 0.20	6.89 ± 0.58	1.00 ± 0.00	114.30 ± 0.00	0.41 ± 0.05	24.50 ± 0.33	2.00 ± 0.44	0.004 ± 0.10
TVSU/368	35.00 ± 0.33	1.00 ± 0.00	6.42 ± 0.08	1.00 ± 0.33	96.33 ± 0.58	0.20 ± 0.01	3.67 ± 0.33	1.00 ± 0.01	0.002 ± 0.20
TVSU/401	35.00 ± 0.33	7.33 ± 0.01	10.54 ± 0.28	3.50 ± 1.00	95.00 ± 0.00	1.50 ± 0.02	25.28 ± 0.18	7.00 ± 0.03	0.015 ± 0.30
TVSU/424	40.00 ± 0.33	1.00 ± 0.01	6.32 ± 0.18	0.50 ± 0.01	113.26 ± 0.33	0.20 ± 0.03	29.70 ± 0.33	1.00 ± 0.06	0.002 ± 0.33
TVSU/465	35.00 ± 0.33	11.00 ± 0.12	10.61 ± 0.33	4.00 ± 0.30	100.34 ± 0.33	4.24 ± 0.33	24.27 ± 0.67	11.00 ± 0.33	0.042 ± 0.33
TVSU/524	39.00 ± 0.12	16.67 ± 0.88	17.13 ± 0.33	9.00 ± 0.03	111.98 ± 0.13	3.47 ± 0.67	24.90 ± 0.20	17.00 ± 0.67	0.037 ± 0.33
TVSU/534	41.00 ± 0.14	6.23 ± 0.01	12.69 ± 0.58	4.00 ± 0.24	119.95 ± 0.67	1.30 ± 0.58	45.15 ± 0.40	6.00 ± 0.03	0.013 ± 0.01
TVSU/562	40.00 ± 0.03	3.00 ± 0.01	7.48 ± 0.30	1.50 ± 0.00	130.73 ± 0.33	1.02 ± 0.01	32.33 ± 0.11	5.00 ± 0.03	0.010 ± 1.00
TVSU/689	38.00 ± 0.03	12.33 ± 0.03	14.30 ± 0.20	9.00 ± 0.40	120.67 ± 0.00	2.64 ± 0.33	56.00 ± 1.42	13.00 ± 0.67	0.026 ± 0.33
TVSU/733	37.00 ± 0.03	17.02 ± 0.12	11.38 ± 0.30	5.00 ± 0.21	130.00 ± 0.02	3.47 ± 0.30	19.52 ± 0.33	17.00 ± 0.33	0.034 ± 0.30
TVSU/1202	36.00 ± 0.10	14.00 ± 0.02	10.54 ± 0.20	4.00 ± 1.00	101.33 ± 0.33	3.46 ± 0.33	18.42 ± 0.33	17.00 ± 0.67	0.034 ± 0.10
TVSU/1243	38.00 ± 0.20	9.67 ± 0.03	13.78 ± 0.33	6.00 ± 0.20	119.50 ± 0.33	1.97 ± 0.33	40.44 ± 0.30	9.00 ± 0.28	0.019 ± 0.03
TVSU/1258	40.00 ± 0.03	8.00 ± 0.88	8.32 ± 0.30	3.00 ± 0.01	115.43 ± 0.67	1.63 ± 0.58	17.25 ± 0.13	8.00 ± 0.54	0.016 ± 0.33
TVSU/1260	38.00 ± 0.33	2.00 ± 0.33	6.52 ± 1.01	1.00 ± 0.00	135.98 ± 0.23	0.41 ± 0.02	24.50 ± 0.33	2.00 ± 0.03	0.004 ± 0.33
TVSU/1419	39.00 ± 0.20	1.00 ± 0.01	6.32 ± 0.18	1.80 ± 0.02	137.88 ± 0.00	1.20 ± 0.58	39.60 ± 0.52	1.00 ± 0.06	0.012 ± 0.33
TVSU/1543	44.00 ± 0.33	3.33 ± 0.13	8.30 ± 0.32	2.00 ± 0.40	140.00 ± 0.00	0.68 ± 0.12	48.50 ± 0.01	3.00 ± 0.20	0.006 ± 0.03
TVSU/1573	35.00 ± 0.32	3.33 ± 0.18	7.06 ± 0.52	1.50 ± 0.20	108.81 ± 0.00	0.68 ± 0.12	4.30 ± 0.00	3.00 ± 0.42	0.006 ± 0.30
TVSU/1606	40.00 ± 0.32	4.67 ± 1.45	7.21 ± 0.33	1.50 ± 0.20	120.77 ± 0.67	1.00 ± 0.02	12.00 ± 0.38	4.00 ± 0.54	0.010 ± 0.01
LSD (0.05)	1.12	4.55	5.03	2.75	9.55	3.25	6.42	2.11	NS

4.1.3 Plant height

Plant height differed significantly ($P < 0.05$) among the accessions (Table 5) and ranged from (48.00 ± 0.02) in accession NG/BG/8 – A23 to (12.33 ± 0.67) in accession NG/BG/7/ 1 -A15 (Table 6).

4.1.4 Number of leaves, leaf area and leaf area index

Number of leaves per plant differed significantly ($P < 0.05$) among the accessions (Table 5) and ranged from 29.00 ± 0.58 in accession NG/BG/6/1-A13 to 10.00 ± 0.13 in accession TVSU 1573 (Table 6). The accession NG/BG/8 – A23 showed the highest mean value (30.12 ± 0.33) for leaf area while the lowest was observed in accession TVSU 329 with a value of 8.66 ± 1.07 (Table 6). The highest leaf area index was recorded in accession NG/BG/8 – A23 (2.49 ± 1.21) while the least was observed in accession TVSU 329 (0.71 ± 0.10) (Table 6). Significant differences ($P < 0.05$) were observed among the accessions (Table 5).

4.1.5 Terminal leaflet length and leaflet width

Terminal leaflet length differed significantly ($P < 0.05$) among the accessions (Table 5) and ranged from 9.60 ± 0.33 in accession NG/BG/8-A23 to 6.86 ± 0.67 in accessions NG/BG/4-A7 (Table 6). The maximum width was recorded for accession NG/BG/8 – A 23 with a mean value of 4.24 ± 0.53 while accession TVSU 1202 had the minimum width of 1.56 ± 0.34 (Table 6). Significant differences were also observed for terminal leaflet width ($P < 0.05$) (Table 5).

4.1.6 Petiole length, number and internode length

The highest mean petiole length (18.59 ± 0.00) was recorded in accession NG/BG/8 – A23 while the lowest was recorded in accession TVSU 562 (7.00 ± 0.03) (Table 6). Significant differences ($P < 0.05$) were observed among the accessions (Table 5). The highest number of petiole per plant was recorded in accession NG/ BG/1 – A2 (18.00 ± 0.58) while accessions NG/BG/2-A13; NG/BG/2/5 – A 14; NG/BG/5-A8

and TVSU 562 had the least number (1.67 ± 0.33) (Table 6). The number of petiole per plant differed significantly ($P < 0.05$) among accessions (Table 5). The highest mean internode length (12.50 ± 1.03) was recorded in accession NG/BG/8-A23 while the lowest was recorded in accession TVSU 733 (2.30 ± 0.23) (Table 6). Significant differences ($P < 0.05$) were observed among the accessions (Table 5).

4.1.7 Number of pods and seeds per plant

Accession NG/BG/2/1-A3 recorded the highest number of pods and seeds per plant (44.66 ± 2.32 ; 46.00 ± 1.67) respectively, while the least mean value (1.00 ± 0.00) was observed in accessions TVSU 368; TVSU 424 and TVSU 1419 (Table 7). These parameters differed significantly ($P < 0.05$) among accessions (Table 5).

4.1.8 Seed yield per plot

The highest yield per plot was recorded in accession NG/BG/2/1-A3 (9.38 ± 0.33) while the least was observed in accessions TVSU368 424 (0.20 ± 0.01) (Table 7). Significant differences ($P < 0.05$) were observed among the accessions (Table 5).

4.1.9 Pod fresh weight and dry weight

The maximum fresh weight of pod was observed in accession NG/BG/3-A5 (72.33 ± 0.33) while the minimum weight was recorded in accession NG/BG/4-A7 with a mean value of 5.00 ± 0.52 (Table 7). Significant differences ($P < 0.05$) were observed among the accessions in pod fresh weight (Table 5). The highest pod dry weight was recorded in accession NG/BG/3-A5 with a mean value of 42.33 ± 0.00 whereas the minimum was observed in accession TVSU 424 with a mean value of 0.50 ± 0.0 (Table 7). Significant differences ($P < 0.05$) were observed among the accessions in pod dry weight (Table 5).

4.1.10 Seed size (100 seed weight)

The maximum seed size was observed in accession NG/BG/1-A2 (80.02 ± 0.33) whereas the minimum was recorded in accession TVSU 368 (3.67 ± 0.33) (Table 7). Significant differences ($P < 0.05$) were observed among the accessions in hundred seed

weight (Table 7).

4.2 Qualitative analysis

Table 8 presents the qualitative traits of the 38 bambara groundnut accessions studied.

4.2.1 Pod colours

Among the 38 accessions of bambara groundnut evaluated, results revealed the following five distinct colours: yellow, yellow-brown, brown, reddish-brown and black. The accessions with yellow pods had the highest number (18). This was followed by accessions with brown pods (13) then by accessions with yellow-brown pods (5). The accessions with black and reddish-brown pods recorded the least number (1) (Table 9)

4.2.2 Testa colour

Accessions with cream-coloured testa (Plate 3d) had the highest number (16) followed by accessions with brown-seeded colours (10), seeds with light-brown colours (5) came next. Accessions with black-coloured testa were two in number (2) while accessions with dark-brown testa colour, brownish red, greyish-cream, dark-red and reddish-purple recorded the least number (1) (Table 9).

4.2.3 Pod texture and pod shape

Majority of the accessions were rough (narrow grooved plate 3b) (23); others were smooth (14) and only one accession was deeply grooved (1). Accessions with different pod shapes were encountered.

TABLE 8

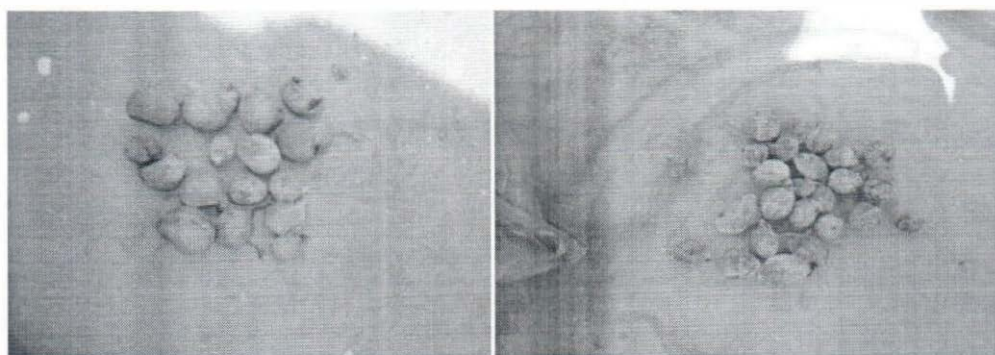
Distribution of 10 qualitative characters in 38 bambara groundnut accessions

S/N	ACCESSIONS	pod colour	pod texture	pod shape	eye pattern	testa pattern	testa colour	seed shape	terminal leaflet colour	growth habit	leaf shape
1	NG/BG/1-A2	Yellow-brown	little grooved	without point	Thick lines	no pattern	cream	Round	Green	bunch	oval
2	NG/BG/2/1-A3	Yellow	little grooved	without point	no eye pattern	no pattern	brown	Oval	Green	bunch	oval
3	NG/BG/2/2-A4	Yellow-brown	little grooved	without point	thick lines	no pattern	cream	Round	Green	bunch	oval
4	NG/BG/3/1-A5	Yellow	little grooved	without point	thick lines	no pattern	cream	Round	Green	bunch	oval
5	NG/BG/6/6-A7	Yellow-brown	little grooved	without point	Butterfly	no pattern	cream	Round	Green	bunch	oval
6	NG/BG/5-A8	Brown	smooth	without point	no eye pattern	no pattern	black	Oval	Green	semi bunch	lanceolate
7	NG/BG/2/3-A9	Brown	little grooved	without point	no eye pattern	no pattern	brown	Oval	Green	bunch	oval
8	NG/BG/2/4-A10	Yellow	little grooved	without point	thick lines	no pattern	cream	Round	Green	bunch	oval
9	NG/BG/6/1-A13	Yellow-brown	smooth	without point	Mottled	dotted	cream	Round	Green	semi bunch	lanceolate
10	NG/BG/2/5-A14	Brown	little grooved	pointed with hooks	no eye pattern	no pattern	brown	Oval	Green	bunch	oval
11	NG/BG/7/1-A15	Black	smooth	pointed with hooks	no eye pattern	no pattern	black	Oval	Green	semi bunch	lanceolate
12	NG/BG/6/2/17	Brown	smooth	pointed with hooks	thin line	no pattern	dark brown	Oval	Green	semi bunch	lanceolate
13	NG/BG/7/2-A18	yellow brown	smooth	without point	Mottled	marbled	creamy grey	Oval	Green	semi bunch	oval
14	NG/BG/6/3-A20	Brown	smooth	without point	no eye pattern	no pattern	brownish red	Oval	Green	semi bunch	oval
15	NG/BG/6/4-A21	reddish brown	smooth	without point	no eye pattern	no pattern	dark red	Oval	Green	semi bunch	oval
16	NG/BG/8-A23	Brown	little grooved	without point	no eye pattern	no pattern	light brown	Oval	Green	spreading	oval
17	TVSU 214	Yellow	little grooved	without point	Butterfly	dotted	cream	Oval	Green	semi bunch	oval
18	TVSU 238	Yellow	smooth	without point	no eye pattern	dotted	light brown	Oval	Green	semi bunch	oval
19	TVSU 261	Brown	smooth	without point	no eye pattern	dotted	brown	Oval	Green	semi bunch	oval
20	TVSU 305	Brown	little grooved	without point	Butterfly	dotted	brown	Oval	Green	semi bunch	oval
21	TVSU 329	Yellow	little grooved	without point	no eye pattern	dotted	brown	Oval	Green	semi bunch	oval
22	TVSU 368	Brown	little grooved	pointed hooks	no eye pattern		light brown	Oval	Green	semi bunch	oval
23	TVSU 401	yellow	smooth	without point	Butterfly	no pattern	cream	Round	Green	semi bunch	oval
24	TVSU 424	yellow	smooth	pointed with hooks	no eye pattern	no pattern	brown	Oval	Green	semi bunch	oval
25	TVSU 465	yellow	little grooved	pointed with hooks	Butterfly	no pattern	cream	Round	Green	semi bunch	oval
26	TVSU 524	yellow	little grooved	without point	Butterfly	no pattern	cream	Round	Green	semi bunch	lanceolate
27	TVSU 534	brown	much grooved	without point	Butterfly	dotted	cream	Oval	Green	semi bunch	oval
28	TVSU 562	yellow	smooth	without point	more food	dotted/strict	brown	Oval	Green	semi bunch	oval
29	TVSU 689	brown	smooth	without point	no eye pattern	no pattern	reddish purple	Oval	Green	semi bunch	oval
30	TVSU 733	yellow	little grooved	pointed with hooks	no eye pattern	no pattern	light brown	Oval	green	semi bunch	lanceolate
31	TVSU 1202	yellow	little grooved	pointed with hooks	no eye pattern	no pattern	cream	Oval	green	semi bunch	lanceolate
32	TVSU 1243	brown	little grooved	without point	no eye pattern	no pattern	cream	Round	green	semi bunch	lanceolate
33	TVSU 1258	yellow	little grooved	pointed with hooks	no eye pattern	no pattern	brown	Round	green	semi bunch	lanceolate
34	TVSU 1260	yellow	little grooved	pointed with hooks	no eye pattern	dotted	cream	Oval	green	semi bunch	lanceolate
35	TVSU 1419	yellow	little grooved	without point	Butterfly	dotted	brown	Oval	green	semi bunch	lanceolate
36	TVSU 1543	yellow	little grooved	without point	Butterfly	no pattern	cream	Round	green	semi bunch	Elliptic
37	TVSU 1573	yellow	little grooved	without point	Butterfly	dotted	cream	Oval	green	semi bunch	Elliptic
38	TVSUI606	brown	little grooved	pointed with hooks	Butterfly	dotted	light brown	Round	green	semi bunch	lanceolate

TABLE 9

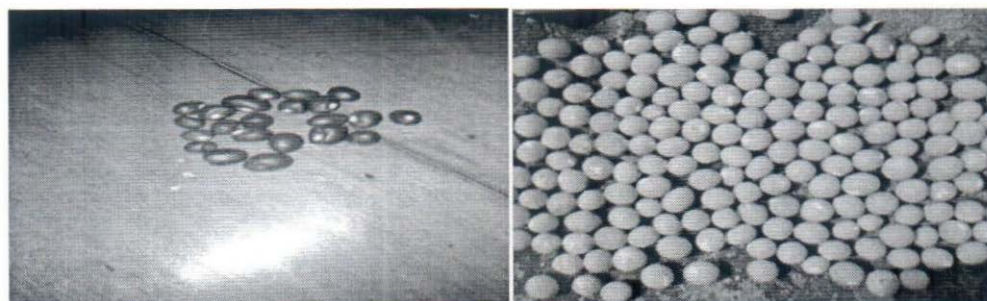
Summary of 10 qualitative characters as expressed in 38 Bambara accessions

Qualitative Characters	Variations	Number of accessions
Pod colour	yellow	18
	brown	13
	yellow-brown	5
	reddish-brown	1
	black	1
Pod texture	narrow-grooved (rough)	23
	smooth	14
	deeply grooved	1
Pod shape	without point (round)	26
	pointed/hooked	9
	pointed	3
Eye pattern	no eye pattern	19
	butterfly	11
	thick lines	4
	mottled	3
	thin lines	1
Testa pattern	no testa pattern	25
	dotted	12
	marbled	1
Testa colour	cream	16
	brown	10
	light-brown	5
	black	2
	dark-brown	1
	brownish-red	1
	greyish-cream	1
	dark-red	1
	reddish-purple	1
Seed shape	oval	25
	round	13
Leaf shape	oval	24
	lanceolate	12
	elliptic	2
Terminal leaflet colour	green	38
Growth habit	semi-bunch	30
	bunch	7
	spreading	1



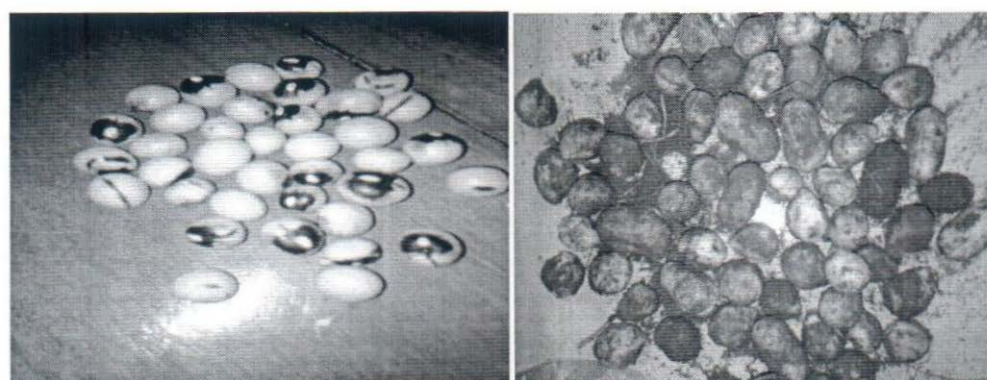
3a

3b



3c

3d



3e

3f

PLATES 3a-3e: Pod shape/Seed colour/Testa pattern of some bambara nut accessions studied .

3a=Pointed & hooked pod shape;

3b=Rough pod texture; 3c=Seeds with no testa pattern.

3d=Cream-coloured seeds with no eye pattern;

3e=Seeds with butterfly-like eye pattern;

3f=Pods (mostly double-seeded) produced by accession NG/BG/8-A23

Topping the list were accessions that were not pointed (round) (26), followed by accessions that were pointed and nooked (9) (plate 3a) and lastly by three accessions that were pointed (Table 9)

4.2.4 Eye pattern and testa pattern

The different eye patterns observed were: those with no eye (19 accessions in number) (plate 3d), butterfly-like eye pattern (11) (plate 3e), thick lines (4), mottled eye patterns (3) and thin line (1). Accessions with no testa pattern (plate 3c) had maximum number (25), followed by accessions with dotted testa pattern (11). The least number was observed in accessions with marbled testa pattern as well as dotted / striped (1) (Table 8).

4.2.5 Seed shape and leaf shape

The seed shapes observed in this study were round and oval. Oval – seed shape was recorded in 25 accessions while round-seeded shape was obtained in 13 accessions. Three shapes of leaf were observed in the present study: oval (24), lanceolate (12) and elliptic (2) (Table 9).

4.2.6 Growth habit and terminal leaflet colour

Result revealed three growth habits, namely: bunch, semi-bunch and spreading. Accessions with semi – bunch growth habits recorded the maximum number (29); followed by accessions with bunch type (8). The least number was observed in accession with spreading growth habit (1). It was observed that the thirty-eight evaluated accessions had green terminal leaflet colour (Table 9).

4.3 Correlation coefficients of vegetative and reproductive attributes in 38 bambara accessions

The Pearson correlation coefficient (r) based on the mean of the accessions was used to determine the relationship among some vegetative and reproductive attributes of bambara groundnut. Leaflet width showed a positive and highly

significant association with leaf area ($r=+0.97$; $P<0.05$) and leaflet length ($r=+0.65$; $P<0.05$). Results showed that leaf area correlated positively and strongly with internode length ($r=0.999$; $P<0.05$) and leaflet length ($r=+0.761$; $P<0.05$). Seed yield per plot showed a positive and significant correlation with number of seeds per plant ($r = 0.543$; $P < 0.05$); pod dry weight ($r= 0.889$; $P < 0.05$); pod fresh weight ($r= 0.836$; $P<0.05$); and number of pods per plant ($r = +0.836$; $P < 0.05$) (Table 10).

4.4 Regression analysis between yield per plot and other attributes

Table 11 shows the regression coefficients between yield per plot with vegetative and reproductive attributes while Figures 1 and 2 show the regression graphs (Line of best fit). Regression analysis was done to examine the influence of the independent variables (other attributes) on the dependent variable (yield per plot). Positive and high regression relationships were observed between yield and leaf area, leaf area index, terminal leaflet width/length, petiole number, leaflet number, internode length, plant height, petiole length, percentage germination, days to seedling emergence, 100 seed weight, number of seeds per plant, days to maturity, days to 50 % flowering, number of pods per plant, pod fresh weight and pod dry weight.

4.5 Path coefficient analysis

Table 12 portrays the path coefficient analysis between yield and other attributes. Path analysis is a cause and effect relationship. It was done to determine the direct and indirect effects of these attributes on yield. Seven attributes (terminal leaflet width, leaf area index, petiole length, pod fresh weight, pod dry weight, days to maturity and percentage germination) had a positive, direct and significant relationship with yield. The number of seeds per plant had an indirect and positive association (Table 12).

TABLE 10

Correlation coefficients of vegetative and reproductive attributes of 38 accessions of Bambara groundnut

	LW	PH	LA	LP	IL	LL	PL	PP	PFW	PDW	D2M	100SW	SPSY
LW	1.00												
PH	-0.1	1.00											
LA	0.97**	-0.255	1.00										
LP	0.3	-0.17	0.363	1.00									
IL	0.97**	-0.258	0.999**	0.367	1.00								
LL	0.65**	-0.435	0.761**	0.425	0.76	1.00							
PL	-0.091	0.077	-0.017	0.274	-0.016	-0.203	1.00						
PP	-0.021	-0.008	0.017	-0.015	0.02	0.328	0.041	1.00					
FW	-0.006	-0.006	0.111	-0.061	0.114	0.209	0.211	0.851**	1.00				
DW	0.015	-0.251	0.091	-0.044	0.092	0.246	0.11	0.889**	0.987**	1.00			
D2M	-0.127	-0.272	-0.269	-0.089	-0.268	-0.303	-0.03	-0.348	0.988**	-0.346	1.00		
100SW	0.0084	-0.018	0.246	0.068	0.247	0.143	0.115	-0.423	0.805**	0.787	-0.239	1.00	
SP	-0.047	-0.021	-0.009	-0.129	-0.006	0.316	0.035	-0.033	-0.033	-0.314	0.061	-0.139	1.00
SY	-0.063	0.014	0.086	-0.002	0.086	-0.233	-0.488	0.836**	0.836**	0.889**	-0.343	-0.471	0.543**1

LW = Leaflet width(cm), PH = Plant height (m); LA = Leaf area (cm²); L/P =Leaves per plant; IL=Internode length; LL=Leaflet length (cm), PL=Petiole length; P/P = Pods per plant; PFW = Pod fresh weight (g); PDW= pod dry weight (g); D2M = Days to maturity; 100SW = 100 seed weight (g), S/P= Seeds per plant; SY = Seed yield per plot (g).

TABLE 11
Regression between yield per plot and other characters

Attributes	Mean(\bar{x})	Line of best fit equation	VR
Leaf area and yield/plot	13.779	$\hat{y}=0.286x + 12.84$	7.466**
Leaf area index and yield/plot	0.417	$\hat{y}=0.016x + 0.361$	9.321**
Terminal leaflet width and yield/plot	2.2771	$\hat{y}=0.042x + 2.138$	4.476**
Petiole number and yield/plot	4.422	$\hat{y}=0.132x + 3.989$	12.218**
leaflet number and yield/plot	14.043	$\hat{y}=1.795x + 10.16$	10.502**
Internode length and yield/plot	6.9033	$\hat{y}=0.152x + 6.407$	5.675**
plant height and yield/plot	23.189	$\hat{y}=0.729x + 20.81$	9.600**
Terminal Leaflet length and yield/plot	8.1036	$\hat{y}=0.008x + 8.077$	9.031**
Petiole length and yield/plot	12.3118	$\hat{y}=0.324x + 11.25$	7.145**
Percentage germination and yield/plot	52.773	$\hat{y}=4.860x + 36.97$	9.245**
Days to seedling emergence	8.0973	$\hat{y}=-0.037x + 8.219$	9.230**
100 seed weight and yield/plot	39.487	$\hat{y}=5.857x + 20.44$	10.502**
No.of seeds/plant and yield/plot	15.8157	$\hat{y}=4.939x - 0.246$	6.619**
Days to maturity and yield/plot	109.2592	$\hat{y}=-2.488x + 118.1$	8.136**
Days to 50% flowering and yield/plot	37.4473	$\hat{y}=0.455x + 38.92$	8.3301**
No.of pods/plant and yield/plot	15.4284	$\hat{y}=4.921x - 0.575$	6.4771**
Pod fresh weight and yield/plot	19.272	$\hat{y}=6.215x - 0.937$	8.948**
Pod dry weight and yield/plot	10.332	$\hat{y}=4.112x - 3.040$	13.192**

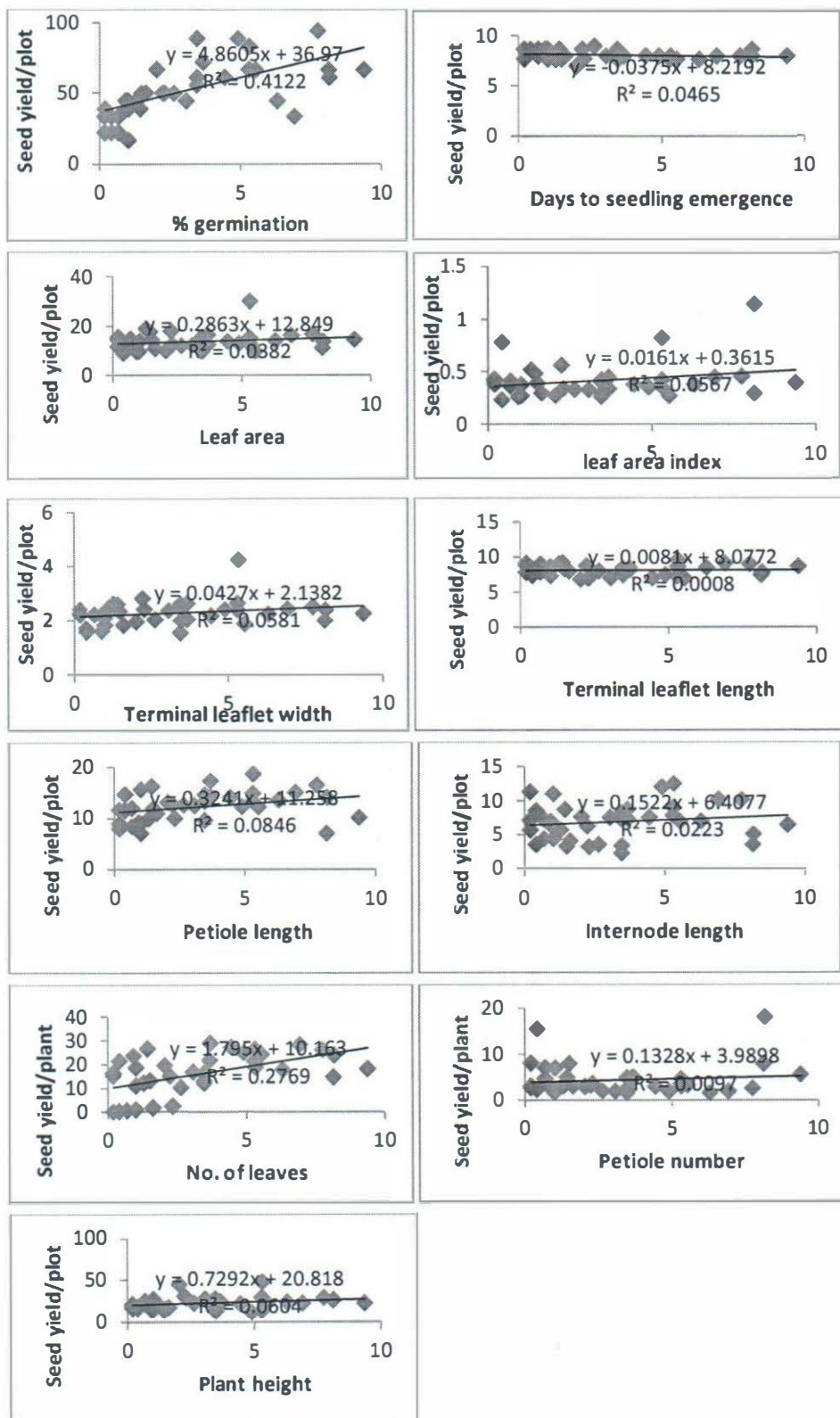


FIG. 1: Regression graphs (lines of best fit) between yield and vegetative characters

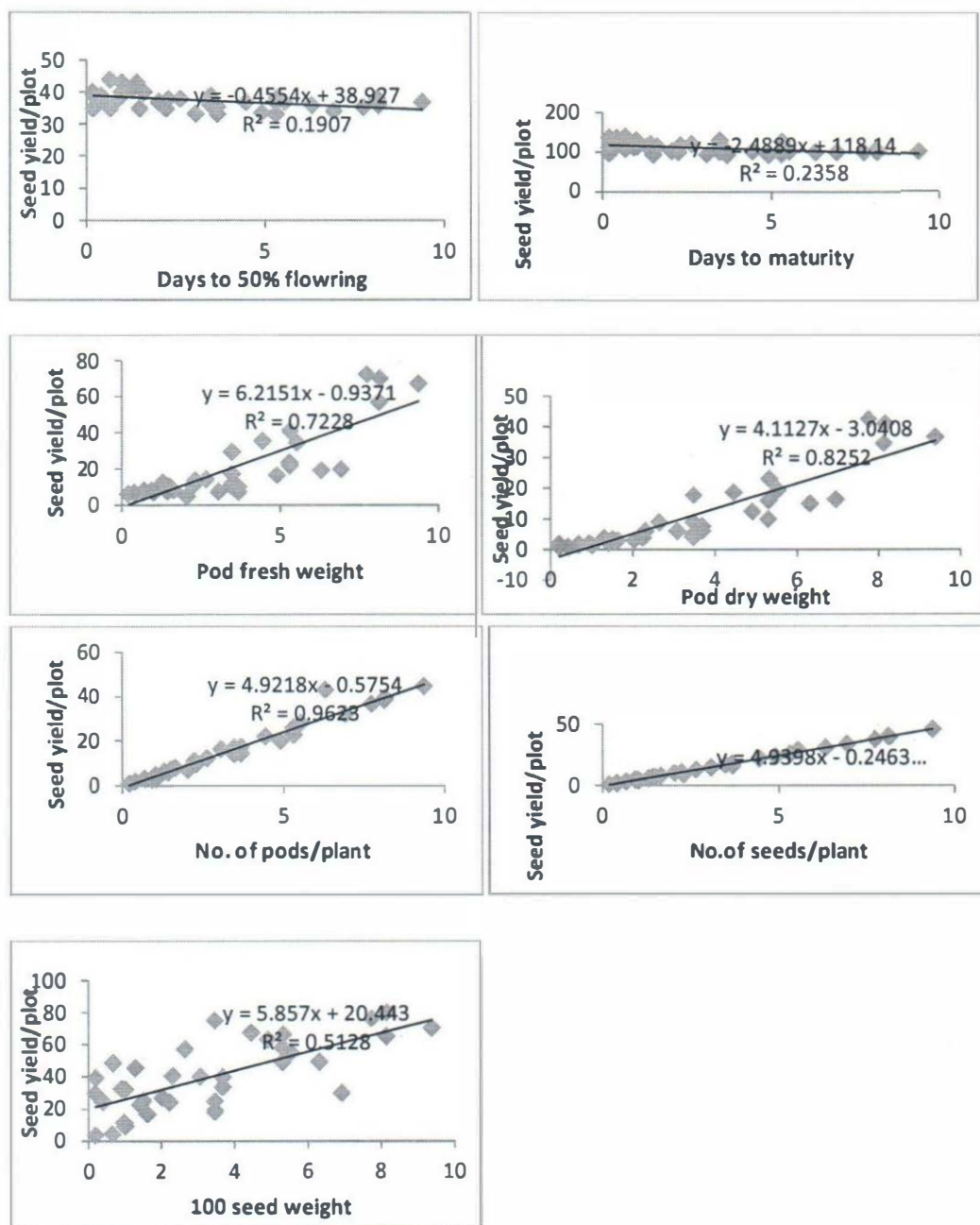


FIG. 2: Regression graphs (lines of best fit) between yield and reproductive characters

TABLE 12

Path coefficient analysis results in 38 accessions of bambara nuts

TRAITS	LW	PH	LAI	LA	LL	L/P	IL	PL	DTF	P/P	PFW	PDW	DTM	S/P	SY	100SW	Y/H	PN	PG	DTSE
LW	5.107**	4.325	1.765	-0.17	0.047	-6.283	3.043	5.989	-0.003	-0.097	-10.37	3.265	-0.036	-0.224	0.013	0.355	-4.324	0.2267	1.0489	0.5804
PH	-0.196	0.069	-0.797	0.488	0.002	-6.851	-1.669	-0.014	-0.341	0.019	-6.631	9.41	3.558	-0.89	0.061	-10.37	3.265	0.4572	-0.3514	-0.035
LAI	1.624	-4.816	1.513**	-0.163	-0.005	-8.105	-2.451	-2.099	-0.122	0.018	-6.278	5.663	5.725	0.462	-0.068	-6.631	9.41	-1.4602	0.2732	-0.530
LA	2.416	13.613	-12.86	-1.052	-0.114	-1.473	-0.835	-2.492	0.389	0.003	-6.283	3.043	5.989	-0.003	-0.097	-6.278	5.663	7.7353	0.1473	0.179
LL	0.027	4.641	5.938	-0.431	-0.042	8.145	-3.603	-5.142	0.082	0.039	-0.998	0.592	-0.002	-0.298	0.071	-6.283	3.043	-1.9222	0.9036	1.269
LN	4.321	-2.468	-2.227	-0.298	0.071	-3.801	-0.612	-1.272	-0.514	0.072	4.321	-2.468	-2.227	-0.298	0.071	-6.851	-1.669	0.7543	0.4439	-0.767
IL	8.392	6.367	-0.473	0.707	-0.004	-6.065	-2.464	-6.937	0.643	-0.05	8.392	6.367	-0.473	0.707	-0.004	-8.105	-2.451	1.8225	0.8686	0.5711
PL	4.693	-1.137	4.29	-0.511	-0.017	-10.015	-5.777	1.771**	-0.504	-0.049	4.693	-1.137	4.29	-0.511	-0.017	-0.036	-0.224	-1.9885	1.2158	0.1473
DTF	0.654	-0.639	-0.467	0.355	0.008	-2.272	-7.728	-0.779	0.081	-0.001	0.654	-0.639	-0.467	0.355	0.008	3.558	-0.89	0.2014	-0.1642	-0.131
P/P	4.268	8.969	4.783	0.436	-0.013	-11.513	-3.638	0.916	-0.6	-0.01	4.268	8.969	4.783	0.436	-0.013	5.725	0.462	-0.2718	1.032	1.637
PFW	2.501	10.156	0.496	0.689	-0.015	0.109	-6.501	2.283	0.954	-0.043	2.501**	10.156	0.496	0.689	-0.015	5.989	-0.003	1.7714	0.3286	1.382
PDW	0.886	4.064	-1.667	-0.029	0.032	5.208	-5.68	0.154	-0.827	0.096	0.886	4.064**	-1.667	-0.029	0.032	-0.014	-0.341	1.4916	0.117	0.309
DTM	3.91	-2.795	1.248	-0.78	0.079	-6.616	-3.341	1.512	0.176	-0.033	3.91	-2.795	1.248**	-0.78	0.079	-2.099	-0.122	-0.9278	0.9452	-0.440
S/P	22.668	0.31	2.939	0.041	0.108	-6.412	-6.477	2.036	-0.108	-0.059	22.668	0.31	2.939	0.041	0.108	0.013	0.019	-0.085	3.1775	-0.395
SY	7.137	1.649	-0.552	0.398	0.267	-6.2	-5.577	-4.054	0.647	-0.01	7.137	1.649	-0.552	0.398	0.267	0.061	0.018	1.2211	0.7462	-0.107
100SW	24.155	-5.772	0.436	-0.423	-0.301	-0.972	-0.216	-1.507	0.681	-0.008	24.155	-5.772	0.436	-0.423	-0.301	-0.068	0.654	-0.5157	3.1402	-1.490
Y/H	-6.497	11.334	-1.228	0.342	-0.026	-0.023	-8.358	-1.752	-0.174	0.031	-6.497	11.334	-1.228	0.342	-0.026	-0.097	0.633**	2.2303	-0.7608	1.6141
PN	0.0833	-1.11	0.7517	-0.64	-0.753	-0.0278	-0.341	-2.373	-2.497	-0.1866	1.326	2.069	0.434	2.416	-0.655	0.654	-0.639	-0.467	0.355	0.008
PG	-0.3535	0.2473	1.79	0.1229	-1.241	-0.3107	-1.823	-1.058	0.886	4.064	-1.667	-0.029	0.032	0.689	-0.033	0.574	-0.013	4.268	8.969**	4.783
DTSE	-1.7984	-0.367	1.6756	0.965	-0.643	0.246	-1.057	0.436	3.91	-2.795	1.248	-0.78	0.079	-0.234	0.452	0.665	-0.015	2.501	10.156	0.496

LW = Leaflet width(cm); PH = Plant height (m); LAI = Leaf area index; LA = Leaf area (cm²); LL=Leaflet length (cm) L/P =Leaves per plant; IL=Internode length; PL=Petiole length; DTF =Days to 50% flowering P/P = Pods per plant; PFW = Pod fresh weight (g); PDW= pod dry weight (g); DTM = Days to maturity; S/P = Seeds per plant; SY = Seed yield per plot (g). 100SW = 100 seed weight (g); Y/H=Yield per hectare; PN=Petiole number; PG=Percentage germination; DTSE=Days to seedling emergence

4.6 Principal component analysis (PCA) of quantitative and qualitative characters in 38 bambara groundnut accessions

The principal component analysis (PCA) for 13 quantitative characters in the 38 accessions is presented in Table 13. The first three principal components (PC1, PC2 and PC3) with eigen values greater than one, accounted for 75.80% of the total variation (Table 12). The first component (PC1) with an eigen value of 3.840 explained 43.67 % of the overall variability among the accessions with most of the variation coming from *plant height, leaf area, leaf width, pods per plant, internode length, 100 seed weight and seed yield*. High loadings for the second component (PC2) with an eigen value of 1.891 which described 20.01 % of the variance was accounted for by *petiole length, pod dry weight, and number of leaves per plant*. *Pod fresh weight and leaflet length* contributed most of the 12.12% explained variation at principal component three (PC3) with an eigen value of 1.001 (Table 13)

The principal component analysis (PCA) for 10 qualitative characters was also performed for 38 accessions and is presented in Table 13. Six principal components with eigen values greater than one, accounted for 84.8290% of the total variation (Table 13).

The first component (PC1) with an eigen value of 3.749 explained 23.430 % of the overall variability among the accessions with most of the variation loading values coming from *eye colour and growth habit*. High loadings for the second component (PC2) with an eigen value of 3.158 which described 19.736 % of the variance was accounted for by *terminal leaflet colour and seed shape*. *Pod shape, testa colour and eye pattern* contributed most of the 14.327% explained variation at principal component three (PC3) with an eigen value of 2.292. The fourth principal component (PC4) had an eigen value of 1.838 and contributed 11.489% to the total variation observed among the 38 bambara groundnut accessions.

TABLE 13

Eigen vectors and values for principal components (PC) based on thirteen quantitative morphological traits in 38 accessions of bambara groundnut (*Vigna subterranea*)

Quantitative traits	Components		
	PC 1	PC 2	PC 3
Plant height	.891	.029	.234
Leaf width	.943	.014	.148
Leaf area	.888	-.212	.219
No.of Leaves per plant	-.093	-.693	-.019
Leaflet length	.261	.542	-.723
Pods per plant	.735	.475	-.116
Internode length	.727	-.274	-.060
Pod dry weight	-.464	.575	.534
Petiole length	.090	.664	.224
Pod fresh weight	.321	.122	.534
100 seed weight	.945	.284	-.213
Seed yield per plot	.856	-.342	-.332
Seeds per plant	.233	.255	-.018
Eigen values	3.840	1.891	1.001
% variation	43.666	20.010	12.120
Cumulative variation	43.666	63.675	75.800

Principal loading attribute to this component was *the testa pattern*. Eigen value for principal component five (PC5) stood at 1.430 contributing 8.936% to the total variations with prominent loading values from *pod texture*. The sixth principal component (PC6) had an eigen value of 1.106 and contributed only 6.912% to the total variations observed in the accessions. Loading value for this principal component includes the *leaf shape* (Table 14).

4.7 Estimation of Phenotypic and Genotypic variances; Phenotypic and Genotypic coefficients of variation and heritability of quantitative attributes in 38 bambara groundnut accessions

Results of genetic variance, genotypic coefficient of variation, phenotypic variance, phenotypic coefficient of variation and heritability of the quantitative attributes of 38 accessions of bambara groundnut are given in Table 15. The result showed that the highest percentage genotypic coefficient of variation (GCV) of 171.952% was obtained in terminal leaflet width while the least GCV of 3.878% was recorded in percentage germination. Similarly, the phenotypic coefficient of variation (PCV) was highest and lowest in terminal leaflet width and percentage germination at 175.080% and 4.323% respectively. Heritability estimates in the broadsense were high in most of the traits of the accessions. The highest was recorded for pod fresh weight at 99.127% while the lowest went to terminal leaflet length at 27.110% (Table 15).

4.8 Cluster analyses based on morphological data

4.8.1 Cluster analysis

Cluster analysis was done using the unweighted pair group method with arithmetic means (UPGMA) and a dendrogram of 38 bambara groundnut accessions based on the morphological data generated. Accessions were grouped into three major clusters. Cluster one had 7 sub-clusters which consisted of 33 accessions (21 from IITA and 12 from local farmers), cluster two had 4 local accessions and cluster three was an outlier (TVSU 1419) (Figure 3).

TABLE 14

Eigen vectors and values for principal components based on ten qualitative morphological traits in 38 accessions of bambara groundnut

Qualitative traits	Components					
	PC1	PC2	PC3	PC4	PC5	PC6
Eye colour	-0.857	0.051	0.158	0.225	-0.328	-0.054
Growth habit	0.62	0.71	-0.099	0.153	0.025	-0.045
Terminal leaflet colour	0.325	0.812	-0.004	-0.127	0.036	0.191
Eye pattern	-0.384	-0.003	-0.632	0.139	0.463	0.097
Leaf shape	0.409	-0.369	0.063	-0.151	0.181	0.692
Testa colour	0.013	0.323	0.529	0.318	-0.266	0.453
Testa pattern	0.111	0.314	-0.110	0.763	-0.125	0.306
Pod texture	0.177	-0.327	0.422	0.464	0.593	-0.011
Pod shape	-0.342	-0.065	0.635	0.369	0.420	-0.080
Seed shape	0.555	0.632	0.304	0.121	-0.072	-0.349
Eigen values	3.749	3.158	2.292	1.838	1.430	1.106
% variation	23.430	19.736	14.327	11.489	8.936	6.912
Cumulative variation	23.430	43.165	57.492	68.981	77.911	84.829

TABLE 15

Estimates of genotypic and phenotypic variances (GV and PV), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and broadsense heritability (H^2b) for morphological traits in 38 bambara nut accessions

Attributes	GV	EV	PV	Mean	PCV %	GCV %	H^2b
Plant height	14.783	3.421	18.204	23.189	18.399	16.580	81.200
Leaf area	27.067	3.693	30.760	13.779	40.250	37.757	87.990
Leaf area index	0.090	0.034	0.124	0.417	84.445	71.942	72.580
Terminal leaflet width	15.330	0.562	15.892	2.277	175.080	171.952	96.460
Terminal leaflet length	2.197	0.260	2.457	8.103	19.344	18.292	27.110
Internode length	14.021	2.027	16.048	6.903	58.032	54.243	87.369
Petiole length	16.094	2.197	18.291	12.311	34.739	32.586	87.988
Days to 50% flowering	14.975	2.810	17.785	37.447	11.261	10.333	84.200
No. of pods/plant	292.270	3.056	295.326	15.428	111.390	110.810	98.960
Pod fresh weight	642.831	5.660	648.491	19.272	132.140	131.559	99.127
Pod dry weight	224.201	2.711	226.912	10.332	145.800	144.922	98.805
Days to maturity	2155.570	2804.788	4960.358	109.26	64.460	42.493	43.455
No. of seeds/plant	273.042	4.243	277.285	15.815	105.290	104.482	98.469
100 seed weight	666.898	39.690	706.588	39.487	67.317	65.399	94.382
Seed yield/plot	10.741	1.368	12.109	3.253	106.970	100.748	88.702
% germination	4.190	1.016	5.206	52.773	4.323	3.878	80.484
Days to emergence	1.005	0.989	1.994	8.097	17.439	12.381	50.401
Petiole number	26.425	0.667	27.092	4.422	117.710	116.248	97.538
No. of leaves	134.731	24.326	159.057	14.043	89.808	82.655	84.706

EV=Error variance.

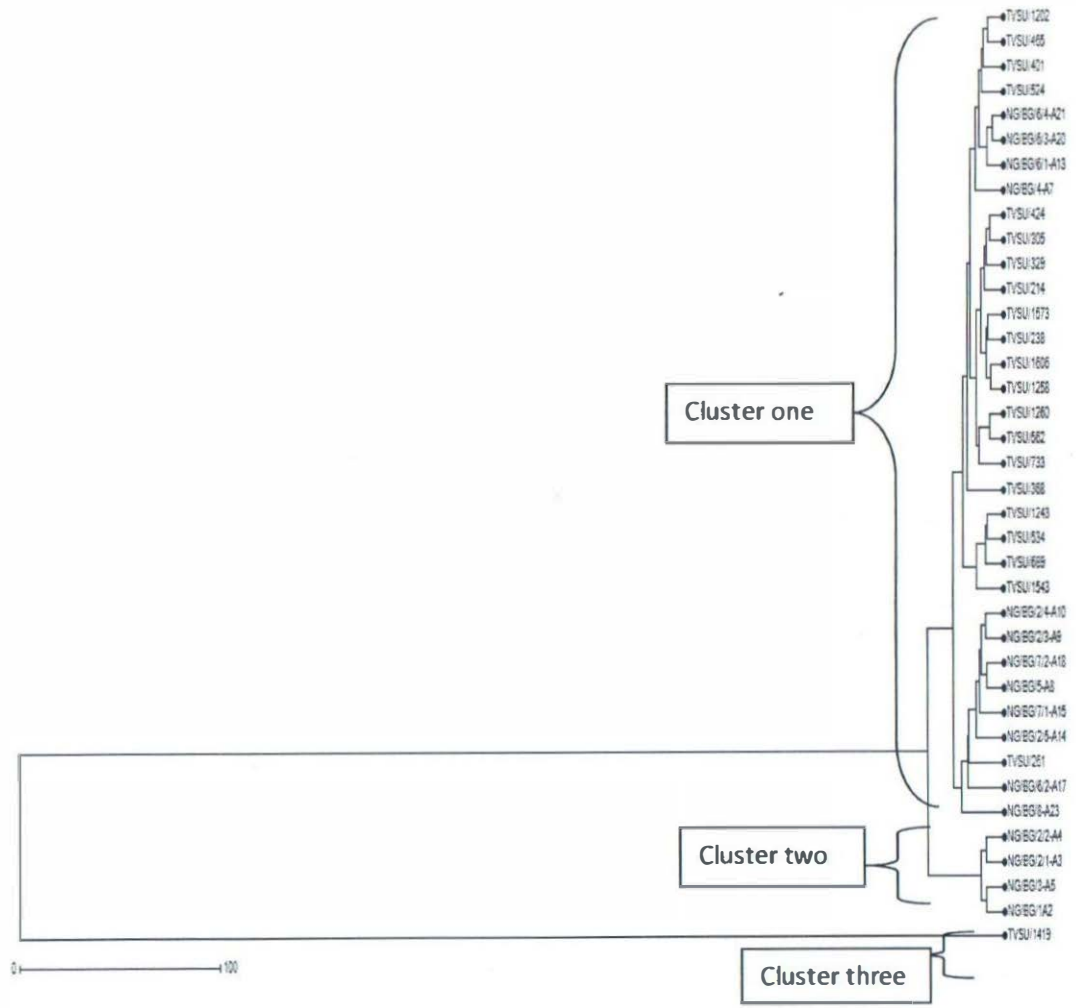


FIG. 3: Dendrogram of 38 bamabara groundnut accessions based on morphological data

The accessions clustered based on morphological affinity in addition to their geographical location/origin. For instance, cluster one contained all the accessions obtained from IITA, except one (TVSU 1419). TVSU 1419 was one of three least yielding accessions (one pod per plant). On the basis of the attributes, the four best yielding accessions (NG/BG/1/1-A2 (Gombe), NG/BG/2/1-A3 (Jos), NG/BG/2/2-A4(Plateau) and NG/BG/3/1-A5(Bornu) as revealed by this study were grouped on cluster two of the dendrogram (Figure 3).

4.9 Molecular analysis

4.9.1 Genetic diversity studies in 38 accessions of *Vigna subterranea* based on seven (7) SSR markers

Table 16 gives a summary of the results of genetic diversity studies of 38 bambara groundnut accessions using seven SSR markers. Eleven (11) randomly selected SSR markers specific to bambara groundnuts were used for screening the 38 accessions. Seven out of the eleven SSR markers amplified reproducible polymorphic bands with primers 1 and 7 as examples (Plates 4 and 5). The expected heterozygosity value ranged from 0.35 for primer 7 to 0.63 for primers 16 and 23 with an average of 0.53. The polymorphic information content (PIC) had a mean of 0.45 across all markers and ranged from 0.43 (primers 4 and 16) to 0.48 (primer 7). Effective multiplex ratio (E) which is also the number of effective polymorphic loci was similar for all markers at 1.00, while the marker index (MI) value was at an average of 0.53.

The discriminating power (D) had the maximum value for primer 7 at 0.95 with an average of 0.60. A total of 17 alleles were detected with an average of 2.4 for all markers (Table 16).

TABLE 16

Genetic diversity indices in 38 accessions of *Vigna subterranea* and polymorphic information content based on seven SSR markers

	He	PIC	E	MI	D	BS	NA
Primer I	0.46	0.46	1	0.46	0.44	200-300	3
Primer 3	0.51	0.45	1	0.51	0.51	80-200	3
Primer 4	0.52	0.43	1	0.52	0.44	150-200	2
Primer 7	0.35	0.48	1	0.35	0.95	50-100	3
Primer 16	0.63	0.43	1	0.63	0.64	100-150	2
Primer 19	0.61	0.46	1	0.61	0.63	120-150	2
Primer 23	0.63	0.47	1	0.63	0.63	80-100	2
Mean	0.53	0.45	1	0.53	0.6		2.4

He= expected heterozygosity, PIC= polymorphic information content, E= effective multiplex ratio, MI= marker index, D= discriminating power, BS= band size, NA= allele number

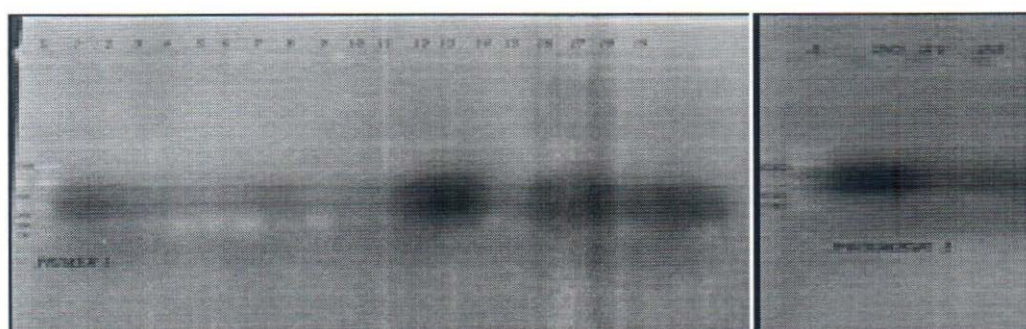
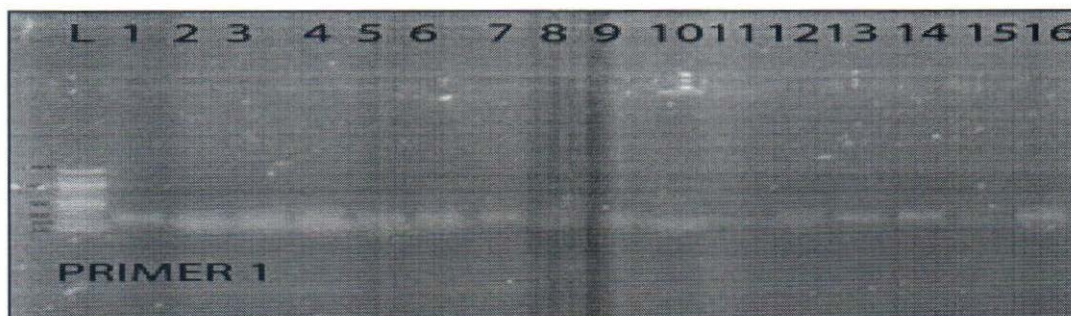


PLATE 4: Band patterns of 38 bambara accessions with Primer I

1=NG/BG/2/1-A3; 2= NG/BG/2/2-A4; 3= NG/BG/3-A5; 4=NG/BG/4-A7; 5=NG/BG/5-A8; 6=NG/BG/2/3-A9
 7= NG/BG/2/4-A10; 8= NG/BG/6/1-A13; 9= NG/BG/2/5-A14; 10 =NG/BG/7/2-A18; 11 = NG/BG/6/3-A20
 12=NG/BG/6/4-A21; 13 =NG/BG/6/2-A17; 14= NG/BG/8-A23; 15= NG/BG/1/1-A2; 16 =NG/BG/7/1-A 15
 17=TVSU 214; 18=TVSU 238; 19=TVSU 261; 20=TVSU 305; 21=TVSU 329; 22=TVSU 368; 23=TVSU 401
 24=TVSU 424; 25=TVSU 465; 26=TVSU 524; 27=TVSU 534; 28=TVSU 562; 29=TVSU 689; 30=TVSU 733
 31=TVSU 1202; 32=TVSU 1243; 33=TVSU 1258; 34=TVSU 1260; 35=TVSU 1419; 36=TVSU 1543
 37=TVSU 1573; 38=TVSU 1606; L=DNA ladder.
Numbers 1 to 22 of the band pattern represent accessions 17 to 38

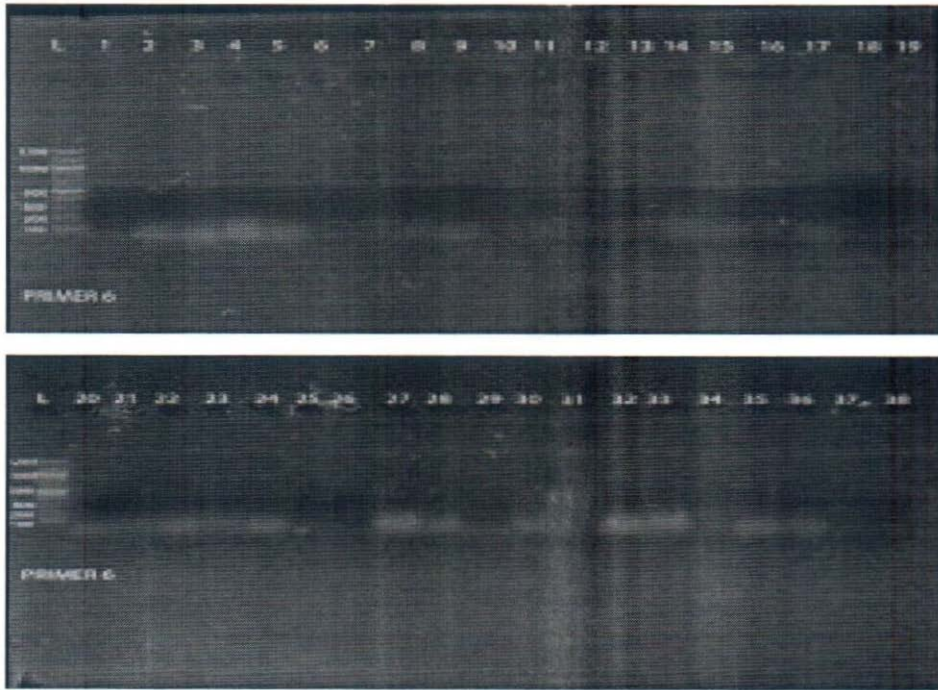


PLATE 5: Band patterns of 38 bambara accessions for primer 7

Note: The name Primer 6 was given here based on serial numbering in Table 2 but in the actual sense, it is primer 7

4.9.2 Principal coordinate analysis (PCoA)

A two dimensional scatter graph (P1 and P2) for the 38 bambara groundnut accessions was generated from seven SSR markers with DARwin 5.0 version. This was done to reveal genetic similarities and dissimilarities among the accessions. Result recorded mixtures of accessions across both axes (P1 and P2) but accessions obtained from IITA dominated the left-hand side of the graph while the locally-sourced ones were more on the right side. The P1-axis contained 20 accessions. Thirteen of these accessions were obtained from IITA and seven from local farmers. Similarly, P2-axis had 17 accessions (IITA=8; local farmers=9). Accession (TVSU 1419) was equally an outlier located on the X-axis. In the first axis (P1), accessions were clearly demarcated, although they associated closely with one another. Most of the accessions were also grouped based on their geographical locations/origin, especially those obtained from IITA (TVSU 401, TVSU 424, TVSU 524, TVSU 534, and TVSU 562 from the Cameroons) (Figure 4). Others include TVSU 305 and TVSU 1202 from Burkina Faso as well as TVSU 689 and TVSU 733 from Zambia.

Also, some accessions collected from IITA which originated from Nigeria had close association with accessions sourced from local farmers (NG/BG/1/1-A2 and TVSU1258). In the second axis (P2), accessions associated more closely and overlapped. Result showed that three (NG/BG/2/1-A3(Jos), NG/BG/2/2-A4(Plateau) and NG/BG/3/1-A5(Bornu) of the best four-yielding accessions obtained in the present study were found on this axis. They overlapped with TVSU 1543(unknown location), TVSU 261(Nigeria) and TVSU 465(Cameroon), respectively. TVSU 238(Ghana) was distinctly apart (Figure 4).

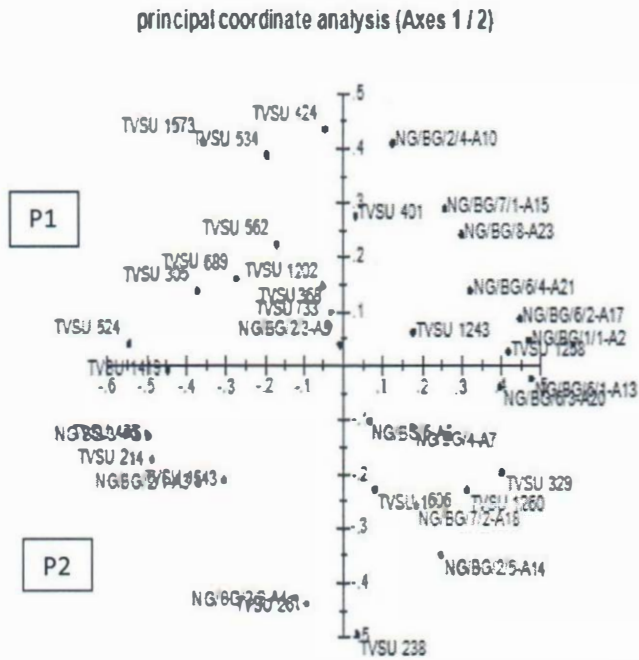


FIG 4: Scatter graph of PCoA of SSR markers for 38 accessions of bambara groundnut

=NG/BG/2/1-A3; 2= NG/BG/2/2-A4; 3= NG/BG/3-A5; 4=NG/BG/4-A7; 5=NG/BG/5-A8; 6=NG/BG/2/3-A9
7= NG/BG/2/4-A10; 8= NG/BG/6/1-A13; 9= NG/BG/2/5-A14; 10 =NG/BG/7/2-A18; 11= NG/BG/6/3-A20
12=NG/BG/6/4-A21; 13 =NG/BG/6/2-A17; 14= NG/BG/8-A23; 15= NG/BG/1/1-A2; 16=NG/BG/7/1-A15
17=TVSU 214; 18=TVSU 238; 19=TVSU 261; 20=TVSU 305; 21=TVSU 329; 22=TVSU 368; 23=TVSU 401
24=TVSU 424; 25=TVSU 465; 26=TVSU 524; 27=TVSU 534; 28=TVSU 562; 29=TVSU 689; 30=TVSU 733
31=TVSU 1202; 32=TVSU 1243; 33=TVSU 1258; 34=TVSU 1260; 35=TVSU 1419; 36=TVSU 1543
37=TVSU 1573; 38=TVSU 1606;

4.10 Discussion

Legumes have a major role to play in the fight against malnutrition and in the contribution to food security (Brink *et al.*, 2006; Aliyu *et al.*, 2016). Bambara groundnut which is a leguminous crop is neglected and underutilized despite its huge potentials. It is not widely known and so is less cultivated. This study focused on the morphological evaluation and genetic diversity studies of 38 bambara groundnut accessions for a possible adaptation to South-South Calabar ecological zone.

The quantitative traits studied showed substantial level of variability. The seedling emergence time of 7-9 days is within the range of 7-15 days given by IPGRI (2002) for this crop. This result is equally in line with the findings of Brink *et al.* (2006) and Toure *et al.* (2012) who reported that seedling emergence could take 5-21 days and 6-15 days after sowing, respectively. However, this is contrary to the report of Karikari (2000) who observed that it took 14-24 days for emergence. These various reports confirm the existence of substantial level of variability in the crop.

In the present study, days to 50% flowering ranged from 33 to 44. This result falls within the range of 30 – 55 days to 50% flowering as reported by Brink *et al.* (2006); Ouedraogo *et al.* (2008); Toure *et al.* (2012) and Shegro *et al.* (2013). Similarly, days to maturity in the present study ranged from 93 to 140 days. Baudoin and Margeai (2001) also reported the growth cycle of bambara groundnut to be between 100 and 180 days. However, records of shorter growth cycles of about 90 days were recorded in Ghana (Berchie *et al.*, 2010). The early flowering accessions particularly NG/BG//7/1-A15 and NG/BG/7/2-A18) also matured early and produced considerable number of pods (20 and 23 per plant), respectively in this study and could be considered in the selection and breeding process even though they were not among the best four-yielding accessions.

In this study, the maximum plant height (48.00 cm) was recorded in accession NG/BG/8-A23. Tall plants may have an advantage when intercropped with other plants, and may compete favourably in a community (Evans, 1995). On the other hand, accession NG/BG/7/1-A15 which had the shortest height (9.00 ± 0.67) in the present study turned out to be one of the early-flowering and early maturing accessions, an indication that no accession should be written off completely, irrespective of their stature. Shegro *et al.* (2013), in their assessment of variability in bambara observed a mean plant height of 37.50 cm, which is within the range observed in this study.

The number of pods is an important yield component and could be used for grain prediction in selecting bambara groundnut landraces (Sobda *et al.*, 2013). In the present study, accession NG/BG/2/1-A3 recorded the highest number of pods per plant (44.66 ± 2.32). Accessions that recorded yields of 20kg and above could be included in the farming system in Calabar area. The very poor yield from accessions TVSU 1419, 368 and 424, which produced one pod per plant, could be attributed to genetic rather than environmental effect since they were all raised in the same environment. Molosiwa (2012) observed less number of pods in lines 95DOD from Tanzania and 113Bots5 from Botswana and attributed their poor performance to the environment.

Seed yield is a quantitative character which is said to be mainly influenced by the environment and has low heritability (Lawrence, 1968; Ene-Obong and Okoye, 1992 and Ofori, 1996). In the present study, the highest number of seeds per plot was observed in accession NG/BG/2/1-A3 (46.00 ± 1.67) while the least number was recorded in accessions TVSU 424, TVSU 1419 and TVSU 368 with a mean value of 1.00 ± 0.01 . Average yield of bambara groundnut is generally low and unstable compared to other cultivated *Vigna* crops. This could be attributable to lack of improved cultivar, poor seed storage and the environment which may be characterized by various

abiotic and biotic stresses (Dimkatso, 2006; Odongo *et al.*, 2015). In this study, the highest yield of 9.38g (0.0938t/ha) was observed in accession NG/BG/1-A3. This is lower than the yield (4t/ha) recorded by Kouassi and Zoro (2009) in a controlled field experiment in Cote d' Ivoire, in the Middle Belt and in Northern Nigeria. Nevertheless, this study has shown that bambara groundnut could also have a good yield in the South-South-Calabar ecological zone if properly managed.

Qualitative characters equally showed substantial amount of variability in this study in terms of pod colour, pod shapes and growth habits. Similar reports were given by Molosiwa (2012) who observed all pod colour classes with the exception of the black ones. Three types of growth habits (bunch, semi-bunch and spreading) were observed in the present study and accessions with semi-bunch growth recorded the maximum number (30). Similar growth habits were recorded by Molosiwa (2012) and Ddamulira *et al.* (2016). Ofori (1996) reported that the bunch morphology type could enhance yield in bambara groundnut. It was observed in the present study that the four best yielding accessions had the bunch type growth habit (Table 8). Accession NG/BG/8-A23 with the spreading growth habit had the highest mean leaf area and also produced vigorous pods. Most of these pods contained double seeds (plate 3f). Similar findings were made by Ofori (1996); Missangu *et al.* (2007) and Onwubiko *et al.* (2011). The spreading morphology type could be useful in mixed cropping while semi-bunch type may be good for monoculture (Molosiwa, 2012). Thus, selection of accessions based on these factors could improve the productivity of bambara groundnut.

Seed coat colour is a major trait that affects consumer acceptability, their preference and use patterns differ from place to place (Tian and Xu, 1993). Results of the present study showed nine seed colours among accessions. The cream-coloured testa had the highest number (16) indicating this as the colour of seed that most farmers

select during the planting season. The result is in agreement with the dominant cream colour observed by Ddamulira *et al.* (2016); but differed from Molosiwa (2012) who recorded majority as red-coloured seeds. The report of two surveys carried out in Swaziland and Botswana showed that farmers plant mixtures of bambara seeds but preferred cream-colour ones (Brink *et al.*, 1996; Sesay *et al.*, 2003; Oyiga *et al.*, 2010). The preference of cream coloured seeds to other colours may be due to the fact that cream coloured seeds are less bitter (less tannin content) and take less time to cook, (Akpalu *et al.*, 2013). The results of the morphological studies are equally in line with findings made by other researchers like Goli (1995), Ntundu *et al.* (2006), Olukolu *et al.* (2012), Aliyu and Massawe (2013) and Molosiwa *et al.* (2015). The documented variations among the characters revealed a good potential for the improvement of the crop (Molosiwa, 2012).

Principal component analysis (PCA) showed that 100 seed weight, number of leaves per plant, terminal leaflet length, terminal leaflet width, plant height, seed yield per plot and pod per plant were the key contributors to the observed variations. Thus, both the vegetative and reproductive attributes jointly contributed most of the variations and these could be used to separate and identify accessions. Aliyu *et al.* (2016) observed similar patterns of loadings in their review of genetic diversity of bambara groundnut, whereby the reproductive components as well as various vegetative indices ranked high in all the three principal components.

Results of correlation studies indicate positive and highly significant associations among several traits such as leaf area and both leaflet length and leaflet width. Ouedraogo (2008) and Shegro *et al.* (2013) observed similar associations and attributed it to a functional relationship between leaflet length and width. The significant associations obtained from both correlation and regression analyses among

several traits imply that improvement in one trait could result in correlated responses in other traits. Consequently and based on the results obtained in this study, number of pods per plant, number of seeds per plant, pod dry weight and pod fresh weight may be regarded as the major yield factors. Thus, selection for these factors could be helpful in the improvement of yield in bambara groundnut. It is known that improvement efficiency for crops is related to the magnitude of heritability and genetic coefficient of variation (GCV) of individual traits (Baye, 2002). Therefore, traits with high values of GCV and heritability such as leaflet width, petiole number, pod fresh weight, pod dry weight, pods/plant, seeds per plant and seed yield/plot as observed in this study could be selected for the enhancement of bambara crops. Similar reports were made by Ene-Obong and Okoye (1992) in *Sphenostylis stenocarpa*; Nwofia (2004) in cowpea; as well as Oyiga and Uguru (2011) and Jonah *et al.* (2013) in bambara groundnut.

The dendrogram grouped the 38 bambara groundnut accessions into three major clusters with several sub-clusters using the morphological data (Figure 2). Furthermore, the best four-yielding accessions grouped on cluster two of the dendrogram suggested that morphological characters can be used to identify important traits such as yield in bambara crops (Makanda *et al.*, 2009).

Molecular analysis: Seven (7) SSR markers were used in the genetic analysis of 38 bambara groundnut accessions. Two distinct features may be used to verify the level of polymorphism in markers. These are polymorphic information content (PIC) and heterozygosity estimates (Shete *et al.*, 2000). Markers with PIC above 0.5 are usually considered as highly informative (Bostein *et al.*, 1980). In this study, the average polymorphic information content found among markers was 0.45. This result is higher than the average PIC value (0.29) given by Odongo *et al.* (2015) when they assessed 105 bambara groundnut accessions with 12 SSR markers. Molosiwa *et al.* (2015)

reported an average PIC value of 0.42 ranging from 0.08 to 0.89 using 68 SSR markers for 24 bambara crops. The expected heterozygosity (He) estimated in this study stands at an average of 0.53. This was also different from the mean value (0.35) given by Odongo *et al.* (2015) but slightly above that of Molosiwa *et al.* (2015) at 0.50. On the contrary, Mohammed (2014) reported a higher average of 0.78 having evaluated 50 bambara groundnut accessions with five SSR markers. The differences observed in these values could be as a result of the type of markers and number of accessions employed. The principal coordinate analysis (PCoA) revealed that accessions were spread on the P-1 and P-2 axes. Most of the accessions had close association with one another indicating similar traits among them. The overlapped accessions demonstrated a close genetic relationship, suggesting they could have the same origin. This is an indication that accessions could easily be tracked for identification and selection for breeding programmes. Amadou *et al.* (2001) and Massawe *et al.* (2003) recorded similar trend of associations and proposed that such close associations between bambara groundnut accessions could mean that they were related or they were the same genotypes. They attributed it to indiscriminate transfer and unorganized collection of seeds from one neighbouring country to another and among farmers within the same country. This would result in a single accession bearing several different names and identities, but possessing the same genetic information. The result of the present study confirmed that accessions which overlapped with the best-yielding ones (Figure 4) can perform well in terms of yield in Calabar agro-ecological zone. Accessions that were distinct show a distant relationship from the others and could be used by breeders in the improvement of bambara crops.

In this study, result of the genetic analysis showed a moderate level of polymorphism within the accessions. The analysis also demonstrated the ability of the

selected SSR markers to distinguish among accessions (Aliyu and Massawe, 2013; Mohammed, 2014). The moderate level of genetic diversity recorded (mean of 0.53) may be as a result of the varied sources of planting material which were collected locally and from some African countries (Molosiwa, 2012). The present study also revealed that SSR markers exhibited a similar clustering pattern with the morphological data in the accessions. This was shown by the grouping together of the highest yielding accessions (NG/BG/2/1-A3 with 9.38g, NG/BG/1-A2 (8.16g); NG/BG/2/2-A4 (8.13g) and NG/BG/4-A5 (7.76g) on the P2-axis of the PCoA for SSR markers (Figure 3) and cluster two of the dendrogram generated from morphological data (Figure 2). Similarly, the PCoA grouped accessions mainly based on their origin and source of collection. Considering the low cost, simplicity and agricultural relevance of morpho-agronomic characters, it is still a veritable tool in germplasm variation studies (Molosiwa, 2012). A study of the two methods used in the present work showed that both methods are important in diversity studies and therefore could be employed to complement each other. The results of the evaluation of the morphological and genetic diversity of bambara groundnut using SSR markers as revealed in this study could help in the identification and selection of appropriate bambara crops for breeding purposes.

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1 Summary

In the present study, variability of 38 accessions of bambara groundnut were investigated using morphological and molecular markers. Findings revealed that there was an early emergence of seedlings (7-9 days); early flowering (from 33-44 days) and early maturity (93-140 days). These are good agronomic attributes of crops that could find importance in disease escape as well as in some adverse environmental conditions and should be considered in the selection process.

Attributes such as plant height, leaflet number, leaf area, seed weight, seed yield per plot, pod dry weight, pod fresh weight, terminal leaflet width and length, petiole and internode lengths, eye colour, growth habit, terminal leaflet colour, seed shape, eye pattern, pod shape, testa colour, testa pattern, pod texture and leaf shape were revealed as contributing most significantly to the variations observed in this study using the principal component analysis (PCA). Accession NG/BG/2/1-A3 sourced from local farmers in Plateau State Nigeria was the highest yielding accession (9.38g). This was followed by accessions NG/BG/2/2-A2 (8.16g); NG/BG/2/1-A4 (8.13g) and NG/BG/4-A5 (7.76g). These accessions could be included in the farming system in Calabar area. Although yields of bambara groundnut in the Middle Belt and Northern Nigeria as well some African countries were higher than what was obtained in this study; results of the present work showed that bambara nut could also have a good yield and be adapted to Calabar ecological zone, if well managed. Result also revealed that locally-sourced accessions performed better in yield than the improved varieties from IITA. This was confirmed in the grouping pattern of PCoA and cluster analysis where the highest yielding accessions were clustered.

It suggested that accessions could also be grouped based on morphological and agronomical attributes, for example seed yield. This would help breeders to select appropriate planting materials for future breeding purposes. The present study also confirmed the use of SSR markers as tools that could be used to group and differentiate between bambara groundnut accessions mainly based on their areas of geographical location/origin . Furthermore, the sub-clustering pattern generated by the dendrogram revealed some level of intra-landrace polymorphism. This suggested that accessions existed in various forms which could be harnessed for the improvement of bambara crops. This study revealed that morphological evaluation and the use of molecular markers could both be employed to assess the diversity of bambara groundnut and information obtained would assist in selection for crop improvement and germplasm collection storage.

5.2 Recommendation

More research, using morphological and more molecular tools be carried out on the accessions evaluated in this study over a number of years and location in order to ascertain their stability.

That a larger number of SSR markers be screened in addition to the number employed in the present study in order to obtain more information in the crop.

5.3 Contributions to knowledge

- i. The present study has established some accessions that could be exploited by breeders in the improvement of bambara crops. These include: NG/BG/2/1-A3 with a yield of 9.38g; NG/BG/1-A2 (8.16g); NG/BG/2/2-A4 (8.13g) and NG/BG/4-A5 (7.74g). They could be included in the farming system in the South-South Calabar, ecological zone.

- ii. The number of pods per plant, pod fresh weight, pod dry weight and number of seeds per plant had positive and significant relationship with yield from regression and correlation analyses; therefore selection based on these traits would help in the improvement of yield in bambara groundnut.
- iii. The study has upgraded available molecular information for this crop and established the level of genetic diversity present as moderate (5.3)
- iv. The study has identified traits with high heritability and genetic coefficient of variation (GCV) which could be exploited in the breeding of this crop,
- v. This study is a detailed research undertaken to introduce bambara groundnut into Calabar agro-ecology and so could be a source of information for those intending to carry out any research on this field of study.

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APPENDIX

Appendix 1: Preparation of standard solutions

A CTAB buffer (Cetyl Trimethyl Ammonium bromide)

Compositions: 100ml of 1M Tris, pH 8.0

280ml 5M NaCl

40ml 0.5M EDTA

20g CTAB

Final volume is made up to 1 litre with water

B TAE buffer for electrophoresis

50x TAE buffer

Dissolve 242g Tris base in water

Add 57.1 ml glacial acetic acid

Add 100ml of 0.5M EDTA, pH 8.0

Final volume is brought to 1 litre

C 1x TAE buffer

20ml of 50x TAE buffer

Make up to 1 litre with water

D TE buffer for DNA preservation

10mM Tris base dissolved in 1.0M HCl until pH 8.0

1mM EDTA

APPENDIX 2

Jarwin 5.0

PRIMER
SCORES

38

17

unit	primer 1	primer 1	primer 1	primer 3	primer 3	primer 3	primer 4	primer 4	primer 6	primer 6	primer 6	primer 6	primer 9	primer 9	primer 10	primer 10	primer 8	primer 8
NG/BG/2/1-A3	1	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	0	0
NG/BG/2/2-A4	0	0	1	0	1	1	0	0	0	0	0	0	1	0	1	0	0	1
NG/BG/3/1-A5	1	0	0	0	1	1	0	1	0	0	1	0	1	0	0	0	0	1
NG/BG/4-A7	0	0	1	0	1	1	1	0	1	0	0	1	1	0	0	1	1	0
NG/BG/5-A8	0	1	0	0	1	1	1	0	0	1	0	0	1	0	0	1	0	1
NG/BG/2/3-A9	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
NG/BG/2/4-A10	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
NG/BG/6/1-A13	0	1	0	1	0	0	1	0	0	1	0	1	0	1	0	1	0	0
NG/BG/2/5-A14	0	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0
NG/BG/7/2-A18	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	0	1	0
NG/BG/6/3-A20	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
NG/BG/6/4-A21	1	0	0	1	0	0	1	0	0	1	0	1	0	1	0	1	0	0
NG/BG/6/2-A17	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	0
NG/BG/8-A23	0	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	1	0
NG/BG/1/1-A2	0	1	0	1	0	0	1	0	1	0	1	0	1	0	0	1	1	0
NG/BG/7/1-A15	0	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	1	0
TVSU 214	0	0	1	0	1	0	0	1	0	0	1	0	1	0	1	0	0	1
TVSU 238	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0
TVSU 261	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
TVSU 305	0	0	1	1	0	0	0	1	0	0	1	0	0	1	0	1	0	1
TVSU 329	0	1	0	0	0	1	1	0	0	1	0	1	0	0	1	0	1	0
TVSU 368	0	1	0	0	1	0	1	0	0	1	0	0	0	1	0	1	0	1
TVSU 401	0	1	0	1	0	0	1	0	1	0	0	0	0	1	0	1	0	1
TVSU 424				1	0	0	1	0	1	0	0	0	0	1	0	1	0	1
TVSU 465	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1
TVSU 524	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
TVSU 534	1	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	1
TVSU 562				0	1	0	1	0	0	1	0	0	0	1	0	1	0	1
TVSU 689	1	0	0	0	1	0	1	0	0	0	1	0	1	0	1	0	1	1
TVSU 733	1	0	0	0	1	0	1	0	0	1	0	0	1	0	0	1	0	1
TVSU 1202				0	1	0	1	0	0	0	0	0	0	0	0	1	1	0
TVSU 1243	1	0	0	0	1	0	1	0	1	0	1	0	1	0	0	1	1	0
TVSU 1258	0	1	0	0	0	1	1	0	1	0	0	0	1	0	0	1	1	0
TVSU 1260	0	1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0
TVSU 1419	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1
TVSU 1543	0	1	0	0	0	1	0	1	0	0	1	0	0	0	0	1	0	1
TVSU 1573	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1
TVSU 1606	0	1	0	0	0	1	1	0	0	0	0	1	1	0	1	0	0	1

**MANAGEMENT OF PERSONNEL SERVICES AND
UNIVERSITY GOALS ATTAINMENT IN
CROSS RIVER STATE, NIGERIA.**

BY

**WONAH, FIDELIS ADUMA
REG NO: EDM/Ph.D/17/014**

**A DOCTORATE DEGREE DISSERTATION CARRIED OUT IN
THE DEPARTMENT OF EDUCATIONAL MANAGEMENT
FACULTY OF EDUCATION
UNIVERSITY OF CALABAR
CALABAR-NIGERIA**

SUBMITTED TO

**POST GRADUATE SCHOOL
UNIVERSITY OF CALABAR
CALABAR, NIGERIA**

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) DEGREE
IN ADMINISTRATION OF HIGHER EDUCATION**

AUGUST, 2021

DECLARATION

I WONAH, FIDELIS ADUMA with Registration Number: EDM/Ph.D/17/014, hereby declare that this study titled: Management of personnel services and University *goals attainment in Cross River State, Nigeria is original and has been written by me. It*

is a record of the researcher work and has not been presented before in any previous publication.

Wonah, Fidelis Aduma

Signature: .....
(Candidate)

Date: 08/02/2022.....

CERTIFICATION

We certify that this dissertation entitled "Management of personnel Services and University Goals attainment in Cross river State, Nigeria" by **WONAH, FIDELIS ADUMA** (Reg. No. **EDM/Ph.D/17/014**) is an original work carried out under our supervision and has been found to have met the regulations of the University of Calabar. We therefore certify the work for the award of the degree of Doctor of Philosophy (Ph.D) in Educational Management (Administration in Higher Education).

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ABSTRACT

This study examined Management of personnel services and University goals attainment in Cross River State, Nigeria. To achieve the purpose of the study, eight research questions were raised and eight hypotheses were formulated. Related literature was reviewed according to the sub variables. Correlational research design was adopted for the study. A total sample of one hundred and forty one (141) heads of Department from the two public Universities in cross river state were selected for the study. The selection was done through census sampling technique. The instrument used for the data collection was questionnaire titled: Management of Personnel Services and University Goals Attainment Questionnaire (MPSUGAQ).The research instrument was validated based on content and face validity by three experts in administration of higher education, Department of Educational management and measurements and evaluation, department of educational foundation, University of Calabar. Cronbach reliability analysis was used and the result is ranged from 0.72 to 0.91. Data collected were subjected to statistical analysis using Pearson's Product Moment Correlation analysis (r) and multiple regression statistics analysis at.05 level of significance. The results of the analysis revealed that management of staff recruitment service, staff training and development service, staff wages and salary administration, staff orientation service, staff health service, staff motivation/welfare service and staff retirement/pension service significantly relate with universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities Cross River State, Nigeria. It was recommended among others that the university management should give staff training and development opportunities to develop their career as well as make adequate provision for staff motivation and welfare services.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Human beings are considered more significant in any organization in the world because of their value and contribution towards the achievement of organizational goals. No organization can function effectively without human being that do the job and that is why they are regarded as the most tangible assets in any organization. The management of staff personnel services in any organization is therefore very important because the attainment of set goals of any organization depend largely on staff personnel, while the efficiency of any organization be its educational, social, religious, public or private is dependent on organizational management of personnel.

Goals attainment is the ways by which mobilization of resources both human and materials are being pursues collective toward a specific purpose or goals achievement. Also, goal is a future idea or people plan, envisions toward achieving a desired result. University education is defines according to the Federal Government of Nigerian (FGN, 2014) as the training received after secondary level of education. As content in the national policy on education, The Federal Republic of Nigeria (FRN,2014) Spelt out the educational goals of the university as: inculcate and develop proper values for individual survival in the society; national promotion, interaction and understanding internationally; manpower training toward national development; individuals capability intellectual development toward understanding and external and local environments appreciation; forge and cement national unity; community service and scholarship promotion and encouragement; and intellectual skills and physical skills acquisition to enable useful members of the society and self-reliant of the individuals. Thus, these

university goals can be attained if the university management ensures proper management of staff personnel services as well as making provision for high level training of the students.

Unfortunately, researcher's observation and experience have shown that university goals seem not to have been properly attained. Evidences have shown that some of the graduates are unemployable, some find it difficult to be self-employed; some who are working find it difficult to account for the worthwhile knowledge acquired from the university, while some of the graduates are roaming on the street and thereby engaging in some sort of social vices like robbery, kidnapping, cultism and prostitution. This is evident in the fact that the contribution of the graduates toward inculcation of proper values for the survival of the individual, manpower training toward national development of the society as well as lacking the intellectual skills and poor academic training which may result to their being described as half baked graduates in the society.

The researcher is of the opinion that could it be that poor management of staff personnel services such as staff recruitment, staff training and development, staff wages and salaries, staff orientation, staff health services, staff motivation and welfare and staff retirement and pension can contribute to university goals not been properly attained? Also, could it be as a result of some the universities seems to recruiting staff without following due process? For instance, some of the recruited staff lack training and development opportunities, Some work without being paid salary for about a year, No good medical facilities for staff, allowance was denied until strike strategy was being enforced, some of the staff find it difficult to access their retirement benefit after contributing their services to the development and growth of the university. This seems to the manifestation of untimely death in service and production of half baked graduate.

Agboola and Akporehe (2016) viewed staff personnel management as the process of maintaining and sustaining the work force in higher educational system for the purpose of contributing to the attainment of higher educational goals. The personnel and workforce in higher institutions comprises academic or teaching staff whose functions include teaching, research and community service, and non-academic or administrative staff that perform administrative tasks. Thus, no higher institution can function effectively without the collaborative work and use of both teaching and non-teaching personnel in various categories.

Obi (2013), opined that personnel management can be viewed from different perspectives. Personnel management has been viewed as a process whereby every supervisor or managers are committed with the responsibility or function of managing people whom are working under in an organization in order to achieve desired goals. In addition, it has been seen as a function that is performed by personnel department in an establishment. Flippo (2009) who elaborately and comprehensive defined personnel management as the process by which human resources are plan, controlling, organising as well as directing the procurement, development, integration, compensation of resources toward accomplishment of that individual, societal and organisational objectives.

Ogunsaju (2016) viewed staff personnel services as the effective human resources management and mobilisation that is required proper staff selection, recruitment, training and placement as well as outline goals and objectives toward organizational achievement. The researcher also opined that successful attainment of organizational goals can be attributed to adequate management of human resources and related activities in an organization. From the above, management of personnel services is observed as non-discriminatory, affirmative management of

human resources in effective way that the individual, the society and organisation will benefit.

Nnachukwu and Okorji (2014) state the variables of staff personnel management to include: Training and development, manpower planning, staff recruitment, motivation and welfare, salary and wages administration, Industrial relation, orientation, appraisal performance, employee retirement, discipline, personnel audit, job analysis, employee communication, and collective bargaining. The management of these variables are considered paramount and may likely contribute to the universities goals attainment in the State. For the study purpose, the following management of staff personnel services which include: staff recruitment services, training and development, wages and salary administration, staff orientation services, staff health service, staff motivation and welfare, and staff retirement and pension services were used to form the core of the analysis.

However, proper management of staff personnel services may produce efficient and effective work force among staff for achievement of university goals. It was on the consideration of these facts that the researcher sought to examine the relationship between management of staff personnel services and universities goals attainment in Cross River State, Nigeria.

1.2 Theoretical framework

The study was guided with the following theories.

- 1.2.1 Human relation theory by Elton Mayo (1932)
- 1.2.2 Administrative management theory by Henri Fayol (1916).
- 1.2.3 Path-goal theory by Evans (1970) and House (1971).
- 1.2.1 Human relation theory of Elton Mayo (1932)

Human relations management theory was developed based on the Hawthorne studies conducted by Elton Mayo (1932) in USA; and other leading advocates. The people desire and belief that to be part of a supportive team that will assist in the growth and development of an organization was the theory focus. Thus, if special attention is been received by employees and full participation is encourage, they work is perceive as significant to them, this will resulting in more productivity in an organization.

The following were the underlying assumptions of the human relations management theory:

Man requires fulfilling his capacity to develop skills in a productive and mature way. Man want social needs, self-controlled and self-motivated to be able to work well; Man is pressured and threatened by externally imposed incentives; sense of belonging and recognition are very important need to man ; The influence from the peer group pressure has more impacts than controls from the management. Man prefers personal satisfaction of needs than achieving organizational objectives.

The theory projected the implementation approaches on how workers as socio-psychological beings can be handling, as well as the new ways labour productivity can be increase. The theory proposed that in any organization the values, motivation, moral qualities as part of psychological needs of human being should be considered. The theory affirmed that employee goal setting, personal growth and development are essential to effective achievement of organization goals.

Workers who do the work should be considered relevant in an organization and there is need for them to be motivated and recognized as an integral part for the good of the organization which make the theory become important to the study.. It is therefore, the duty of the universities management to ensure that a good network is established between the management and the staff that will allow for the maximum contribution of the University for the Attainment of the set university goals.

The theory is related with the independent variables of the study (management of staff personnel services).

1.2.2 Administrative management theory by Henri Fayol (1916)

In (1916), Henri Fayol propounded administrative management theory. The theory center on managers can function in an organization through; planning, organizing, controlling and coordinating the activities of the organization in order to achieve its stated goals.

The assumption of the theory was that; organizational goals can be achieve through only structures performance. Workers and employees in an organization are assign tasks through structures. Structures lead to supervision which brings about organizational goals achievement and good communication within the structures brings organizational effectiveness.

According to Fayol (1916),The administrator who wish to success in achievement of organizational goal can applied the fourteen principles, for instance breaking down of task among individual workers.It is important to have good communication and relationship between management and employees of an organisation.

Fayol's principles are applied universally for achieving better efficiency in organisations.

The relevance of this theory to the study of management of staff personnel services and university goals attainment is that if the university management can apply the fourteen principles highlighted in the study mostly, (division of work, discipline, equity and Subordination of individual interests to the general interest), management of staff personnel services and universities goals attainment will be achieved successfully.

1.2.3 Evans (1970) and House (1971) theory of Path-goal .

Evans (1970) and House (1971) developed Path-goal theory. The theory is based on how the university manager can effectively set objectives or goals and achieve results. This theory points out that the main function of a leader in any organisation is to clarify and set objectives or goals and remove all obstacles from the path.

The assumption of this theory is that a leader is effective to the extent that he is able to influence and clarify effort, performance, reward paths and help his staff to move along this path by providing necessary guidance support or coaching and removing all barriers along the path, make satisfaction of subordinate needs contingent upon the performance level desired by the organisation.

This theory however recognizes some situational factors that can moderate the leader's effectiveness. These are the characteristic of the subordinate and their personalities, attitudes, abilities etc and environmental factors like position, power and job characteristics. Thus, the theory is made up of four types of leadership behaviour.

Effective leaderships thus depend on the characteristic of the followers because of their expectations, needs, abilities and work environment in the forms of jobs. The leader constitutes the source of satisfying followers' needs. He influences the path between goals and behaviour. The path is smoothen, the performance and goals become attainable queasily if group members calculate in goals-setting and decision-making. Sherkelar (2001) noted that an effective leader has to design in system of people management in the knowledge economy such that, it take into account the aspiration and expectation of the knowledge employees, changing motives of employers demand of the situation, the need to clarify roles, interpersonal relations and the rewards acceptable to knowledge workers.

The theory become importance to the study if the university management can apply wisely these dimensions of leadership practices, and job performance practice such as: to clarify and set objectives or goals and remove all obstacles from the path, satisfying staff needs, expectations, abilities and providing them with good working environment, it will enhance the achievement of goals and objective in the university and making the university students useful to themselves and the society at large.

1.3 Statement of the problem

Management of personnel services in the university has been considered significant because the realization of organisational goal is purely dependent on employee being recruited. Regrettably, from the researcher's experience and observation, it has shown that some of goals of the university such as proper inculcation of values for individual survival, manpower training toward national development of the society as well as lacking the intellectual skills and physical skills which will make them to be self-reliant and important members of the world have not been properly attained. This may likely be as a result of the university management not making adequate provision for high level training for their staff, or poor management of their staff services. For instance, some of the graduates that are supposed to contribute to development of the nation through intellectual skills acquired; inculcate proper values for the survival of the individual and society as a result of high level relevant manpower training received, seem to lack the intellectual skills and poor academic training.

This have manifested in some of the graduates found roaming the street and sometimes engaging in some sort of social vices like robbery, kidnapping, cultism and prostitution. Some find it difficult to be self-employed; some who are

working find it difficult to account for the worthwhile knowledge acquired from the university, while some of the graduates are being described as half baked and unemployable in the society. Also, the researcher is of the view that these problems may be attributed to poor management of staff recruitment, poor staff healthcare services, lack of staff motivation and welfare, poor staff empowerment, poor staff remuneration, Lack of staff orientation services, and poor staff retirement and pension services.

However, several attempts such as establishment of staff development unit, pension unit, academic planning division and medical center have been made by the university management to solve the problem of poor management of staff personnel services to enhance university goals attainment. Despite all these efforts made by the university management to enhance university goals attainment, the problems still persist. It is on this premise that the scholar intends to provide answer to the question, in what way does management of personnel services relate with universities goals attainment?

1.4 Purpose of the study

Management of personnel services and university goals attainment in study area was the researcher purpose of investigation. Specifically, the study investigates whether:

1. Management of staff recruitment service relate with university goals attainment (in terms of: (a) knowledge acquisition, (b) curriculum content (c) social development.
2. Management of staff training and development service relate with university goals attainment.

3. Management of staff wages and salary administration relate with university goals attainment.
4. Management of staff orientation services relate with university goals attainment.
5. Management of staff health services relate with university goals attainment.
6. Management of staff motivation and welfare services relate with university goals attainment.
7. Management of staff retirement and pension service relate with university goals attainment.
8. Joint cumulative effect of management of staff personnel services such as staff recruitment services, staff training and development service, staff wages and salary administration, staff orientation service, staff health service, staff motivation and welfare and staff retirement and pension service relate with universities goals attainment.

1.5 **Research questions**

To guide this study, the following research questions were raised:

1. In what ways do management recruitment service relate with university goals attainment in terms of: (a) knowledge acquisition, (b) curriculum content
(c) Social development?
2. In what ways do management of staff training and development service relate with university goals attainment?
3. In what ways do management of staff wages and salary administration relate with university goals attainment?
4. How does management of staff orientation services relate with university goals attainment?

5. In what ways do management of staff health services relate with university goals attainment?
6. In what ways do management of staff motivation and welfare services relate with university goals attainment?
7. In what ways do management of staff retirement and pension service relate with university goals attainment?
8. In what ways do joint and relative effect of management of staff personnel services such as staff recruitment services, staff training and development service, staff wages and salary administration, staff orientation service, staff health service, staff motivation and welfare and staff retirement and pension service relate with universities goals attainment?

1.6 **Statement of hypotheses**

The following hypotheses were formulated and tested.

1. Management of staff recruitment service does not significantly relate with university goals attainment in terms of :(a) knowledge acquisition, (b) curriculum content (c) social development.
2. Management of staff training and development service does not significantly relate with university goals attainment.
3. Management of staff wages and salary administration does not significantly relate with university goals attainment.
4. Management of staff orientation services does not significantly relate with university goals attainment.
5. Management of staff health services does not significantly relate with university goals attainment.
6. Management of staff motivation and welfare services does not significantly relate with university goals attainment.

7. Management of staff retirement and pension service does not significantly relate with university goals attainment.
8. The joint and relative effect of management of staff personnel services such as staff recruitment services, staff training and development service, staff wages and salary administration, staff orientation service, staff health service, staff motivation and welfare and staff retirement and pension service does not significantly relate with university goals attainment.

1.7. Significance of the study

The following groups and individuals may be benefiting from the study: university administrators, Staff, students as well as the general public.

The university administrators may benefit from this study when they learn from the results of the study and the recommendations which may be implemented to improve quality of graduates produced as well as maintaining of standard in the university.

To the university staff, the study may benefit them if all the recommendations are executed; it may improve the better condition of service in the university. Also, Lecturers have been the focus of the educational planner (curriculum planner) in recent years. The lecturers may benefit a lot from this study because it may expose the significance of management of staff personnel services to them.

Students may benefit from this study because it may improve the standard of the university which will help them to study and graduate with good grade that may help them to contribute to national development.

To the general public, when the above mentioned are benefiting from the study, definitely, it may affect the general public because whatever that is being

learnt in the school environment is for society consumption. Also, the study may contribute to the body of knowledge.

1.8 Assumptions of the study

The assumptions of the study are as follows:

1. Management of staff personnel services can be identified and measured.
2. The instrument of the study can assume honest response.

1.9 Scope of the study

Management of staff personnel services and university goals attainment in Cross River State, Nigeria was the study focused. The study was also restricted to the following sub-variables: management of staff recruitment services, staff training and development service, staff wages and salary administration, staff orientation service, staff health service, staff motivation and welfare and staff retirement and pension service which was measured alongside with the dependent variable, university goals attainment (in terms of:(a) knowledge acquisition,(b) curriculum content (c) social development).

1.10 Definition of terms

Management of staff recruitment service: This can be defined as a process of managing various activities that involve in the selection of staff in order to enhance the effectiveness of an organisation workforce.

Management of staff training and development: This can be defined as the process of managing the engaged workers in a training that will contribute to the development of an organization.

Management of staff wages and salary administration: This refers to as the process of effective management of workers' salaries.

Management of staff orientation service: This is seen as process whereby staff, personnel, co-workers are introduced to all the facilities in an organisation to function effectively.

Management of staff health service: This refers to a coordinated and comprehensive set of health promotion strategies implemented in an organisation to assist staff combat their health challenges.

Management of staff motivation and welfare service: This can be defined as a process whereby workers are provided with the entire necessary requirement that enable them function effectively.

Management of staff retirement and pension service: This refers to as effective management of workers retirement benefit in an organization.

University goals attainment: This can be defined as the process whereby the plan of education given after secondary education is expected to bring result at end of the programme.

CHAPTER TWO

LITERATURE REVIEW

This chapter deals with the review of related literature. The review focus on the following sub-headings:

- 2.1 Management of staff recruitment service and university goals attainment
- 2.2 Management of staff training/development and university goals attainment
- 2.3 Management of staff wages/salaries and university goals attainment
- 2.4 Management of staff orientation services and university goals attainment
- 2.5 Management of staff health services and university goals attainment
- 2.6 Management of staff motivation/welfare and university goals attainment
- 2.7 Management of staff retirement/ pension and university goals attainment
- 2.8 Summary of literature review

2.1 Management of staff recruitment service and university goals attainment

Adu-Darko (2014) carried out a study on employee recruitment and a selection practice in the construction industry in Ashanti region of Ghana. Selection practices and recruitment of staff in the Ashanti region was the study purpose. Construction companies' adoption method of staff selection and recruitment was the major study focused. The study employed survey design. The research population was sixty-two (62) workers. Instrument for data collection was the multi-choice of open and closed ended type of questionnaires which were used to gather information from the respondents' on employee recruitment and selection practices. SPSS was used analyses. The result of the analyse shown that methods of job selection was through labour office and newspaper advert. This implied that recruitment and selection methods have significant influence on construction

workers' performance. Among the recommendation was that all job profiles should reflect the based requirements for job recruitment and selection.

Michalis and Dimitros (2015) examined the impact process and methods of staff recruitment in mobile telephony Industry in Greece. Mobile telephony firms in Greece method of staff selection and attraction was the major purpose of the study. Questionnaire was used to collect information from 421 staff working in the three major mobile telephony firms in Greece. The collected data was statistically analysed. The result showed recruiting workers through social media and newspapers was the most widely way used in worker recruitment. Also interview was the most appropriate selection method consider by workers. The firms' use of attraction and selection methods was accepted by workers. Meeting up with worker expectations was considered important, while the prestige of the position was least important. Continue use of interviews as the major staff selection method by operating firm of mobile telephony was the study finding.

In (2014), Bernard and Okofu conducted a study to explored selection and recruitment process of staff among a civil work in Nigerian: The study attempts to examining the process of staff selection and recruitment in the public service of Nigeria. To address the issues the researchers used five research questions. Descriptive statistics was used for analyse. The results analyses revealed that employment of staff in Nigeria civil service was based on religion and altar of ethnicity. The result also showed often sidelined on employment of worker into the civil service.

Bagatova (2017) who study investigated selection, recruitment and retention of employees' improvement in the Dpointgroup Ltd. Evaluation the current Human Resource Management processes Dpoingroup in the company was the purpose of the study. Proper methods of employing staff and strategies of personnel retention

in different firms was the main research problem. Company recent situation analyses from point of human relation of view; the way of staff retention; and improvement of human resource management were the aims of the study. Quantitative and qualitative research methods was used to gather information on the topics through various paper and internet based sources. A qualitative method was used. The result of the finding discovered appropriate methods staff selection and personnel retention.

Ekwoaba, Ikeije and Ufoma (2015) worked on the criteria selection and recruitment impact in organizational performance of the staff. The focal point of the study was to investigate the criteria for selection and recruitment impact on workers performance of Fidelity Bank Plc, Lagos Nigeria. The study population consist of 130 workers. Questionnaire was the main instrument used for data collection. Randomly sampling technique was used to select respondents. The result obtained revealed that the criteria for job selection and recruitment have impact on worker productivity in an organization's significantly with ($X^2 = 53.237$; $df = 4$; $p < 0.05$) and ($chi\text{-square} = 32.108$; $df = 3$; $p < 0.05$).

Ibrahim (2014) sought to examine selection exercise and recruitment irregularities in the Nigerian Public Service .The aims of the study is to increases the workforce and filling in the vacant positions in the civil service. Qualitative research strategy using comprehensive document review was adopted for the study. Employment prehistoric issues such as sentiment, nepotism, favouritism and ethnicity were identified as a major hindrance to opportunity of gaining employment. Stable political intervention by the politicians desire to get their relatives employ in the civil service not considering the Federal character principle of recruitment further compounded the problem in the form of ethnic balancing were the main obstacle identified in the study. This adversely led to labour turnover

and increased costs of governance. To restore good sense in the recruitment activities, the country civil Service should lay more emphasis on meritocracy irrespective of applicant's background and/or affiliation and the issue of political obstruction should be brought to a halt. Candidates to be considered for recruitment should have good and moral attitude in addition to skills and recruiters be accorded the desired independence and freedom as this will enable them to use appropriate methods of conducting the exercise in order to get it right.

In (2010) Ikvesi conducted a research on selection procedures and recruitment on the efficiency of the public service in Oshimili south local government of Delta state Nigeria. Both primary and secondary sources of data was used. The study population consist of twenty five (25) workers. The information was gathering through constructed questionnaire in both open and close ended pattern. Content approach for data analysis was adopted for the study through simple percentage, and descriptive tables. The result showed that the selection and recruitment procedures in public service in Nigeria are highly politicized, qualification standard in gaining employment in civil service and the use of federal principle character, indigeneship, quota system, son of soil syndrome, etc. are mostly accepted; weak recruitment and selection processes has a significant relationship between Nigerian public service inefficiency. To ensure meritocracy in staff recruitment and selection in the public service in Nigeria the study recommended introduction of more strict measures in staff recruitment based on the above findings.

Onwe, Nwaba and Nwoku (2013) carried out a study on selection and recruitment politics in the Nigerian Civil Service in Ebonyi State. The political effect on recruitment and selection exercise process in the Nigerian public service, especially in Ebonyi State civil service. The study showed that there is a regular

feature in the politics in civil service recruitment exercise in Nigeria. The recruitment exercise have been identified with following effects: low productivity, corruption, indiscipline, inefficiency, etc. Also, the study opined that selection and recruitment activities exercise should be done by experts in human resource management. Also, the autonomy of the civil service commission should not only be .in principle but in practice. The implication of the above is that lack of interference in the operations of the commission will enable it objectively and efficiently discharge its responsibilities without fear and favour to ensure efficient public service delivery.

Briggs (2017) conducted a study to investigate recruitment problems in Nigeria civil service. The study aims at determine the ways in which job specification and job description in the process of recruitment can be utilize. The study size consists of 190 civil servants working in the five federal ministries grouped. Sampling method used was stratified random sample. Design used was descriptive survey design and the analysis used was descriptive statistics. The study revealed that there is a problem of standard personnel requirements and job description didn't effectively use in the process of recruitment mostly at the lowest levels grade category. It was recommended based on the findings that informal individual source of job selection should be de-emphasized, and rather encourage sources from school system and professional body and employees rule and regulation that will protect them in the private sector should be promulgate by the federal government in order to reduce consistent pressures for employment in the public sector. Lastly, the number of federal civil service commissioners should be increased with the establishment of zone and state offices.

2.2 Management of staff training/development and university goals attainment

Mohd, Jamil, Azhn, Rahayu, Kamisah and Norlizah (2016) evaluated the impact of school-based assessment on teachers training programme in Malaysia. Examine teacher in-service reaction to the programmes training and teacher contribution towards learning in terms of the acquisition of knowledge, skill and positive attitude was the study purpose. The study adopted quantitative survey design in which 200 teachers from primary school who are on training programme were selected through randomly sampled technique. A self-developed questionnaire was administered and the data was analyzed using Kirkpatrick Evaluation Model and regression analysis. Findings revealed that the variables of the independent showed 21.7 percent to the variance of the knowledge variable of dependent with 17.20 percent to the variance of the skills dependent variable with 19.4 percent to the variance of the attitudes dependent variable. From result was suggested that the School-Based Assessment (SBA) training programme teacher for should be continued with strategic planning to enable teachers meet up with their professional challenges in the school.

Udida, Okpa and Wonah (2015) conducted a study on employee opportunities development and teachers' in nursery schools effectiveness in Cross River State, Nigeria. A survey design was adopted for the study. A sample of 200 teachers was sampled from a population of 1,258 primary schools in the study area. Questions used were three and research hypotheses used were for the study with 20 items constructed questionnaires in a likert scale 4-point of was used to eliciting information from the respondents. P.P.M.C Statistics and mean and standard deviation were used for data analysis. The analysis finding showed a positive with workshop attendance and teachers' effectiveness. It was generally concluded that

workshop participation enhances teachers' effectiveness. It was recommended among others that the government as well as state education board should organized regular workshop/seminar for teachers to improve their performance.

Eze (2016) explored training and retraining on teachers' impact and teachers' perception of productivity in Enugu State, Nigeria. The purpose of the study was to find out how teachers' training and retraining and their productivity impact in Enugu State. Research design used was survey. The population of the study was 256 teachers in secondary schools. Researcher used 20-item questionnaire to collect data from the study area. The analysis revealed that teachers' training and retraining significantly relate with their productivity. The result also showed (3.30) male and female (2.94) perception of differed teachers' development opportunities impacted on their performance. In conclusion, trained and retrained teachers regularly increase their job productivity.

Uysal (2012) evaluated the nature of in-service training programme for primary school language teachers in Turkey. The quantitative study utilized a survey method for eliciting responses from a cross – section of academic staff of the Turkish primary schools sample sizes of 72 teachers who were drawn as part of the target study group using a convenience technique sampling. The 60 returned questionnaire were electronically analyzed and results presented using descriptive and inferential statistics. Finding indicated that although teachers' attitude was positive towards the course in general, the programme had limitations especially in terms of its planning and evaluation phases, and its impacts on teachers' practices.

Tahir (2014) worked on the impact of in-service development and training programme and United Bank Limited employees' productivity in city of Peshawar KPK, Pakistan. The study purpose was to investigate the impact of employee' productivity and performance through their training and development. The

quantitative survey research design purposively sampled 110 respondents from a pool of 300 teachers in the study area. Data were collection through questionnaire while descriptive statistics was used to test variables consistency and reliability. The results revealed that employee performance and productivity significantly relate with in-service development and training programme of employee in Pakistan.

In (2012) a studied in-service training of library staff user development experience in South Africa University of Technology, cape Peninsula was conducted by Lockhart and Majal. The significance of the interventions and training opportunities given to non – academic staff working in South African libraries was the study aims. To achieve this purpose, hypotheses were postulated. Two hundred academic librarians across the district comprised the study sample. To analyze the obtained data, designed instrument was used. The result showed that the collaboration and partnerships amidst the librarians was the function of training opportunities & interventions.

Allison (2013) carried out a study to find out the professional development components which support employees in an era of high stakes accountability. The study consisted of all the personnel working in High School and obtained license with Teachers Registration Council (TRC). Convenient sampling technique was used. Five (5) respondents were sample out for study through interview. Collected data were tested by using critical analysis procedure .The research findings showed that to institutional goals for the improvement of teaching and learning significantly relate with professional development programmes. In–service training programmes should be encouraged by school administrator in order to develop teacher skills and improve teaching and learning was connected to the institutional mission.

Shelton (2011) investigated the effects of employee in-service development programmes on job satisfaction and employee retention in Vodafone, Ghana. To determine the relationship between career development opportunities and employee effectiveness was the purpose of the study. A combination of random sampling, stratified, and accidental techniques was used to obtain information from 142 employees who represented the percentage of the target population of 1,420. The estimates ranging from .56 - .86, for various sub-scales was considered reliable and valid to collect information from the participants, while data analysis utilized Pearson correlation tool. The study finding indicated that employee retention, job satisfaction and effectiveness was highly correlated with employee in-service development programmes, followed by skills improvement, attitude formation/development, resources management, in that order.

Craig (2017) conducted a study on teachers' difference in assessment literacy of pre-service and in-service. Survey research design was used to compare and measure assessment literacy teachers' perception of pre-service and in-service. The result obtained showed that teachers who participated in in-service training performed highest in class 3, while Pre-service teachers performed highest too in class 1. Results interpretation showed lowest assessments on teachers' performance in class 5, using procedure for grading valid development. The two groups' results revealed that five of the seven competency areas showed significant differences on teacher' in-service and pre-service teachers.

Aduwa-Ogiegban (2013) worked on Nigerian in-service Teachers' Self-Assessment in Core Technology Competences and Their Professional Development Needs in ICT. The aim was to assess in-service teachers and students' of postgraduate south-south geopolitical zone Universities in Nigeria. The study used survey research design. Two hundred and thirty eight (238) teachers' which

includes: 130 female and 108 male teachers consists the study population. The study analysis showed extensive in-service opportunity advancement in 16 ICT are skill and areas of competency training is 12, in-service teachers preferred attendance at university courses, conferences/seminars, and mentoring as the major modes of in-service training in ICT skills and in-service teachers lacked competencies in core technology areas.

In a study by Ogunrin (2011) on teachers perception of in-service workshop training and their capacity development in Oyo State, Nigeria. Perceptions of in-service training of teachers' data were obtained from ninety two (93) teachers from different secondary schools across all 30 local government areas. For data collection, a 20-item instrument with adequate psychometric background was used. Generally, the results showed that Nigerian Teachers implicitly perceived in-service showed positive significant in teachers' capacity development efforts in Nigerian.

In an investigation of retraining teacher perceptions and their delivering competencies in Biology lessons at secondary school level, Zakia, Muhammad, Maqsud, and Muhammad (2014) sampled a total of one hundred and sixty (Biology Teachers participated in the study. 160) Objectives were to determine the perception of lesson delivery Biology lesson by teachers and their competencies in and thus analyse their competencies at four formal steps in Federal Government Secondary School in Punjab. Questionnaire was used to gathering information. Modified 5 point Likert scale items were developed. Instrument for secondary school principal and Biology teachers was established. The finding revealed teachers' who engaged in-service are knowledgeable with good presentation of their lesson and multiple choice question design. It was recommended that model teaching aid like interactive white board and computer should be used effective in school.

2.3 Management of staff wages/salary and university goals attainment

In a study by Onuora, Okeke and Ibekwe (2019) on employee compensation management and their organizational effectiveness in public secondary schools in Anambra State, Nigeria. Descriptive survey research design was adopted for the study. Two hundred and fifty seven (257) Teachers' in Anambra State public secondary schools constitute the study group. Structured item was the type questionnaire used. The stated null hypotheses was analyse using Z-test at.05 significance level. The results of the finding revealed that there is a negative significance effect on employee competency based compensation; Equity based compensation and employee performance in Nigeria organization. It was recommended that there should be Performance-based compensation plans, compulsory equity-based compensation and competency-based compensation policy for all level of employee working in an organization.

Okwudili and Enyioko (2015) studied academic staff struggles for wage control in Enugu State. Survey research design was adopted for the study. Five hundred (500) civil servants were sampled from the population for the study. A questionnaire was used for data collection. A test statistic of ANOVA was used for data analysis. Findings revealed that policy decisions on wage control do to not influence employees of Nigerian Union of Local Government. Also source of conflict between states to pay the wages of local government employees was attributed to corruption. Recommendation was made that all times both representatives of workers and employers should engaged in consultative salaries, Wages and allowances collective bargaining.

In an investigation of disburse salary differences and workers satisfaction in public sector and private universities, Tinuke (2019) sampled a total of two hundred faculty workers comprised of fifty staff selected randomly from

respondents. 5 research questions and five hypotheses were posed and tested. The study employed the survey research design. Disbursement of salary satisfaction results showed greater productivity and performance among workers while disburse dissatisfaction resulting to worker low productivity, lack of commitment, moonlighting, absenteeism, and high rate of labour turnover which affects performance. The finding revealed pay disparity among faculty workers in public and private universities. This implies that faculty staff enjoy job security, working conditions, bendable working time, less supervision, freedom of association, fewer workloads, and understandable communication line, pay package and promotion prospects in the two universities are significantly differ. Stoppage in disbursement in salary differences among worker was recommends enabling them satisfied with their work; steady upgrading of working conditions and enhancement of career advancement was recommended. Reviewed of worker salary and regular career advancement policies should be encouraged to avoid worker remained permanent in their carer.

Akinfolarin (2015) investigated academic staff salary management and their performance effectiveness. The study use descriptive survey research design. 50 faculty staffs 10 academic heads constitutes the study group. Four (4) Point Likert-type-rating scales were used in measuring the items. Frequency count and simple percentage were the means of data analysis. Results showed that payment for innovation and creativity, award with impressive titles, appreciation on genuine effort and acknowledgement boost university lecturers' productivity. Also, lack of provision of regular payment of salary and other remuneration by the head to promote the performance 60% of the respondents agreed to it. The study recommended adequate provision of chances for research development and professional growth, prompt payment of lecturers' salaries, academic staff working

relationship and, availability of Institutional facilities, further advance their performance among others by Universities managers and other tertiary institution.

In an investigation of worker salaries effects and their task productivity, Abdullahi and Babagana (2015) sampled a total of forty five faculty staff. Research design used were analytical and correlations. Data were collected through quantitative means. Results showed significant relationship between staff remuneration, staff level of motivation, extreme allowance and working conditions of faculty staff significantly affected students' academic performance. The study recommends that strategies like worker regular payment of salaries, observation of school policies, giving students' adequate attention and these should be put in place by government or management to enhance worker job satisfaction.

Employee motivational techniques and on their performance in ElectriCo Sri Lanka, Edirisooriya (2014) sampled one hundred (100) employees from population of 1,075 employees in the ElectriCo. Method of data collection involved self-designed questionnaire. Descriptive statistics and inferential statistics was employed in analyse collected data. The finding indicated relationship on performance employee in term of intrinsic reward and extrinsic reward.

In study conducted on compensation impact on employee performance (empirical evidence from banking sector of Pakistan by Hameed, Ramzan, Zubair, Ali and Arslan(2014) sampled two hundred (200) Bank worker in Pakistan. To solicit information on worker reward such as wages, indirect compensation, salaries and employees' performance, a questionnaire was designed. To analyze the collected data, Correlation analysis and Regression analysis was applies using SPSS 17.0 version. The result showed that employee performance significantly relate with compensation. The research indices use showed insignificant impact on worker productivity as revealed by regression analysis.

In an investigation on impact of worker incentive and their productivity in manufacturing companies in Ibadan, Oyo State, Nigeria, Sajuyigbe, Olaoye and Adeyemi (2013) purposively sampled 100 respondents. For data collection, structured questionnaire was used. Multiple regression analysis was used to analyse the collected data. The finding revealed that jointly prediction of dimensions of reward on employees' performance.

2.4 Management of staff orientation services and university goals attainment

In an investigation of factors influencing teachers' job satisfaction in public secondary schools in Mubi north local government area of Adamawa state, Nigeria, Oluremi (2017) sampled out two hundred (200) teachers' from secondary school which constitute the population. Survey method was adopted for the study. Stratified sampling technique was used, 'Teachers' Job Satisfaction Questionnaire "(TJSQ) was the questionnaire titled. 0.86 reliability coefficient was considered after applying test retest reliability method. Data were analyzed using descriptive and inferential statistics. The findings of the study suggested that: teachers were satisfied with their monthly salary, fringe benefits and administrative support provided to them.

The findings of the study also revealed that the roles of school managers in ensuring teachers' job satisfaction were flexible curriculum, interpersonal and intrapersonal relations at school, involvement of teachers in decision making in schools, flexible school timetable, fringe benefits, autonomy to perform own duties with no interference.. The findings of hypothesis one revealed that there was a significant difference between policy and professional development of teachers. The results of the second hypothesis revealed that there was no significant difference between female and male teachers in their perception of salary as a factor

affecting job satisfaction. In conclusion, factors influencing teachers' job satisfaction were promotion, salary, fringe benefits and motivation. If these factors are made available to teachers, there shall be effective job performance.

However, if all these factors are not made available, the teachers shall develop negative attitude to work and as such can lead to poor academic performance of students in examinations. In order to boost the level of motivation and satisfaction of teachers the study recommended that there should be regularity in the promotion of teachers and such promotion should be based on merit to encourage hard work and promotion should be promptly effected and arrears paid in block or in reasonable instalments to make teachers happy and instill in them more enthusiasm to perform their duties.

Amadi and Anaemeotu (2013) worked on the effect of implementation of orientation programmes on worker productivity in secondary schools in Etche Local Government Area. It is a literature study. The result of the findings indicated that professional development of teachers refocusing the status quo of the school system which can maintained moderate academic benchmark; in-service training fully integrates teachers' talents and potentiality towards realizing the objectives and goals of the school system; workshops/conferences/seminars provide the medium for sharing assumptions, values, beliefs as well as engendering inter institutional resources and exchanging scholarly ideas. It is therefore concluded that enabling environment and opportunities be created for consistent acquisition of knowledge, skills and potentialities to pursuit the academic excellence. Hence, it was recommended that sufficient resources should be provided to assure effectiveness during the programme; there should be provision for positive reinforcement after training for transmission of the acquired knowledge and skills; varieties of development programme or activities should be provided to accommodate the

interest of non-academic staff; teachers should be allowed to use research/publication as a yardstick for their promotion as in the universities system

Macheng (2016) examined the impact of teacher orientation programme in junior secondary schools in Botswana. The factors that affected teacher professional development was examine in six (6) accidentally selected J .S.S class in northern state of Nigeria. The study was quantitative and qualitative in nature. Data were gathered using survey questionnaires and interviews. A computer aided statistical analysis (SPSS version 20) was used to analyse the quantitatively derived data. The analysis engaged both descriptive and inferential statistical analysis. The findings indicated lack of structures or programmes in junior secondary schools to facilitate teacher development and growth. In conclusion, it is vital for the Ministry of Education and Skills Development to continuously develop teachers professionally to cope with the changes in their teaching and learning environment.

Amadi (2013) examined the implementation of teachers' induction programmes their academic performance in secondary schools in Etche local government area, Rivers state of Nigeria. Research survey design was used. Two research questions were formulated for the study. The population sample of the study consists of 399 teachers from seventeen (17) secondary schools in Etche Local Government Area. The sampling technique used was random sampling method. The instrument utilized was questionnaire coded professional development and teachers' academic performance questionnaire (PDTAPQ). Out of 399 copies of questionnaire distributed 378 were retrieved for analysis of the research questions. The result of the findings indicated that professional development of teachers refocused the status quo of the school system which can maintained moderate academic benchmark; in-service training fully integrates teachers' talents and potentiality towards realizing the objectives and goals of the school system;

workshops/conferences/seminars provide the medium for sharing assumptions, values, beliefs as well as engendering inter institutional resources and exchanging scholarly ideas. It was therefore concluded that enabling environment and opportunities be created for consistent acquisition of knowledge, skills and potentialities to pursuit the academic excellence. Hence, it was recommended that sufficient resources should be provided to assure effectiveness during the programme; there should be provision for positive reinforcement after training for transmission of the acquired knowledge and skills; varieties of development programme or activities should be provided to accommodate the interest of non-academic staff; teachers should be allowed to use research/publication as a yardstick for their promotion as in the universities system.

Salau, Falola and Akinbode (2014) examined teachers' perception about the meaning and benefits of induction in Ogun State public secondary schools. Perception of teacher behaviour against induction/orientation and how induction programmes enhance worker commitment to the organizational effectiveness was investigated. Descriptive research method was adopted for this study using two hundred and seventy one (271) valid questionnaires which were completed by academic and non-academic staff of Olabisi Onabanjo University in Ogun State Nigeria. The data collected were carefully analyzed using descriptive statistics to represent the raw data in a meaningful manner. The findings revealed that induction significantly influences staff attitude and behaviour towards organizational effectiveness. This means that well packaged induction programme will positively influence staff attitude. It was recommended that induction programmes should be reviewed and improved upon from time to time to earn employees loyalty and positive attitudes towards work.

2.5 Management of staff health services and university goals attainment

Aremo and Ibukun (2017) conducted a study in Universities in South western Nigeria on way of medical care requirement among staff and health insurance of staff. The study population consists of 800 staff and students. Information was gathered cross-sectional from four Universities covering four states of south western Nigeria namely: University of Ibadan, Obafemi Awolowo University Ekiti State University and Olabisi Onabanjo University, sampling techniques using a three-stage was applied in selecting data through structured questionnaire. Multiple regression tool was used in analyse data. Respondents from staff were 47.6% while students account for 53.5%. Also, the usage of the university's healthcare center or hospital was observed to be higher (43.9%) than any other healthcare facility, although more than half of the participants (57.8%) that chose this provider are female.

Kamau, Osuga, and Njuguna (2017) study examine challenges facing quality health care services implementation of the referral system in Kiambu County, Kenya. The study aim at investigating the impact of medical staff ability, infrastructure, physical condition data and financial resources on implementation of health care referral system. The population of the study consists of two hundred and seventy one (271) respondents. Data collection tools were both questionnaires and interview. Analysis was done through a descriptive and inferential. The finding indicates healthcare support services with coefficient 4.457; positive coefficient of 4.104 for infrastructure, capacity of health care workers, with significant coefficient of 4.013 for staff health care ability, coefficient of 4.105 for financial resources and health data system. The study concluded that ability of medical staff, infrastructure, financial resources health information systems and are challenges in implementation of health care referral system.

Embu (2012) evaluated the availability and utilization of healthcare support services, demographic characteristics and sustainability of tertiary institutions of Nasarawa State. To achieve this purpose, a total 1000 subjects comprising 600 students, 200 academic and non-academic staff and 200 healthcare workers and administrators were randomly selected from six tertiary institutions of Nasarawa State. Two sets of questionnaires (one set for all respondents and another set for healthcare workers and administrators) on availability and utilization of healthcare services were prepared for the study. This was then administered on the respondents. Data collected for the study was analyzed, using analysis of variance (ANOVA) with descriptive statistics of frequency, standard deviation (SD), percentage and mean. It was found that healthcare services in tertiary institutions in Nasarawa state were not adequate, the respondents' income level significantly affected their perception of availability and utilization of healthcare services, non-utilization of the healthcare services was as a result of certain factors which included high cost of drugs and services offered, the healthcare system itself and the negative attitude of the healthcare workers. The demographic had effects on the perception of the respondents on the various variables of healthcare services in tertiary institutions in Nasarawa State.

Anetoh, Jibuaku, Nduka and Uzodinma (2017) designed a study in explored students' perception towards implementation of school health insurance programmes in Medical Centre of the Nnamdi Azikiwe University Awka. Study population consists of four hundred and twenty (420) undergraduate students in the study area. Sampling technique used was stratified random. Means of an adapted questionnaire was carried out on students' information about the school health insurance programmes. In analysed collected information SPSS was used. In general, awareness of students' level of school health insurance programmes was

found showed a high. Also, the result recorded who have never benefited from the scheme with a score of (56.3%), while 52.8% and (87.9%) account for overwhelming number of the students who suggested continuation of the scheme. Students of the Nnamdi Azikiwe University general responses about school health insurance programmes awareness was found satisfactory. Strong commitment to the objectives of the scheme was recommended to the health worker at the University Medical Centre.

In an investigation of on the utilization of medical services in University among Students, Abdullah (2017) sampled out two hundred and forty (240) students. Assessments of six month perceived barriers towards utilization of university health centre services by the students of the university were the study aim. Data gathering involve using a self-administered questionnaire. Research design was cross-sectional design. Data were analysing using frequencies. Findings revealed that quota of students in six months with following scores (23.5%), (14.7%), (11.8%) used medical centre services because of related health issues. The level of students' satisfaction with health centre services showed 64.6%. Thus, challenges observed concerning students utilization of health care were Students'/ medical staff relationships (17.1%), drugs unavailable (22.5%), inadequate referral services (8.3%) and patience over waiting period were (5%).

In an investigation on the factors affecting utilization of University health services in a tertiary institution in South-West Nigeria, Obiechina and Ekenedo (2013) randomly sampled out five hundred and forty persons which includes 280 males and 260 females. Students' perception of tertiary institution health care services provision and assess students' assess towards it utilization was objective of the study. Sampling technique used was simple random. Questionnaire was employed to gathered information. Descriptive statistics of frequency count and

percentage were used for data analyzing. The finding revealed the following scores; (72.0%) for high cost of drugs , (67.2%) hour spent for waiting treatment , (81.7%) for inadequate referral services, (54.8%) for essential drugs non-availability and (60.6%) respond to factors affecting the utilization of university health service satisfaction were considered. while 77.6% and 74.3% respectively were recorded for Students. Compulsory implementation of National Health Insurance scheme into tertiary institution to enable students have free access treatment were part of the recommendation for the study.

Adeyemo, Ohaeri, Patrich and Ogodo (2016) whose carried out a study in Benin City, Edo State, Nigeria in order to determine the influence on management of school healthcare support services on the sustainability of tertiary institutions. Eight hundred (800) students' was sampling out for the study. Descriptive survey design adopted for the study. Data were collected through a structured questionnaire. Information was analysing utilizing descriptive statistics and PPMC tool. Finding revealed that poor implementation of health examination and health counselling services made majority of the respondents to engage in taking substance and drugs to complement medical services. Also, the study showed that the most commonly abused drugs were coffee and alcohol in the tertiary institutions. Majority of the respondents agreed that students lost focus of their studies and abuse drugs as a result of poor implementation of health remedial services in the tertiary institutions.

In an investigation on behaviour pattern in the utilization of the National Health Insurance Scheme (NHIS) among health workers at the University of Nigeria Teaching Hospital (UNTH), Ituku-Ozalla, in Enugu State, Nigeria, Ekwuluo, Eluwa, Okereke, and Orji (2018) sampled out a total of 1500 medical students were used for the study. Descriptive survey design was adopted for the

study. Interview questionnaire were used to gathered information. Responses about the awareness of the schemes were 18.2% and those that are not aware were 1.8%. Positive responses about attitude towards the scheme were 36.3%, Those that could not utilize the scheme for academic purposes were 87.3%. The school management could not implement wellness policies and health programs in the school.

In an investigation on a way of improving deterring patients' satisfaction in a tertiary institution and the quality of care in southeast Nigeria, Umeano Enemuoh, Onwujekwe, Uzochukwu and Ezeoke (2014) Three hundred and sixty (360) respondents were systematically selected through a cross sectional study. Grouping of worker satisfaction based on the services provision quality, the participants completed a 5 point Likert scale self-administered questionnaire. They also rated important factors where best services were offered. Mean score = 3.75 were recorded for moderately contented with the services offered. Mean score = 3.45 revealed also good quality health facility for all the variables. Mean rating of 4.1 showed highest level satisfaction for Pharmacy. Findings revealed that worker are moderately contented with the services provided as well as the quality of care by the different service providers of the health facility.

In a study on staff health status, students and services delivery in Public and private secondary schools in Kogi State, Kolawole (2015) sampled 1320 staffs and students (770 students and 550 staff) from private and public schools. Data were collected from a conveniences using School Health Services Questionnaire (SHSQ). Descriptive statistics were used. ANOVA and t-test analysis were used for data analyses. The analysis indicated that in both public and private secondary schools across Kogi State, school health services are unsatisfactory implemented.

2.6 Management of staff motivation/welfare and university goals attainment

Nabi (2017) conducted a study on impact of motivational tools and betterment for employee performance. De-motivation factors affecting employee performance negatively was also the study focused. Interview of self-administrated questionnaire was used to gathered information for the study. Descriptive statistical were the methods used for analyses. The analyses showed that achievement of organizational goals is purely associated with employees' positive motivation.

A study conducted on the relationship between Motivation and employee productivity in First Bank Lagos, Nigeria by Ajayi (2015) sampled a total of 450 workers as a study population. To bring out the worker most excellent performance in organization through many ways of motivational strategies were examine as the purpose of the study. Data collected were analyse using Chi ($\chi^2 = \text{Chi-squared}$) statistical tool. The finding indicated that employee motivation to work better has positive effect on quality of supervision. Also, greater impact on performance and organizational productivity depend on financial motivations which involve monetary rewards.

In explored the impact of motivation on teachers' job performance in public University, Akhtar and Igbal (2017) sampled one hundred (100) lecturers' from public universities making 60% of the population. Research design was descriptive survey design. 5-point Likert type scale questionnaire was the instrument used for data collection by the researchers used the as data collection. The finding revealed that teachers' motivation significantly impact job performance.

A research conducted on evaluated staff motivation, dissatisfaction and job performance of academic staff of Ibrahim Badamasi Babangida University, Lapai, Nigeria by Mohammed (2011) the researcher' sampled out a 219 academic staff as

population of the study. Out of a population of the study one hundred and forty one, sixty four percentages of the academic staff of the University were sampled. Survey research method was employed to collect research data. To measure the research variables descriptive statistical tools were used. The result of the finding showed that level of motivation by such as provision of working environment significantly relate to staff performance. Motivational problem of the faculty employee should be taking seriously in order to facilitate effective teaching and knowledge delivery in universities and other tertiary institutions was part of recommendation.

In an exploratory study on motivation and research productivity among Romanian academics of Economics and Business Administration in a university system by Horodnic and Zaic (2015) the use of extrinsic and intrinsic motivation was the purpose of study. The study group were faculty staff of Economics and Business Administration. Regression model of Tobit was used on a representative sample. The study revealed that intrinsic motivation is positively correlated with research productivity, whereas extrinsic motivation is negatively correlated. These results imply that scientists who take a strong interest in their work are, as a consequence, more productive researchers; scientists who are, in general, extrinsically motivated will however substitute their efforts toward activities that are more financially profitable in an economy undergoing transition.

In an investigation on monitoring and evaluation (M&E) relationship practices and academic staff motivation in higher education in Rwandan by Boniface, Alfred and Tuyisime (2019) sampled one hundred and five academic staff. The study focus is on monitoring and evaluation practices applied. Mixed-methods were employed for data collection from academic staff. The result obtained indicated that evaluation by supervisor, students–staff evaluation, peer evaluation, and staff self-evaluation significantly motivate academic staff to

performance effectively in their job. Moderate weak correlations ranging from 0.269 to 0.4461 were established for M&E practices and faculty employee motivation. There should design a policy on M&E, which would guide supervisors in M&E exercise was part of the researchers' recommendation.

A study conducted on motivational strategies and personnel job performance effectiveness in university libraries in Nigeria by Toyin (2018) fact finding interviews and questionnaires method was used for data collection. Result revealed that the inefficiency problem would be encountered if staff were not motivated and financial technique, incentive strategy; job enlargement, job enrichment, promotions, awards, monetary, and non-monetary compensation were considered as part of motivation. Motivating library personnel for effective job performance was discovered as prime importance in the university.

Ajalie (2017) worked on the effect of employee motivation on organizational productivity. To examine the effect of worker incentive on organizational efficiency was the main purpose of the study. Descriptive and causal research design was used for the study. survey method was considered. 475 constituted size of the study group. To determine the sample unit, 217 were selected. A questionnaire self-administered well-structured was used for data collection. Cronbach's alpha coefficient of 0.868 was reliability of the research instrument. Multiple regressions were the information analyses tool. The result of the tested hypotheses indicated that extrinsic factors and employee motivation with rating score of 35.8% relate with organizational productivity. The conclusion of the study showed significant predictors between intrinsic and extrinsic factors and productivity. That appropriate measures should be taking by management of organizations to provide worker incentive to improve their output were part of the study recommendation.

2.7 Management of staff retirement/pension and university goals attainment

In an investigation on the state of contributory pension scheme on employees' productivity: Evidence from Lagos state government, Ahmed, Abayomi and Nureni (2016) randomly sampled out one hundred and twenty respondents (120). The implications of the contributory pension scheme among public servants pensioners welfare and productivity in Lagos State was the main purpose of the study. The use of books and individual interview were the methodology employed to achieve the objectives study. SPSS software was used for data analyses. The finding of the analyses indicated that adequate retirement package has significant relationship with employees' productivity. Stakeholders should organize clients' sensitization programmes as well as participate in the supervision of review of the pension scheme in order to enhance the workability and acceptances of the contributory pension scheme were part of the recommendation.

A study conducted on non-contributory pension scheme and the welfare of retired civil servants in Ebonyi State, Nigeria by Nweke (2015) randomly sampled out four hundred employees' who have leave services which constitute the population of study. The study used survey design. The researcher gather information from twenty four employee of pension department and sixty eighty employee from Sub-Treasury spread across the 13 local government areas in Ebonyi State and sixteen employee from State Auditing pensions unit as contain in the payroll of 2011. Data were collected in two sets of semi-structured questionnaire which involved respondents' demographic characteristics, retirees' coping strategies. Collected data were analyzed employing inferential and descriptive statistics. The respondents' were 12.5 for years; age was 55.2. About 80% of the retirees indicated that their pensions were not adequate in meeting their

major welfare needs such as accommodation, adequate diet, health services and education for children. The most widely adopted coping strategies by retirees were investment of gratuities (45.5%) and relocation to family houses (32.3%). Major challenges faced by non-contributory pension scheme were lack of biometric data capturing machine (81.2%), high workload on staff processing pensions (61.2%), poor funding by the government (75.3%) and mismanagement of pension funds (54.2%). There is significant relationship between monthly pensions of retirees, educational qualifications of retirees, poor planning for retirement, welfare of retirees, postponement in the payment of retirement benefits, embezzlement of pension funds, interfering delays and governments' reluctance to review pensions and their welfare provisions. In order to meet the needs of retirees in Ebonyi State, pension management should restructure the administration of the non-contributory pension scheme.

A study conducted on the stability of the contributory pension scheme (CPS) and University goals in Nigeria by Chris (2015) employed primary and secondary source as a mean of data collection. To look at if contributory pension scheme, better risk management, effective investment strategy in existence capable of ensuring sustainability of the new scheme has important on the capital market and economic development of Nigeria were the objective of the study. To analyze data collection, linear regression analysis was the statistical tools employed. The finding indicated positive on contributory pension Scheme and the development of the Nigeria Capital market. The study also found out that contributory pension expenditure relate with the GDP (gross domestic product) in Nigeria. Furthermore, the findings showed important proof of better risk management and savings strategies in existence to ensure sustainability of the contributory pension scheme in Nigeria.

In an investigation on the impact of contributory pension scheme on economic growth in Nigeria by Ameh, Ajie and Nuhu (2017) Pension scheme contributory impact on Nigeria financial growth was the focus of the study. World Bank Development Indicators (database) and PenCom Annual Reports were the various sourced of data for collection. SPSS software was used in computed gathered information. The result indicated that pension contribution, savings mobilized over the years and pension fund assets impact on economic growth positively . Pension management should place more emphasis on genuine area and saving trust to increase Gross Domestic Product (GDP) of the country (Nigeria), product in the resources market as well as government bond, were part of the study recommendation. Finally, there should be timely settlement between Pension Fund Administrators (PFAs). This will bring honest and liability to the system

A study conducted on important of the 2004 pension policy on the welfare of the Nigerian federal ministries civil servants by Ahmed and Oyadiran (2013) sampled out 1500 persons from 5 federal ministries in Abuja. The new pension policy and living standard of the retired civil servants in Nigeria was the main focus of the study. Questionnaire employing random sampling technique was utilized. Simple percentage was used for data analysis. It was indicated from emerged findings that new pension implementation and welfare of the civil servants are positively related. Pension administration to ensure effective supervision, monitoring, and enforcement effective implementation of penalties as provided by the Act on non-compliers regardless of their status in the society were study recommendation among others in view of the above findings .

In an investigation on difference comparison of pension schemes in Nigeria from 1951 to date with focus on the pre and the post 2004 era by Bassey and Etim (2018) sampled out 60 staff drawn from the University of Calabar Teaching

Hospital, Calabar. comparison of the pre and post 2004 pension Schemes in terms of which of the Pension era have minimized the plight of Pensioners and rationale following the failure of the previous schemes were identifies in the study. Five point Likert scale well-structured questionnaire was administered. Employing Chi square(X^2) statistical tool in analysed information. The result of the findings showed that 2004 pension Scheme has significant differences in reducing the difficulty of Nigerian Pensioners when compared to the Pre 2004 Schemes and should be encouraged. The Paper conclude that representative of the government and other stakeholders apart from encouraging the 2004 Scheme, should give pension matters top priority because after hard service comes a period of retirement. Series of recommendations have been made which if adhered to with a proper pension management orientation would distinguish Nigeria among her contemporaries in terms of having a hitch free Pension management system for her retirees. Also, fully funded nature of the Scheme couple with the clear legal and administrative sanctions spelt out for erring parties, the underfunding ,and corruption which informed the frequent pension verification exercise that characterized the Pre 2004 Schemes have been reduced to the barest minimum and that the effort of successive governments in Nigeria towards encouraging Pension Schemes from Colonial period to date is commendable but considering the present day significance of pension.

Yaro (2019) researched on the impact of pension administration on employees and university goals attainment in Nigeria. The main focus was the introduction of Pension scheme as it is implied in organization, as well as the statement of general problems and significant of the study were discussed in the initial chapter. A comprehensive review of related literatures of different authors use also made. Here, we have conceptual domain of pension, were it was defined by

several scholars and its importance conferred appraisal. Primary data were gathered through the utilization of personal interviews and detailed questionnaires. The total population size of the Premium pension ltd staff and client use estimated to be hundred and fifty which were sent questionnaire and one hundred and thirty three responded to the question asked, which were later tabulated in the subsequent analysis. The sample random sampling is the method used by the researcher in determining the sample and sampling techniques used is the purposive type. Also the statistical technique used in testing the hypothesis was the chi-square statistical method. The data collected from respondent were presented and analyzed with simple percentage. So, the results of the findings show that pension Administration has great impact on Employee in Nigeria.

In a study conducted on successful management of life after retirement and its impact on retirees' worker from the public service: a case study of Benue State, Nigeria by Akuraun and Kenneth (2013) adopted survey research method. Employees' preparedness strategies for retirement and the post-retirement was the objective of this research. Sources of data collection were both secondary and primary data. Method adopted in selecting the sample was disproportional stratified sampling. Simple percentages were utilized in testing hypotheses. Many challenges such as corruption, sufficiency, managerial efficiency, transparency, governance and regulation faced by pension reform in Nigeria.

A study conducted in on the old pension scheme with the Pension Reform Act 2004 comparison by Odia and Okoye (2012), In order to compare and contrast the pre-2004 pension scheme with Pension Reform Act 2004, comparative analysis technique was utilized for the study. The adequacy of PRA 2004 and the pre-2004 pension scheme were compared, and the prevalent incompleteness in the old pension scheme was expected to solve through the PRA 2004. Regular supervision,

rigid coordination, and regulation of the pension industry in Nigeria were the study recommendation.

A research carried out on contributory pension system as a tool for economic growth in Nigeria by Gunu and Tsado (2012) to analyze data collected, descriptive statistics, percentages and charts were used for the study. To enhance in development of the investment market and financial growth in Nigerian, contributory pension scheme has contribution to that effect.

In (2010) investigation on pension reforms in Nigeria for the period 2006 to 2010 by Dostal finds that the funded pension system has not had any significant impact on the development of financial market and that real sector investment was not boosted by savings from pension scheme. Also the macroeconomic credibility of the government has declined. The implication of the findings was that the regulatory environment failed to encourage interaction between pension reform and economic reform while problems of regulation within the system have also contributed to a lack of reform credibility.

Nyong and Duze (2011) carried out a study on the Pension Reform Act 2004 and retirement planning in Nigeria. The study used survey research design and a multi-stage random sampling technique to select the sample size of 3000 from the population of serving teachers and teacher pensioners in Federal and State Public Secondary Schools between the ages of 55 and 59 years. The results revealed that the objectives of PRA 2004 were yet to be achieved since retired persons still suffered trauma, pains and even death before they received their pension packages. The study recommended e-payment of pensions to ensure easy referencing, easy update and logistics of pension scheme system.

2.8 Summary of literature review

The research evidence presented in this review showed that management of staff personnel services relate with university goals attainment to a large extent. This literature reviewed the various positions of the different authors which have help to increase the researcher horizon in having a wider knowledge about the study and also equipped the researcher with total information in these areas of study.

However, correlational research design, descriptive survey ex-post facto research and designs experimental research design were adopted by the researchers. Checklists, questionnaires, interviews, content analysis and observations were the major instruments of their data collections. In the case of staff recruitment service, staff training/development and staff motivation/welfare, some of the reviewed works indicated a strong positive significant influence on the university goals attainment.

More so, some of the reviewed works on staff wages/salaries, staff orientation service and staff pension/retirement services revealed significant relationship on university goals attainment in both public and private universities while few studies failed to show statistical significance. Although, as observed in the literature review earlier made, none of the study was carried on the researcher study area and the population size and statistical tools used was different, as such this research attempt to fill the identified gaps on management of staff personnel services and university goals attainment created by the review in order to contribute to knowledge.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter describe the various research methodology used in the study.

The chapter was discussed under the following sub-headings.

- 3.1 Research design
- 3.2 Area of the study
- 3.3 Population of the study
- 3.4 Sampling techniques
- 3.5 Sample
- 3.6 Instrumentation
 - 3.6.1 Validity of the instrument
 - 3.6.2 Reliability of the instrument
- 3.7 Procedure for data collection/scoring
- 3.8 Procedure for data analysis
- 3.9 Operational definition of research variables

3.1 **Research design**

Correlational research design was adopted for this study. This is a type of design that makes effort to finds out the relationship degree that exist among variables set that cannot be manipulated or determined by the researcher. The relationship within a sample or group present is naturally. (Idaka, & Anagbogu, 2012). The appropriate consideration of the design for the research was that the design gives the researcher the opportunity to study the relationship that exist between two variables, the independent (management of staff personnel service) and dependent variable (university goals attainment).

3.2 Area of the study

Area of research was the two government owned universities in the study area; (CRUTECH) and (UNICAL) university of Calabar, all in Cross River State, Nigeria.

The federal government of Nigeria established University of Calabar in 1975 which was Calabar campus of the University of Nigeria, Nsukka initially. The school was fondly called 'UNICAL' by students and staffs. The school is among second generation federal universities in Nigeria. The school has a graduate school, sixteen faculties, three Institutes with one hundred and forty (141) department.

The aims of the academic programmes of the university was to produce a broad and a sound graduate foundation upon which further professional and intellectual pursuits can be based at the graduate school level. Built to fulfill its motto 'Knowledge for Service', the university place a great premium on learning and character. Hence, the university officially recognized degrees such as bachelors, masters and postgraduate degrees in several disciplines and sometime present programmes for accreditations or courses leading to award of degrees.

The school is located in the southern part of the country, a region known for its rich cultural heritage and beauty. Number of events is quite host yearly and has been one sure spot for tourists craving to have a feel of the region. Interestingly, in the university, male students are called 'Malabites', while the females are called 'Malabresses'. The male hostel is called 'Malabo' and the name originated as a result of the challenges faced by students at a time which coincided with the suffering by Nigerian deportees in Malabo, Equatorial Guinea.

In August 2002, Cross River State Bill No. 9 recently amended as Bill No. 6 of 2004 established CRUTECH: Cross River University of Technology. The three former tertiary institutions namely: The College of Education, Akamkpa, the

Ibrahim Babangida College of Agriculture, Ovonum, Obubra) and the Polytechnic, Calabar, owned by the Cross River State Government were merged together to become Cross River University of Technology. To provide basic training and research and to impart research skills to equip Nigerians of various backgrounds in all areas of technology was the primary aim of establishing the school. To enable the exploitation of the enormous natural resources for sustainable development of Cross River State, emphasis is however placed on catchment areas of the school.

The school is a corporate body with perpetual succession and a common seal. In September 2002, the Cross River University of Technology began its operations after one year of its existence, an in-house assessment was conducted during a visitation exercise. Emerging problems were identified and addressed. The law establishing the university, Bill No. 9 of 2002 was amended as Bill No. 6 of 2004 and structural reorganization and staff re-designation were affected.

High quality production, well-trained graduates and researchers well-equipped for the provision of quality life, food, fiber, and shelter for the people in a sustainable manner, using well researched techniques of Science and Technology are the main responsibilities of CRUTECH. In this regard, no person shall be required to satisfy requirements as to race (including ethnic grouping), sex, place of birth, family origin, religious or political persuasion as a condition of becoming or continuing as a student, the holder of a degree or other awards of the university, or of appointment or employment at the university. In other words, no person shall be subjected to any disadvantage or accorded any disadvantage in relation to the university. This however does not prevent the university from imposing any disability or restriction on any person, where such a person will fully refuse or fails on grounds of religious belief or similar grounds to undertake duty generally and

uniformly imposed on all persons or any group of them and which in the opinion of the university is reasonably justified in the national and State interest.

3.3 Population of the study

The study population comprised all the one hundred and forty one (141) departmental heads in Cross River State public own universities. According to data obtained from the Registry, senior establishment unit of UNICAL and CRUTECH, there are one hundred and forty one (141) heads of department in the study area. UNICAL (107) and CRUTECH (34) which was used as the study population. (UNICAL and CRUTECH (Registry Unit August, 2019).

3.4 Sampling techniques

Census sampling technique was employed for this study. The technique was used due to the fact that the study groups were not large and the researcher can use all the member of the population of the study. All the one hundred and forty one (141) heads of department in the universities was select for the study.

3.5 Sample

One hundred and forty one (141) HODs in the Cross River University of Technology and University of Calabar and was the sample size of the study.

3.6 Instrumentation

The study instrument was the researcher-developed questionnaire titled: Management of Staff Personnel Services and University Goals Attainment Questionnaire (MSPSUGAQ). The items were group into two parts: A and B. Part A sought for respondents' demographic data such as name of the University, Department/Faculty, gender and rank.

Part B: consist of sixty (60) subjects. To measure each of the sub-variables Six (6) items was used. (SA), (A), (D) and (SD) of the 4- point modified likert scale was used. Variables of the independent were measured thus: Management of staff recruitment service was measured using items 1-6 of the (MSPSUGAQ), Management of staff training and development was measured using items 7-12 of the (MSPSUGAQ), Management of staff wages and salary administration was measured using items 13-18 of the (MSPSUGAQ), Management of staff orientation service was measured using items 19-24 of the (MSPSUGAQ), Management of staff health service was measured using items 25-30 of the (MSPSUGAQ), Items 31-36 of the (MSPSUGAQ) was used to measured Management of 'staff motivation/welfare service, Items 37-42 of the (MSPSUGAQ) was used to measured Management of staff pension/retirement service was measured using and the dependent variable which is university goals attainment was measured using items 43-60 of the (MSPSUGAQ).

3.6.1 Validity of the instrument

The research instrument validity is the extent to which the instrument purports to measure what is expected. Content and validity face of the research instrument was validated by experts in University of Calabar, Faculty of Education, department of Educational foundations, measurement and evaluation units and department of Educational management, administration of higher education unit. Before using the instrument, the developed items were given to experts who carefully vet the items. The items considered relevant was retained, while dropped irrelevant items.

3.6.2 Instrument reliability

This refers to as a process whereby an instrument demonstrates the degree of consistency in measuring what it does in research. A trial testing using fifty (50)

head of department selected from University of Uyo was determine by carrying out the instrument reliability (questionnaire). To determine the reliability of the instrument, Cronbach Alpha method was used. The Cronbach reliability analysis results are presented on Table 1 ranged from 0.72 to 0.91.

3.7 Procedure for data collection

Personal administration of the instrument with help of two trained research assistants was done by visiting the various Universities. The instruments were given to selected respondents and some of the respondent attended to the questionnaire immediately while other gave request to get the questionnaire next day. In completion of the exercise, out of one hundred and forty one (141) administered questionnaire copies, one hundred and thirty (130) were successfully retrieved from the respondents and attrition of eleven (11) questionnaires was recorded and the retrieved questionnaires were used for the data testing.

3.8 Procedure for data preparation and scoring

Coding and scores was assigned to each item after collecting the questionnaire. To provide a guide for making data preparation easy and coding the data collected for analysis, a coding schedule was prepared by developing a key for each item. The questionnaire items were separated out depending on the variables they were meant to measure, items in the questionnaire using four-point modified likert scale were positively worded with strongly agree scored 4-points, Agree ,3-points, disagree with 2-points and strongly disagree with 1-point for respectively responses, the scoring technique were reversed for negatively worded items.

TABLE 1

Cronbach alpha reliability result of the instrument (N= 50)

Variables	No. Items	\bar{X}	SD	α
Staff recruitment service	6	15.43	6.24	.91
Staff training and development service	6	16.86	5.81	.88
Staff wages and salary administration	6	16.16	4.97	.87
Staff orientation service	6	15.01	5.90	.82
Staff health service	6	14.10	5.47	.77
Staff motivation/welfare service	6	16.68	4.18	.84
Staff pension/retirement service	6	15.88	5.01	.72
Knowledge acquisition	6	14.78	5.60	.75
Curriculum content	6	15.07	3.38	.78
Social development	6	13.57	2.50	.76

Source: Author's computation of fieldwork, 2019

TABLE 2

Coding schedule for the Research Instrument

Variables	Groups	Code	Column
Institution	UNICAL	1	1
	CRUTECH	2	2
Management of staff recruitment service	Add sum of scores on items 1-6 of section Of (MSPSUGAQ)		3
Training and development staff service	Add sum of scores on items 7-12 in section B of (MSPSUGAQ)		4
Management of staff wages and salary administration	Add sum of scores on items 13- 18 in section B of (MSPSUGAQ)		5
Management of staff orientation service	Add sum of scores on items 19- 24 in section B of (MSPSUGAQ)		6
Management of staff health service	Add sum of scores on items 25- 30 in section B of (MSPSUGAQ)		7
Management of staff motivation and welfare service	Add sum of scores on items 31- 36 in section B of (MSPSUGAQ)		8
Management of staff retirement and pension service	Add sum of scores on items 37- 42 in section B of (MSPSUGAQ)		9
University goals attainment	Add sum of scores on items 43- 60 in section B of (MSPSUGAQ)		10

3.9 Procedure for data analysis

Hypothesis One:

Management of staff recruitment service does not significantly relate with university goals attainment (in terms of knowledge acquisition, curriculum content and social development).

Independent variable: Staff recruitment service.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r).

Hypothesis Two:

Management of staff training and development service does not significantly relate with university goals attainment.

Independent variable: Staff training and development service.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r)

Hypothesis Three:

Management of staff wages and salary administration does not significantly relate with university goals attainment.

Independent variable: Staff wages and salary administration.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r).

Hypothesis Four:

Management of staff orientation services does not significantly relate with university goals attainment.

Independent variable: Staff orientation services.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r)

Hypothesis Five:

Management of staff health services does not significantly relate with university goals attainment.

Independent variable: Staff health services.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r)

Hypothesis Six:

Management of staff motivation and welfare services does not significantly relate with university goals attainment.

Independent variable: Staff motivation/welfare services.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r)

Hypothesis Seven:

Management of staff retirement and pension service does not significantly relate with university goals attainment.

Independent variable: Staff retirement and pension service.

Dependent variable: university goals attainment.

Test statistic: Pearson's Product Moment Correlation analysis (r)

Hypothesis Eight:

Management of staff personnel services does not significantly relate with universities goals attainment.

Independent variable: Management of staff personnel services.

Dependent variable: university goals attainment.

Test statistic: Multiple regression statistics.

3.10 Operational definition of research variables

Staff recruitment service management: This can be defined as a process of managing various activities that involved in an employment of staff in order to enhance the effectiveness of an organisation workforce. items 1-6 of section B of (MSPSUGAQ) measured it.

Development and staff training management: This refers to as the process of managing the engaged workers in a training that will contribute to the development of an organisation. It was measured by items 7-12 of section B of (MSPSUGAQ).

Management of staff wages and salary administration: This refers to as the process of effective management of workers' salaries. It was measured by items 13-18 of section B of (MSPSUGAQ).

Management of staff orientation service: This is seen as process whereby staff, personnel, co-workers are introduced to all the facilities in an organisation to function effectively. It was measured by items 19-24 of section B of (MSPSUGAQ).

Management of staff health service: This refers to a coordinated and comprehensive set of health promotion strategies implemented in an organisation to assist staff combat their health challenges. It was measured by items 25-30 of section B of (MSPSUGAQ).

Management of staff motivation/welfare service: This refers to as a process whereby staffs are provided with the entire necessary requirement that enable them to work effectively. It was measured by items 31-36 of section B of (MSPSUGAQ).

Management of staff pension/retirement service: This refers to as effective management of workers retirement benefit in an organization. It was measured by items 37-42 of section B of (MSPSUGAQ).

University goals attainment: This refers to as the education given after secondary education. It was measured by items 43-60 of (MSPSUGAQ) section B .

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter is focused on data analysis, result of the analysis, interpretation of results, presentation of the results and discussion of findings. It is therefore organized under the following sub-heading:

- 4.1 General description of the research variables
- 4.2 Presentation of results
- 4.3 Discussion of findings

4.1 **General description of the research variables**

Management of staff personnel services and Universities goals attainment in Cross River State, Nigeria was study investigation. The major independent variable investigated in the study was management of staff personnel services while the dependent variable was Universities goals attainment. Meanwhile, management of staff personnel services was viewed from seven perspectives which included: staff recruitment service, staff training and development service, staff wages and salary administration service, staff orientation service, staff health service, staff motivation and welfare service, staff retirement and pension service. Universities goals attainment was viewed from three perspectives which included: knowledge acquisition, curriculum content and social development. The mean scores and standard deviations of the study variables are presented in Table 3.

TABLE 3

Descriptive statistics

Mean and standard deviation of variables in the study (N=130)

Variables	N	Min	Max	Sum	Mean	Std. Dev
Staff recruitment	130	12.00	24.00	13435.00	19.19	2.44
Staff training	130	12.00	24.00	12326.00	17.60	3.07
Staff wages	130	12.00	24.00	12332.00	17.62	3.09
Staff orientation	130	12.00	24.00	13341.00	19.05	2.58
Staff health	130	12.00	24.00	13457.00	19.22	2.42
Staff motivation	130	12.00	24.00	12706.00	18.15	2.96
Staff retirement and pension	130	12.00	24.00	12315.00	17.59	3.08
Knowledge acquisition	130	12.00	24.00	13465.00	19.23	2.42
Curriculum content	130	12.00	24.00	13351.00	19.07	2.54
Social development	130	12.00	24.00	12340.00	17.63	3.08
Overall	130	40.00	71.00	38031.00	54.33	6.82
Valid N (Listwise)	130					

Author's computation of field work at Cross River State public Universities,
Feb.2020

The finding of data analyses in Table 3 revealed that the mean score obtained from the 130 respondents as regards to management of staff recruitment service was 19.19 with a standard deviation of 2.44 while the mean score of 17.60, 17.62 and 19.05 with a standard deviation of 3.07, 3.09 and 2.58 were obtained from the respondents as regards management of training/development service, management of staff wages/salary and staff orientation service. However, the mean score of 19.22, 18.15 and 17.59 with a standard deviation of 2.42, 2.96 and 3.08 were obtained from the respondents as regards management of staff health service, management of staff motivation and welfare service and management of staff retirement and pension service. Furthermore, the mean score of 19.23, 19.07 and 17.63 with a standard deviation of 2.42, 2.54 and 3.08 were obtained from the respondents as regards Universities goals attainment in terms of knowledge acquisition, curriculum content and social development. Meanwhile, the overall goal attainment yielded 54.33 score with 6.82 for mean and standard deviation as obtained from the sampled respondents in public Universities in Cross River State.

4.2 Presentation of results

4.2.1 Hypothesis one

The first hypothesis states that management of staff recruitment service does not significantly relate with University goals attainment in terms of knowledge acquisition, curriculum content and social development. Management of staff recruitment service is the independent variable in this hypothesis while University goals attainment is the dependent variable assessed from three perspectives which are knowledge acquisition, curriculum content, social development as well as the overall goal attainment in Cross River State public Universities. The variables were measured continuously. Hypothesis was tested using P.P. M.C. statistics was applied. The result is presented in Table 4.

TABLE 4

Pearson product moment correlation analysis of the relationship between management of staff recruitment service and University goals attainment (N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of recruitment (X ₁)	130	13.6951	2.30362			
Knowledge acquisition (Y ₁)	130	12.0041	2.49162	128	.489*	.000
Curriculum content (Y ₂)	130	12.2398	2.74111	128	.403*	.000
Social development (Y ₃)	130	11.6260	3.68316	128	.289*	.000
Overall goal attainment (Y ₁ -Y ₄)	130	13.0934	3.14256	128	.311*	.000

*p<.05

The result in table 4 showed that for management of staff recruitment service and knowledge acquisition ($r = .489^*$, $p < .05$), for management of staff recruitment service and curriculum content ($r = .403^*$, $p < .05$) and for management of staff recruitment service and social development ($r = .289^*$, $p < .05$), and for management of staff recruitment service and the overall goals attainment ($r = .311^*$, $p < .05$). A cursory look at the p-values shows that $p(.000)$ is less than $p(.05)$ for the three dimensions and for the overall goals attainment. It revealed that management of staff recruitment service significantly relate with University goals attainment for the three dimensions assessed and for the overall. Hence, the null hypothesis is rejected.

4.2.2 Hypothesis two

The second hypothesis states that management of staff training and development service does not significantly relate with University goals attainment in terms of knowledge acquisition, curriculum content and social development. The independent variable in this hypothesis is management of staff training and development service while the dependent variable is public University goals attainment assessed from three perspectives which are knowledge acquisition, curriculum content and social development as well as the overall goal attainment in Cross River State public Universities. The variables were measured continuously. The result is accessible in Table 5.

The result in table 5 showed that management of staff training/development service and knowledge acquisition ($r = .411^*$, $p < .05$), for management of staff training and development service and curriculum content ($r = .373^*$, $p < .05$) and for management of staff training/development service and social development ($r = .171^*$, $p < .05$), and for management of staff training/development service and overall goal attainment ($r = .211^*$, $p < .05$). A cursory look at the p-values shows that $p(.000)$ is less than $p(.05)$ for the three dimensions as well as the overall goals attainment. This implies that management of staff training/development service

TABLE 5

Pearson product moment correlation analysis of the relationship between management of staff training and development service and University goals attainment (N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of staff training (X ₁)	130	12.1260	2.57388			
Knowledge acquisition (Y ₁)	130	12.0041	2.42162	128	.411*	.000
Curriculum content (Y ₂)	130	12.2398	2.24111	128	.373*	.000
Social development (Y ₃)	130	11.6260	2.68216	128	.171*	.000
Overall goal attainment (Y ₁ -Y ₄)	130	13.1944	2.14556	128	.211*	.004

*p<.05

significantly relate with University goals attainment in terms of knowledge acquisition, curriculum content and social development as well as the overall goals attainment for the three dimensions assessed. Hence, the null hypothesis is rejected.

4. 2. 3 Hypothesis three

The third hypothesis states that management of staff wages/salary service does not significant relate with university goals attainment in terms of knowledge acquisition, curriculum content and social development. The independent variable is management of staff wages/salary service while the dependent variable is University goals attainment assessed from three perspectives which are knowledge acquisition, curriculum content and social development as well as the overall goals attainment. The variables were measured continuously.

The result in table 6 showed that management of staff wages/salary service and knowledge acquisition ($r = .199^*$, $p < .05$), for management of staff wages/salary service and curriculum content ($r = .916^*$, $p < .05$) and for management of staff wages/salary service and social development ($r = .135^*$, $p < .05$), and for management of staff wages/salary service and overall University goals attainment ($r = .123^*$, $p < .05$). A cursory look at the p-values shows that $p(.000)$ is less than $p(.05)$ for the three dimensions assessed as well as for the overall goals attainment. The result indicated that management of staff wages/salary service significantly relate with University goals attainment for the three dimension assessed. Hence, the null hypothesis is rejected.

Hypothesis four

Management of staff orientation service does not significantly relate with University goals attainment in terms of knowledge acquisition, curriculum content and social development. The management of staff orientation service is independent variable while the dependent variable is University goals attainment assessed from three perspectives which are knowledge acquisition, curriculum content and social

TABLE 6

Pearson product moment correlation analysis of the relationship between management of staff wages/salary service and University goals attainment (N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of staff salary (X ₁)	130	12.3618	2.98076			
Knowledge acquisition (Y ₁)	130	12.0041	2.49162	128	.199*	.002
Curriculum content (Y ₂)	130	12.2398	2.74111	128	.916*	.000
Social development (Y ₃)	130	11.6260	3.68316	128	.135*	.034
Overall goal attainment (Y ₁ -Y ₄)	130	13.1944	2.14556	128	.123*	.001

*p<.05

TABLE 7

Pearson product moment correlation analysis of the relationship between management of orientation service and University goals attainment (N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of orientation (X ₁)	130	12.0407	3.01668			
Knowledge acquisition (Y ₁)	130	12.0041	2.49162	128	.393*	.000
Curriculum content (Y ₂)	130	12.2398	2.74111	128	.240*	.000
Social development (Y ₃)	130	11.6260	3.68316	128	.166*	.009
Overall goal attainment (Y ₁ -Y ₄)	130	13.1944	2.14556	128	.227*	.000

*p<.05

development as well as the overall goals attainment in public Universities in Cross River State. The variables were measured continuously. To this hypothesis, P.P.M.C. statistics was applied. The result is accessible in Table 7.

The result in table 7 showed that management of staff orientation service and knowledge acquisition ($r = .393^*$, $p < .05$), management of staff orientation service and curriculum content ($r = .240^*$, $p < .05$) and for management of staff orientation service and social development ($r = .166^*$, $p < .05$), for management of orientation service and overall goals attainment ($r = .227^*$, $p < .05$). A cursory look at the p-values shows that $p(.000)$ is less than $p(.05)$ for the three dimensions as well as for the overall goals attainment in the public Universities assessed. This implies that there is a significant relationship between management of orientation service and University goals attainment for the three dimensions assessed. Hence, the null hypothesis is rejected.

4.2.5 Hypothesis five

The fifth hypothesis states that management of staff health service does not significantly relate with university goals attainment in terms of knowledge acquisition, curriculum content and social development. The independent variable in this hypothesis is management of staff health service while the dependent variable is University goals attainment assessed from three perspectives which are knowledge acquisition, curriculum content and social development. The variables were measured continuously. To this hypothesis, Pearson Product Moment Correlation was applied. The result is presented in Table 8.

TABLE 8

Pearson product moment correlation analysis of the relationship between management of staff health service and University goals attainment (N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of staff health (X ₁)	130	14.3862	3.00225			
Knowledge acquisition (Y ₁)	130	12.0041	2.49162	128	.204*	.004
Curriculum content (Y ₂)	130	12.2398	2.74111	128	.261*	.000
Social development (Y ₃)	130	11.6260	3.68316	128	.670*	.000
Overall goal attainment (Y ₁ -Y ₄)	130	13.1944	2.14556	128	.350*	.001

*p<.05

The result in table 8 showed that management of staff health service and knowledge acquisition ($r = .204^*$, $p < .05$), for management of staff health service and curriculum content ($r = .261^*$, $p < .05$) and for management of staff health service and social development ($r = .670^*$, $p < .05$), and for management of staff health service and overall goals attainment in public Universities in Cross River State ($r = .350^*$, $p < .05$). A cursory look at the p-values shows that $p(.000)$ is less than $p(.05)$ for the three dimension as well as for the overall assessed. This implies that there is a significant relationship between management of health service and University goals attainment for the three dimensions and for the overall assessed. Hence, the null hypothesis is rejected.

4. 2. 6 Hypothesis six

The sixth hypothesis states that management of staff motivation/welfare services does not significantly relate with university goals attainment in terms of knowledge acquisition, curriculum content and social development. Management of staff motivation/welfare services is the independent variable while University goals attainment is the dependent variable assessed from three perspectives which are knowledge acquisition, curriculum content and social development. The variables were measured continuously. P.P.M.C. statistics was applied. The result is accessible in Table 9.

The result in table 9 showed that management of staff motivation/welfare services and knowledge acquisition ($r = .314^*$, $p < .05$), management of staff motivation/welfare services and curriculum content ($r = .394^*$, $p < .05$) and for management of staff motivation/welfare services and social development ($r = .178^*$, $p < .05$), and for management of staff motivation/welfare services and overall goal attainment ($r = .114^*$, $p < .05$). However, a cursory look at the p-values shows that

TABLE 9

Pearson product moment correlation analysis of the relationship between
management of staff motivation/welfare service and University goals attainment

(N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of staff health (X ₁)	130	10.9472	3.48309			
Knowledge acquisition (Y ₁)	130	12.0041	2.49162	128	.314*	.004
Curriculum content (Y ₂)	130	12.2398	2.74111	128	.394*	.000
Social development (Y ₃)	130	11.6260	3.68316	128	.178*	.010
Overall goal attainment (Y ₁ -Y ₄)	130	13.1944	2.14556	128	.114*	.000

*p<.05

$p(.000)$ is less than $p(.05)$ for the three dimension as well as for the overall assessed. This implies that management of staff motivation/welfare services significantly relate with university goals attainment assessing form three dimension.

4. 2. 7 Hypothesis seven

The seventh hypothesis states that management of staff pension/retirement service does not significantly relate with University goals attainment in terms of knowledge acquisition, curriculum content and social development. Management of staff pension/retirement service is the independent variable while University goals attainment is the dependent variable assessed from three perspectives which are knowledge acquisition, curriculum content and social development. The variables were measured continuously. Pearson Product Moment Correlation was used for hypothesis testing.

The result in table 10 account for management of staff retirement/pension service and knowledge acquisition with($r= .198^*$, $p<.05$), for management of staff retirement/pension service and curriculum content ($r=.271^*$, $p<.05$) and for management of staff retirement/pension service and social development ($r=.168^*$, $p<.05$) and for the management of staff retirement/pension service and overall goal attainment ($r=.371^*$, $p<.05$). A cursory look at the p-values shows that $p(.000)$ is less than $p(.05)$ for the three dimensions as well as for the overall perspective assessed. This implies that management of staff retirement and pension service significantly relate with University goals attainment for the three dimensions assessed. Hence, the null hypothesis is rejected.

4. 2. 8 Hypothesis eight

Management of staff personnel services does not significantly relate with University goals attainment in terms of knowledge acquisitions. The result presented in Table 11 showed a correlation matrix of the interrelationship among the sub-variables of management of staff personnel services (staff recruitment, staff

TABLE 10

Pearson product moment correlation analysis of the relationship between
management of staff retirement/pension service and University goals attainment

(N=130)

Variables	N	Mean	S.D	Df	r-cal	p-val
Management of staff health (X ₁)	130	12.3699	3.84142			
Knowledge acquisition (Y ₁)	130	12.0041	2.49162	128	.198*	.002
Curriculum content (Y ₂)	130	12.2398	2.74111	128	.271*	.000
Social development (Y ₃)	130	11.6260	3.68316	128	.168*	.008
Overall goal attainment (Y ₁ -Y ₄)	130	13.1944	2.14556	128	.371*	.001

*p<.05

training, staff wages, staff orientation, staff healthcare, staff motivation and staff pension) and a sub-variable of school goal attainment in terms of knowledge acquisition in Cross River State public Universities. P.P.M.C statistics was used for hypothesis testing.

The results obtained showed a significant relationship between staff recruitment, staff training, staff wages, staff orientation, staff healthcare, staff motivation, staff retirement/pension and Knowledge acquisition in public Universities in the study area: .642, .274, .091, .019, .398 .256 and .761 in this order.

4.2.9 Hypothesis nine

Management of staff personnel services does not significantly relate with University goals attainment in terms of curriculum content. The result presented in Table 12 showed a correlation matrix of the interrelationship among the sub-variables of management of staff personnel services (staff recruitment, staff training, staff wages, staff orientation, staff healthcare, staff motivation and staff pension) and a sub-variable of school goal attainment in terms of curriculum content Cross River State in public Universities. P.P.M.C statistics was applied. The result is accessible in Table 12.

The results obtained showed a significant relationship between staff recruitment, staff training, staff wages, staff orientation, staff healthcare, staff motivation, staff retirement/pension and curriculum content in public Universities in the study area: .366, .000 .509 .013 .076 .936 and .096 in this order.

4.2.10 Hypothesis ten

Management of staff personnel services does not significantly relate with University goals attainment in terms of social development. The result presented in Table 13 showed a correlation matrix of the interrelationship among the sub-variables of management of staff personnel services (staff recruitment, staff

training, staff wages, staff orientation, staff healthcare, staff motivation and staff pension) and a sub-variable of school goal attainment in terms of social development in Cross River State public Universities. P.P.M.C statistics was applied. The result is accessible in Table 13.

The results obtained showed a significant relationship between staff recruitment, staff training, staff wages, staff orientation, staff healthcare, staff motivation, staff pension and social development in public Universities in the study area: .366, .000, .509 .013 .076 .936 and .096 in this order.

4. 2. 11 Hypothesis eleven

Management of staff personnel services does not significantly relate to the overall goals attainment in public Universities in Cross River State. The result presented in Table 14 showed a correlation matrix of the interrelationship among the sub-variables of management of staff personnel services (staff recruitment, staff training, staff wages, staff orientation, staff healthcare, staff motivation and staff pension) and the overall goals attainment in public Universities. P,P.M.C statistics was used for hypothesis.

The results obtained showed a significant relationship between staff recruitment, staff training, staff wages, staff orientation, staff healthcare, staff motivation, staff pension and overall goals attainment in public Universities in the study area: .322, .000, .225, .002, .204, .625 and .169 in this order.

4. 2. 12 Hypothesis twelve

The twelfth hypothesis states that there is no significant composite and relative contribution of management of staff personnel services sub-variables (staff recruitment service, staff training and development service, staff wages/salary service, staff health service, staff orientation service, staff motivation and welfare

TABLE 11

Summary of a correlation matrix between the sub-scales of staff personnel services and a sub-scale of school goal attainment of public Universities in Cross River State, Nigeria.

Variables	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	Y ₁
Staff recruitment(X ₁)	1.000							
Staff training (X ₂)	.366	1.000						
Staff wages (X ₃)	.054	.509	1.000					
Staff orientation (X ₄)	.684	.013	.903	1.000				
Staff healthcare (X ₅)	.000	.076	.851	.431	1.000			
Staff motivation (X ₆)	.363	.936	.789	.603	.772	1.000		
Staff pension (X ₇)	.194	.096	.999	.170	.335	.342	1.000	
Knowledge acquisition (Y ₁)	.642	.274	.091	.019	.398	.256	.761	1.000

Source: author's computation
of field work, 2019

TABLE 12

Summary of a correlation matrix between the sub-scales of staff personnel services and a sub-scale of school goal attainment of public Universities in Cross River State, Nigeria.

Variables	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	Y ₂
Staff recruitment(X ₁)	1.000							
Staff training (X ₂)	.366	1.000						
Staff wages (X ₃)	.054	.509	1.000					
Staff orientation (X ₄)	.684	.013	.903	1.000				
Staff healthcare (X ₅)	.000	.076	.851	.431	1.000			
Staff motivation (X ₆)	.363	.936	.789	.603	.772	1.000		
Staff pension (X ₇)	.194	.096	.999	.170	.335	.342	1.000	
Curriculum content (Y ₂)	.366	.000	.509	.013	.076	.936	.096	1.000

Source: author's computation
of field work, 2019

TABLE 13

Summary of a correlation matrix between the sub-scales of staff personnel services and a sub-scale of school goal attainment of public Universities in Cross River State, Nigeria.

Variables	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	Y ₃
Staff recruitment(X ₁)	1.000							
Staff training (X ₂)	.366	1.000						
Staff wages (X ₃)	.054	.509	1.000					
Staff orientation (X ₄)	.684	.013	.903	1.000				
Staff healthcare (X ₅)	.000	.076	.851	.431	1.000			
Staff motivation (X ₆)	.363	.936	.789	.603	.772	1.000		
Staff pension (X ₇)	.194	.096	.999	.170	.335	.342	1.000	
Social development (Y ₃)	.366	.000	.509	.013	.076	.936	.096	1.000

Source: author's computation of field work, 2019

TABLE 14

A Summary of a correlation matrix between the sub-scales of staff personnel services and the overall sub-scales of goals attainment in public Universities in Cross River State, Nigeria.

Variables	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	Y ₁₋₄
Staff recruitment(X ₁)	1.000							
Staff training (X ₂)	.366	1.000						
Staff wages (X ₃)	.054	.509	1.000					
Staff orientation (X ₄)	.684	.013	.903	1.000				
Staff healthcare (X ₅)	.000	.076	.851	.431	1.000			
Staff motivation (X ₆)	.363	.936	.789	.603	.772	1.000		
Staff pension (X ₇)	.194	.096	.999	.170	.335	.342	1.000	
Overall goals (Y ₁₋₄)	.322	.000	.225	.002	.204	.625	.169	1.000

Source: author's computation of field work, 2019

TABLE 15

Multiple regression test analysis of seven sub-variables of staff personnel service management as predictors of University goals attainment in terms of knowledge acquisition, curriculum content and social development

	SS	Df	MS	F-ratio	p-level
Regression	13650.043	7	1706.255	62.215	.000 ^b
Residual	18950.727	122	27.425		
Total	32600.770	129			

*Significant $p < 0.05$; $R = .647^a$; $R^2 = .419$; Adjusted $R^2 = .412$

service and staff retirement/pension service) to the prediction of university goals attainment. Management of staff personnel service is the independent variable while University goals attainment is the dependent variable. Multiple linear regression statistical technique was used for hypothesis testing. The result is obtainable in Table 15.

a. Dependent variable: University goals attainment

b. Predictors: (Constant), Staff recruitment service, staff training/development service, staff wages/salary service, staff orientation service, staff health service, staff motivation/welfare service and staff pension/retirement service.

The result indicated that the One-Way Analysis of Variance in multiple regressions produced a moderate percentage of ($t=1.96$, $p>.005$). By this result, the hypothesis is rejected since $p(.000^b)$ is greater than $p(.05)$. This indicates that when the sub-variables of management of staff personnel services are taken together, they significantly predicted the target group of University goals attainment.

The result also showed that a coefficient of multiple regression (R) of $.647^a$ was obtained as well as a multiple regression square (R^2) of $.419$. This coefficient (R^2) showed that the sub-variables of staff personnel service management when merged together, contributed to 41.9 percent of the variation in the sub-variables of University goals attainment. These sub-variables include knowledge acquisition, curriculum content and social development. This coefficient suggests also that 58.1 percent of the variation in University goals attainment could be explained by extraneous variables, that is, variables other than the sub-variables of management of staff personnel services used during the period of this research in Cross River State public Universities.

Meanwhile, contributing relative of management of staff personnel services sub-variables, a test of multiple regressions was performed. The outcome was presented in Table 12. In descending order, the results showed that staff personnel service management in terms of staff training/development service ($\beta=.632$, $p<.05$)

is the strongest predictor, followed by staff health service ($\beta=.306$, $p<.05$), staff recruitment service ($\beta=.027$, $p<.05$), staff motivation/welfare service ($\beta=-.063$, $p<.05$) and staff orientation service ($\beta=-.031$, $p<.05$), in that order ($X_2>X_5>X_1>X_6>X_4$). However, management of staff personnel services with respect to staff wages/pension service ($\beta=-.018$, $p>.05$) and staff pension/retirement service ($\beta=-.006$, $p>.05$) in the order of ($X_3>X_7$) were not significant predictors of goals attainment of public Universities in the context of this study.

4.3 Discussion of findings

4.3.1 Management of staff recruitment service and University goals attainment.

The finding on this hypothesis revealed that management of staff recruitment service significantly relate with University goals attainment in terms of knowledge acquisition, curriculum content, social development and overall goals attainment of public Universities. The finding implication indicated that the higher the level of management of staff recruitment services, the higher the goals attainment of public Universities can be ensured while the level lower of management of staff recruitment services, the lower the goals attainment of public Universities in terms of knowledge acquisition, curriculum content, social development and overall public Universities goals attainment.

The finding of this study is in line with the finding of Adu-Darko (2014) who found that effective recruitment and selection of workers is challenges with a number of barriers hindering worker such as ineffective job analysis, poor human resource (HR) planning, cost of recruitment and selection of employees, incompetency level on the part of employee and inability to present work description to reflect the genuine requirements of the work before recruitment and selection of employees.

TABLE 16

Test of regression weights of staff personnel service management sub-variables

Models	B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	p-level
(Constant)	30.87	3.396		9.091	.000
X ₁ Staff recruitment	.075	.089	.027	.842	.010
X ₂ Staff training	1.406	.066	.632	21.237	.000
X ₃ Staff wages	-.041	.065	-.018	-.629	.529
X ₄ Staff orientation	-.082	.078	-.031	-1.053	.093
X ₅ Staff health	.864	.659	.306	1.311	.090
X ₆ Staff motivation	-.144	.067	-.063	-2.146	.032
X ₇ Staff pension	-.013	.066	-.006	-.201	.841

a: Dependent variable:

Goals attainment

The finding of this study is also in consonant with that of Bernard and Okofu (2014) whose results indicated that employment of staff in Nigeria civil service was based on religion and altar of ethnicity. The result also showed often sidelined on employment of worker into the civil service.

The finding of this study equally corroborates the finding of Michalis and Dimitros (2015), Ibrahim (2014), Ekwoaba, Ikeije and Ufoma (2015) and Bagatova (2017) who found constant political interference in the management of staff recruitment. They further found that recruitment was not done on the principle of Federal character, skills rather than good attitude which compounded the ethnic balancing problem.

The findings of this study also tally with the position of Ikwesi (2010), Onwe, Nwaba and Nwoku (2013) and Briggs (2017) who found selection and recruitment procedures in public service in Nigeria are highly politicized, qualification standard in gaining employment in civil service and the use of federal principle character, indigeneship, quota system, son of soil syndrome, etc. are mostly accepted; weak recruitment and selection processes has a significant relationship between Nigerian public service inefficiency. To ensure meritocracy in staff recruitment and selection in the public service in Nigeria the study recommended introduction of more strict measures in staff recruitment based on the above findings.

The brain behind this finding is that management of employment and selection exercise in public Universities are not credibly handled by experts to enhance the implementation of knowledge acquisition, curriculum content and social development in the institutions. Hence, experts in human resource management should be involved in the employment committee of the University. The implication of this is that the committee will lack political interference in its

operations and will discharge its responsibilities efficiently and objectively without favour and fear to ensure efficient management of recruitment and selection exercise for Universities goals attainment.

4.3.2 Training/development service management and University goals attainment.

The finding on this management of staff training/development service hypothesis indicated significant relationship with universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities. This finding implies that the higher the level of staff training/development services management, the higher the goals attainment of the Universities could be enhanced and vice versa in terms of knowledge acquisition, curriculum content, social development and overall Universities goals attainment.

The finding of this study is in support of the position of Mohd, Jamil, Azhn, Rahayu, Kamisah and Norlizah (2016) which revealed that the School-Based Assessment programme for teacher training should be continued with strategic planning to enable teachers meet up with their professional challenges in the school. It also corroborates the finding of Udida, Okpa and Wonah (2015) who found a significant positive relationship between workshop attendance, knowledge acquisition and teachers' effectiveness in the study area.

The finding of this study is in consonant with the finding of Uysal(2012) and Eze (2016) whose analysis revealed that enhancement of teachers' productivity is based on training and retraining to a great extent. It also indicated (4.02) for male and (3.32) for female differed perception of male on training and retraining impact on teachers' productivity. They also found that attitude of teachers' towards the training programme was positive in general.

The findings of this study equally tally with that of Shelton (2011), Ogunrin (2011), Lockhart and Majal (2012), Allison (2013), Tahir (2014) and Craig (2017) whose findings revealed that the collaboration and partnerships amongst the librarians was the function of training opportunities and interventions. Findings further showed that professional programmes development were appropriately supported and structured to sustain teaching and learning and improvement of institutional goals.

The finding also is in consonant with that of Aduwa-Ogiegban (2013) and Zakia, Muhammad, Maqsud, and Muhammad (2014) who concluded found differences significant in-service teachers with higher scored than their preservice counterparts. The study showed that employee retention, job satisfaction and effectiveness was highly correlated with employee in-service development programmes, followed by skills improvement, attitude formation/ development, resources management, in that other.

The philosophy behind this finding is that staff development and training and is the process of designing and implementing different varieties of planned educational activities meant to knowledge modify or transfer, attitudes and skills through experiences. They are designed to enable the staff to favourably meet up with changing circumstances and demand to new pedagogical methods and technologies in the University system for goals attainment.

4.3.3 Management of staff wages/salary service and University goals attainment

The finding on this hypothesis revealed that management of staff wages/salary service significantly relate with Universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities. This finding implies that the higher the level of management of staff wages and salary services, the higher the goals

attainment of the Universities could be ensured and vice versa in terms of knowledge acquisition, curriculum content, social development and overall Universities goals attainment.

The finding of this study is in tandem with the finding of Okwudili and Enyioko (2015) and Tinuke (2019) whose results showed pay disparity among faculty workers in public and private universities. This implies that faculty staff enjoy job security, working conditions, bendable working time, less supervision, freedom of association, fewer workloads, and understandable communication line, pay package and promotion prospects in the two universities are significantly differ. Stoppage in disbursement in salary differences among worker was recommends enabling them satisfied with their work; steady upgrading of working conditions and enhancement of career advancement was recommended. Reviewed of worker salary and regular career advancement policies should be encouraged to avoid worker remained permanent in their carer.

The finding of this study similarly tally with the position of Edirisooriya (2014), Abdullahi and Babagana (2015), Akinfolarin (2015), which results revealed that payment for innovation and creativity, award with impressive titles, appreciation on genuine effort and acknowledgement boost university lecturers' productivity. Also, lack of provision of regular payment of salary and other remuneration by the head to promote the performance 60% of the respondents agreed to it. The study recommended adequate provision of chances for research development and professional growth, prompt payment of lecturers' salaries, academic staff working relationship and, availability of Institutional facilities, further advance their performance among others by Universities managers and other tertiary institution.

The finding of this study also in corroborate with the finding of Sajuyigbe, Olaoye and Adeyemi (2013) and Hameed, Ramzan, Zubair, Ali and Arslan (2014) which result showed that employee performance significantly relate with compensation. Also as revealed by regression analysis, the finding revealed that jointly prediction of dimensions of reward on employees' performance.

The thinking behind this contradiction in the study finding is that the studies of these researchers were conducted in locations other than the research geographical. Also, the effects of corruption and inability of the University management to pay lecturers adequate wages/salary, allowances and monetary incentives as at when due must could make the respondents to think that management of staff wages/salary services negatively promote University's goals attainment in the sampled institutions.

4.3.4 Management of staff orientation service and University goals attainment

The finding on this hypothesis revealed that management of staff orientation service significantly relate with Universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities. The implication of this finding is that the more the University ensures effective management of staff orientation services, the higher the goals attainment of the Universities could be ensured and vice versa in terms of knowledge acquisition, curriculum content, social development and overall Universities goals attainment.

The study result is consistent with the result of Ogbiji, Eyo and Okoh (2011), Amadi and Anaemeotu (2013) and Oluremi (2017) who found that teachers were satisfied with the implementation of their orientation programme. The study analysis indicated that teachers professional development refocused school system status quo of the school system which can maintained moderate academic

benchmark; in-service training fully integrates teachers' talents and potentiality towards realizing the objectives and goals of the school system; workshops/conferences/seminars provide the medium for sharing assumptions, values, beliefs as well as engendering inter institutional resources and exchanging scholarly ideas.

The finding of this study is equally in consistent with the positions of Amadi (2013), Macheng (2016) and Sadiqa (2016) whose results indicated that professional development of teachers in terms of orientation. It was also found that orientation services fully integrate potentiality and teachers' talents towards realizing the objectives and goals of the school system. The finding of the study revealed also that teachers' performance was positively impacted through well-organised induction/orientation services.

The finding of the study also corroborates the finding of Salau, Falola and Akinbode (2014) which indicates that employee mind-set and conduct towards organizational effectiveness is been influence by their induction. It implies that well organized induction programme will significantly influence employee behaviour. Time to time reviewed of induction programmes may help bring about staff loyalty and significant behaviour towards job performance were part of the study recommendation.

The reason behind this finding is that providing orientation service for staff makes them to develop positive habit toward their job and this can lead to knowledge acquisition, effective implementation of curriculum content and social development of the University. This will make the staff to be more enthusiasm and happy to carried out their task having familiarized with the environment of the University.

4.4.5 Management of staff health service and University goals attainment

The finding on this hypothesis revealed that management of staff health service significantly relate with Universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities. The implication of this finding is that the more the University ensures effective management of staff health services, the higher the goals attainment of the Universities could be ensured and vice versa in terms of knowledge acquisition, curriculum content, social development and overall Universities goals attainment.

The study result is consistent with Aremo and Ibukun (2017) which revealed that employees and students were more overall proportion insured than the uninsured. The school medical center usage was observed were staffs 47.6% while student account for 53.5% account for students. Also, the usage of the university's healthcare center or hospital was observed to be higher (43.9%) than any other healthcare facility, although more than half of the participants (57.8%) that chose this provider are female.

The finding is also in line with the position of Kamau, Osuga, and Njuguna (2017) which revealed a high significant relationship between healthcare support services with coefficient 4.457; positive coefficient of 4.104 for infrastructure, capacity of health care workers, with significant coefficient of 4.013 for staff health care ability, coefficient of 4.105 for financial resources and health data system. The study concluded that ability of medical staff, infrastructure, financial resources health information systems and are challenges in implementation of health care referral system.

The finding is equally in tandem with the finding of Embu (2012) and Anetoh, Jibuaku, Nduka and Uzodinma (2017), Abdullah (2017), Obiechina and

Ekenedo (2013) Adeyemo, Ohaeri, Patrich and Ogodo (2016) and Umeano-Enemuoh, Onwujekwe, and Ekwuluo, Eluwa, Okereke, and Orji (2018) who found that in general, awareness of students level of school health insurance programmes was high. They also rated worker satisfaction level and quality of services provided; the participants completed a 5 point Likert scale self-administered questionnaire. They also rated important factors where best services were offered. Mean score = 3.75 were recorded for moderately contented with the services offered. Mean score = 3.45 revealed also good quality health facility for all the variables. Mean rating of 4.1 showed highest level satisfaction for Pharmacy. Findings revealed that worker are quite satisfied with the services provided as well as the quality of care by the different service providers of the health facility.

The philosophy behind this finding is that health services of school involves a health system that is well-coordinated to ensures a continuum of care from community health care provider for school goals attainment. It creates a positive school climate that fosters knowledge acquisition, increases enrolment and provides reimbursable health services in schools.

4.4.6 Management of staff motivation/welfare service and University goals attainment

The finding on this hypothesis revealed that management of staff motivation/welfare service significantly relate with Universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities. The implication of this finding is that the more the University ensures effective management of staff motivation and welfare services, the higher the goals attainment of the Universities could be ensured and vice versa in terms of knowledge acquisition, curriculum content, social development and overall Universities goals attainment.

The study result is in agreement with the result of Mohammed (2011), Ajayi (2015), Nabi (2017) and Akhtar and Iqbal (2017) whose results showed that achievement of organizational goals is purely associated with employees' positive motivation. They also found that employee motivation to work better has positive effect on quality of supervision. Also, greater impact on performance and organizational productivity depend on financial motivations which involve monetary rewards. The research further showed that teachers' motivation significantly impact job performance.

The finding also credited the finding of Shellnutt (2013), Omollo (2015) and Horodnic and Zaic (2015) and Boniface, Alfred and Tuyisime (2019) whose research showed positive correlation between knowledge acquisition, research productivity and intrinsic motivation, while negative correlate was recorded for extrinsic motivation. The implication of results is that exercise that will bring monetary benefit in an economy undergoing change with productive researchers and strong interest will extrinsically motivated worker.

The finding also tally with the finding of Kuchava and Buchashvili (2016), Yawe (2010), Mukasa (2013), Toyin (2018) and Ajalie (2017) who found that lack of employees' incentive such as regular promotion, financial reward, recognition etc will bring a challenges' of inefficiency in the school system. Motivating library personnel for effective job performance was discovered as prime importance in the university. Also, the result revealed that extrinsic factors and employee motivation with rating score of 35.8% relate with organizational productivity. The conclusion of the study showed significant predictors between intrinsic and extrinsic factors and productivity. That appropriate measures should be taking by management of organizations to provide worker incentive to improve their output were part of the study recommendation.

The brain behind the contradiction in this finding could be as a result of the fact that these researchers conducted their studies in places other than a researcher area of study. Meanwhile, the present study is carried out using all the departmental academic Heads of in all the Cross River State public own Universities.

4.4.7 Management of staff retirement/pension service and University goals attainment

The finding on this hypothesis revealed that management of staff retirement and pension service is significantly relate with Universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities. The implication of this finding is that the more the University ensures effective management of staff retirement/pension services, the higher the goals attainment of the Universities could be ensured and vice versa in terms of knowledge acquisition, curriculum content, social development and overall Universities goals attainment.

The study result tandem with Ahmed, Abayomi and Nureni (2016) the finding of the analyses indicated that adequate retirement package has significant relationship with employees' productivity. Also found positive potentials over the Contributory Pension Scheme (CPS) and benefits pension scheme (DBPS) as revealed in the study.

The finding also credited the finding of Nweke (2015) who found that monthly pensions of retirees, educational qualifications of retirees, poor planning for retirement, welfare of retirees, postponement in the payment of retirement benefits, embezzlement of pension funds, interfering delays and governments' reluctance to review pensions relate with their welfare provisions.

The finding is also in consonant with the position of Chris (2015) who found positive on contributory pension Scheme and the development of the Nigeria

Capital market. The study also found out that contributory pension expenditure relate with the GDP (gross domestic product) in Nigeria. Furthermore, result showed important proof of better risk management and savings strategies in existence to ensure sustainability of the contributory pension scheme in Nigeria.

The finding likewise upheld the finding of Ahmed and Oyadiran (2013), Edogbanya (2013) and Ameh, Ajie and Nuhu (2017) whose results indicated that pension contribution, savings mobilized over the years and pension fund assets impact on economic growth positively. It also indicated positive significant impact on pension fund management and Contributory Pension Scheme (CPS). Pension management should place more emphasis on genuine area and saving trust to increase Gross Domestic Product (GDP) of the country (Nigeria), product in the resources market as well as government bond, were part of the study recommendation.

4.4.8 The composite and relative contribution of management of personnel services to the prediction of University goals attainment

The finding on this hypothesis revealed that the seven dimensions of personnel service management sub-variables (staff recruitment service, staff training and development service, staff wages/salary service, staff orientation service, staff health service, staff motivation/welfare service and staff retirement/ pension service) are significant joint predictors of University goals attainment in Cross River State of Nigeria. Therefore, any possible changes in the predictor variable would likely effect obvious changes in the response variable. An observed p-value ($p > 0.05$) designates in this finding implies not acceptance of the null hypothesis while the opposite side of hypothesis would be upheld if ($*p < 0.05$) in the course of the analysis.

The variable indicated that composite and relative contribution of management personnel service sub-variables has no significant prediction of University goals attainment. The eight hypothesis result finding indicates that when all the sub-variables of staff personnel services were taken together using multiple regression statistics, they significantly contributed to explaining the goals attainment of public Universities in Cross River State. This result is expected from the analysis because of the critical roles that staff personnel service management plays in promoting the University goals attainment.

The result of the relative contributions of staff personnel service management sub-variables indicates that the seven sub-variables considered in this study were all strongly significant in explaining the goal attainment of public Universities in Cross River State. These sub-variables in their relative order of importance are: staff training and development service, staff recruitment service, staff motivation/welfare, staff health service and staff orientation service.

Therefore, the findings corroborate with that of Udida, Okpa and Wonah (2015) and Eze (2016) whose results revealed a significant positive relationship between workshop attendance and teachers' effectiveness in the study area. The analysis finding revealed that enhancement productivity is based on teachers' training and retraining and knowledge acquisition.

The finding also espouses that of Nabi (2017) whose results indicated that achievement of organizational goals is purely associated with employees' positive motivation. They also found that employee motivation to work better has positive effect on quality of supervision. However, the finding equally upholds that of Umeano-Enemuoh, Onwujekwe, Uzochukwu and Ezeoke (2014) who found that the staff and learners in school revealed maximum height in school health insurance programmes awareness. Mean rating of 4.1 showed highest level satisfaction for

Pharmacy. Findings revealed that workers are moderately contented with the provision of quality health facility. It also corroborates with that of Ogbiji, Eyo and Okoh (2011), Amadi and Anaemeotu (2013) and Oluremi (2017) who found that teachers were satisfied with the implementation of their orientation programme. The study analysis indicated that teachers' professional development refocused school system status quo of the school system which can maintain moderate academic benchmark; in-service training fully integrates teachers' talents and potentiality towards realizing the objectives and goals of the school system; workshops/conferences/seminars provide the medium for sharing assumptions, values, beliefs as well as engendering inter-institutional resources and exchanging scholarly ideas.

Hence, it is unequivocal to logically state at this juncture that those institutional administrators in Cross River State public universities could improve the goals attainment of their Universities in terms of knowledge acquisition, curriculum content and social development by means of consistent staff training and development, employing merits in staff recruitment, providing staff motivation, enhancing staff health support services and providing staff orientation services for the benefits of lecturers, students and the host community where the school is situated.

In other words, the seven sub-variables of personnel service management sub-variables significantly contribute to explaining University goals attainment, going by the outcome of this study in Cross River State in public Universities. The predictor variable of pension/retirement benefits service was significant at p-values: .841 respectively which is greater than the alpha level of .05. Statistically, this shows a significant contribution to knowledge acquisition, curriculum content, social development and the overall Universities' goals attainment in the sampled schools.

This finding concerning wages and salary service is significant because the needs of employees pay plans are considered in order to meet their aim. These include motivating and retaining employees, desires for self-esteem and security; attracting, achieving desired performance and competing with similar organizations. That is why salaries and wages cost labour control, builds employee loyalty and, grievances, absenteeism, complaints and commitment, reduce turnover, and to increase job satisfaction. Therefore if wages and salaries of academic staff are effectively managed in Cross River State in public Universities, it would yield significant results in the study because wages/salary service contributes to the accomplishment of any institute. It motivates staff to put in more effort in their services in the organisation and this in turn reflects positively on the efficiency and goals attainment of the organization especially when it is given as fringe benefits, indirect compensation or supplementary pay.

With regards to retirement and pension service, the findings agreed with the findings of Ahmed and Oyadiran (2013), Edogbanya (2013) and Ameh, Ajie and Nuhu (2017) whose results indicated that that pension contribution, savings mobilized over the years and pension fund assets impact on economic growth positively. It also indicated positive significant impact on pension fund management and Contributory Pension Scheme (CPS). Pension management should place more emphasis on genuine area and saving trust to increase Gross Domestic Product (GDP) of the country (Nigeria).

A pragmatic explanation to this finding could be that prolonged corrupt practices have been part of management of retirement and pension services in Cross River State public Universities. Aspects of corrupt retirement and pension retirement management which might have hampered University goals attainment in terms of knowledge acquisition, curriculum content and social development could be outright corruption; poor supervision, poor pension fund administration,; inadequate build-up of funds and embezzlement of pension fund .

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter of the study is concerned with the summary, conclusion and recommendations. The chapter is therefore presented under the following sub-headings.

- 5.1 Summary of the study
- 5.2 Conclusion
- 5.3 Recommendations
- 5.1 Suggestions for further research

5.1 Summary of the study

The study was aimed at examines management of personnel services and universities goals attainment in Cross River State, Nigeria. To achieve the objectives of the study, eight null hypotheses were formulated in the null form.

They include:

1. Management of staff recruitment service does not significantly relate with university goals attainment (in terms of knowledge acquisition, curriculum content and social development).
2. Management of staff training and development service does not significantly relate with university goals attainment.
3. Management of staff wages and salary administration does not significantly university goals attainment.
4. Management of staff orientation services does not significantly relate with university goals attainment.
5. Management of staff health services does not significantly relate with university goals attainment.

6. Management of staff motivation/welfare services does not significantly relate with university goals attainment.
7. Management of staff retirement and pension service does not significantly relate with university goals attainment.
8. The joint and relative effect of management of staff personnel services does not significantly relate with university goals attainment.

Sub variables related to study was reviewed. The study adopted Correlational research design. One hundred and forty one (141) sampled heads of department in cross river state public Universities were used. Census technique was used in sample selection. The questionnaire titled: Management of Personnel Services and University Goals Attainment Questionnaire (MPSUGAQ) was used data collection. Content and validity face of the research instrument was examined by three experts in University of Calabar, department of educational management, administration of higher education unit and department of educational foundations, measurements and evaluation unit. P.P.M.C analysis(r) and multiple regression statistics were used for data analysis at .05 level of significance. The results of the analysis revealed that management of staff recruitment service, staff training and development service, staff wages and salary administration, staff orientation service, staff health service and staff motivation and welfare service and staff retirement and pension service significantly relate with universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall attainment of goals in Cross River State public Universities, Nigeria.

5.2 Conclusion

The study concluded based on the findings that staff recruitment service, staff training and development service, staff wages and salary administration, staff orientation service, staff health service, staff motivation and welfare service and staff retirement/pension service significantly relate with universities goals attainment in terms of knowledge acquisition, curriculum content, social development and the overall goals attainment of the public Universities.

5.2 Recommendations

1. The university management should follow recruitment criteria while employing new staff in order to increase productivity as well as achievement of university goals.
2. The university management should give staff training and development opportunities to develop their staff in order to achieve university goals and staff career development.
3. The university management should avoid unnecessary deduction on staff salary and this encourage productivity among staff.
4. The university management should always make provision for orientation services for newly recruited staff.
5. Management of the university should intensify effort toward improvement of university health care services.
6. The university management should make adequate provision for staff motivation/welfare services that will boost their productivity.
7. Management of the university should encourage proper management of pension scheme for staff.

5.3 Suggestions for further research

A different method of collection of information and testing of hypotheses should be used in a subsequent study for comparison.

1. Further studies should be replicated on variables and this topic in others tertiary institution in different state for comparison.
2. Other variables not incorporated in this study should be included and addressed in the subsequent research.

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QUESTIONNAIRE

Management of Personnel Services and University Goals Attainment

Questionnaire (MPSUGAQ)

Department of Educational
Management
Faculty of Education,
University of Calabar,
Calabar.

Dear Respondent,

I am a post graduate student of the above named department. I am conducting a research on "Management of personnel services and University goals attainment in Cross River State, Nigeria. I wish to solicit for your kind assistance to respond to the attached questionnaire.

Your responses are strictly for research purpose and shall be treated confidentially. Your co-operation and assistance in this direction will be highly appreciated.

Thank you.

Yours faithfully,

Researcher

SECTION A:

Respondent demographic data.

Instruction: Please tick (√) on the column that best demonstrate your feeling.

1. Name of the institution:
2. Sex male: () Female: ()
3. Department/Faculty.....

SECTION B

Instruction: For each of the following questions tick (√) on the option that best describes your option on this subject using the following keys :

Strongly agree _____ SA

Agreed _____ A

Disagreed _____ D

Strongly disagreed _____ SD

S/N	ITEMS	SA	A	D	SD
	Management of staff recruitment service				
1	My institution always follow recruitment criteria's				
2	Recruitment in my institution is been conducted through interview				
3	Newly employed staff are properly been selected in my institution				
4	Recruitment in my institution is based on replacement				
5	New staff are not been recruited through advertisement in my institution				
6	My institution advertised before recruiting staff				
	Management of staff training and development service				
7	Staff in my institution are given opportunity to develop their career				
8	In my institution, staff are involve in in-service training				
9	My institution always encourage staff to attend their annual conferences				
10	Workshop and seminar are always organized for staff in my institution.				
11	University management did not encourage staff training and development in my institution.				
12	Assessment of staff development opportunity is always difficult in my institution				
	Management of staff wages and salary administration				
13	Staff in my institution earn better wages/salary				
14	Staff wages are regularly pay in my institution				
15	There is always delay in payment of staff wages/salary and other allowance in my institution				
16	There is different deduction in staff salary in my institution				
17	University management always discourage unnecessary deduction on staff salary in my institution				

18	There is adequate management of staff wages/salary by bursary department in my university.				
	Management of staff orientation service				
19	University management always provide orientation services for staff in my institution				
20	In my institution, orientation service is done yearly for newly recruited staff				
21	My institution have resource persons who speak to staff as they are employed				
22	My university does not have resource person who can talk to staff after their recruitments.				
23	In my university, newly recruited staff roams about without job specification				
24	Staff orientation service is been handle by various heads of department in my institution				
	Management of staff health services				
25	My institution have health service for staff				
26	Staff in my university have quick health service when sick				
27	My university have sufficient doctor that always attend to staff health challenges				
28	Staff in my institution always complaint of poor health care services.				
29	University management always encourages staff to attend to their health issue.				
30	In my institution we have a first aids box and with a trained personnel to handle staff emergency health issue.				
	Management of staff motivation and welfare service				
31	My university pay staff allowances regularly				
32	Staff due for promotion always get promoted in my institution				
33	There is prompt payment of staff salary in my institution				
34	Staff condition of services is always make easy in my university				
35	University management is fun of owing staff their wages/allowances in my institution.				
36	Staff condition of service for promotion is always difficult in my university				
	Management of staff retirement and pension service				
37	My university have good pension scheme for staff				
38	Staff in my university have access to monitor their retirement benefit				
39	Pension unit in my university always provide adequate service for their beneficiary				
40	Retirement staff in my institution always find it very difficult to get their benefit				
41	Staff retirement benefit services in my institution is very poor				
42	In my university, retirees staff spent two to three year before				

	getting their contributing benefit				
	knowledge acquisition				
43	Students in my university are highly trained				
44	Students graduating from my university can contribute to national development				
45	Graduates from my university acquire both physical and intellectual skills				
46	Students' graduating from my university are self-reliant				
47	Graduate from my university are not regarded as useful members of the society				
48	In my university, graduate are not self-reliant				
	Curriculum content				
49	Courses offered by students in my university can contribute to the development of economy				
50	Students in my university learned compulsory entrepreneurship courses				
51	In my university, courses offered by students cannot contribute to economy development				
52	Courses offered by student in my university certified them with good character and learning after graduation				
53	In my university, courses offered by students covered both practical and theoretical				
54	Courses offered by students in my university cannot inculcate proper values for their survival in the society				
	Social development				
55	Knowledge acquired by students in my university will enable them contribute to social development				
56	Students in my university cannot contribute to social development despite the acquired knowledge in school				
57	In my university, students can contribute toward national unity				
58	Students in my university are given opportunity through scholarship to compete globally				
59	Students in my university can also contribute in community service				
60	The university management did not encourage student scholarship participation.				



DECLARATION

I, Ejabu, Fidelis Enya with Registration Number ACC/Ph.D/17/008, hereby declare that this dissertation on “Thin capitalization and tax burden of transnational companies” is original, and has been written by me. It is a record of my research work and has not been presented before in any previous publication.

Ejabu, Fidelis Enya.
(Student)



Signature

10-12-2021
Date

CERTIFICATION

We certify that this dissertation entitled “Thin capitalization and tax burden of transnational companies” is an original work written by Ejabu, Fidelis Enya (Reg. No. ACC/Ph.D/17/008) has been examined and found to have met the regulations of the University of Calabar, Calabar. We therefore recommend the work for the award of Doctor of Philosophy (Ph.D) Degree in Accounting.

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Ejabu, Fidelis Enya.

2021.

ABSTRACT

This study examined thin capitalization and tax burden of transnational companies. Specific objectives of the study were to examine whether bank loans, lease transaction, debentures loans and bond affect tax burden of transnational companies in Nigeria. The ex-post facto research design was adopted in the study with secondary data collected from published annual financial statements of twenty nine (29) transnational companies in Nigeria. The data obtained were analysed using descriptive statistics and panel least squares regression technique with the aid of estimated techniques including unit root and cointegration tests and cross section dependence test. It was found that thin capitalization helped companies reduce tax burdens by having a larger debt financing structure where interest on debts are non-taxed. The study also showed specifically that loans and debentures had significant positive impact on tax burdens of transnational companies, indicating that these debt structures increase the tax burdens of the companies. The study further found that lease financing and corporate bonds have significant negative effects on tax burden of transnational companies in Nigeria, suggesting that lease financing and corporate bonds are important tax shielding mechanisms for transnational companies in Nigeria. The study concluded that transnational companies in Nigeria tend to engage in thin capitalization in order to reduce tax burdens. The study recommended that; transnational companies should be efficient in the use of non-loan debt instruments such as bond and lease financing so as to enable the reduction of tax burden, that thin capitalization rules should be intensified by the fiscal authority in Nigeria in other to discourage financing shifting towards more debt and debt shifting by transnational companies in Nigeria and that tax administrator should simplify tax rules and burden associated to tax rate so as to clarify issues of legal tax base and exemption packages (**Word count: 296**).

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LIST OF ABBREVIATIONS/ACRONYMNS

METR	Marginal effective tax rate
ETR	Effective tax rate
CFC's	Controlled foreign corporation
OECD	Organization for economic cooperation and development
UNO	United Nation Organization
EU	European Union
MNE	Multi-national Enterprise
TNCs	Transnational companies
NDIC	Nigeria Deposit Insurance Corporation
NPL	Non-performing loan
LTD	Long term debt
STD	Short term debt
VAT	Value Added Tax
NSE	Nigeria Stock Exchange
EBIT	Earnings before interest and tax
IFRS	International Financial Reporting Standard
ASE	Amman Stock Exchange
BAML	Bank of America Merrill Lynch

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The performance of a company generally is mirrored by profitability and shareholders wealth maximization in spite of surrounding corporate challenges. In capital decision making, managers are concerned with the best form of capital that reduces company tax liability and enable increase in shareholders wealth maximization regardless of government policies. Irrespective of several government tax policies that intend to restrict economic transactions of company, tax still constitutes a potentially important consideration in investment policy formulation of transnational companies. Modigliani and Miller, (1958) observed that, growing financial leverage have the potential to assist companies to increase her worth through benefit and protection arising from tax exempted income. This is because companies financed by debt capital are entitled to tax relief on interest paid on any form of debt capital available to them. Debt capital could come from related party transaction often referred to as internal debt, external debt from institutional investors and individuals who may want to invest excess capital to earn interest from a progressive enterprise. Debt categorization does not matter to transnational company, but what is important to them is tax relief they will enjoy when debt instrument is use in their financial composition. The reason is that, tax relief from interest payment has a considerable impact to adequately enhance after tax profit of companies and provide an opportunity for them to invest super profit resulting from tax savings in other profitable ventures thereby expanding their business frontier.

Given the flexibility of tax policy across the globe, major factor which transnational company consider potential to enhance their corporate performance is economic benefit of taxation that will provide value for stakeholders. Hence, the strategy of thin financing

operations with debt instrument against equity become imperative. As a finance strategy, thin capitalization is a product of creativity from specialists in law, accounting, banking and other financial areas engaged by corporate entity for the purpose of reducing tax burden. Therefore, a thinly capitalized organization is that which finance its operation with high debt against equity, for the purpose of gaining tax advantage. Thin capitalization constitute the surest approach to finance investment portfolio abroad due largely to international tax differential with the overall objective of reducing tax returns in the subsidiary's tax jurisdiction, exception of countries with zero tax rate. Taylor and Richardson (2012) observed that unnecessary use of debt instrument in the form of thinly capitalized arrangements by subsidiary companies situated in higher tax authorities have some element of an essential global corporate tax avoidance practise by transnational companies. Tax avoidance debt instruments are bank loans, debenture loans, bonds and lease transaction. These debt instrument have explicit and implicit interest components that reduce tax burden of companies and enhance performance. Debt instruments are consider more lucrative to financial institutions and cheap sources of capital to non-financial institutions such as manufacturing and extracting companies, due to subsisting interest deductibility during tax computation. Tax payers usually seen tax as a burden because it reduces profits, deplete capital that would have been used for business expansion and reduce the amount of earnings available to equity holders. Therefore, the available opportunities surrounding interest deductibility on debt capital within the confine of countries tax legislation enable companies to maximise shareholders wealth and further encourage the choice of thin capitalization scheme amongst transnational companies. The perceived benefits of thin capitalization form the thrust of this study.

1.2 Statement of the Problem.

Companies in Nigeria such as MTN and few others have been experiencing turbulent times with regard to high tax rate and other governance issues that resulted to high tax imposition in most recent period. Given the situation surrounding company's corporate existence in the face of frequent economic turbulence, there is a deep concern to resuscitate stakeholder's investment by taking appropriate decisions on matters relating to capital composition and financing policy in consideration of enabling tax legislations as regards the use of high debt against equity. Irrespective of the economic benefit of taxation on thinly capitalise operations, companies are yet to employ the opportunities surrounding the use of available debt instrument because of countries specific restriction on tax deductibility expenses to thinly capitalize their operations. This alone result to companies paying high tax, revenue depletion and negate corporate expansion through tax savings.

Companies with the choice of high debt against equity in capital formation may be exposed to bankruptcy, insolvency and litigation from creditors when the debt remain unpaid. These could force prospective investors both institutional and individual to restrain their decision of investing excess capital in debt instruments, hence affecting companies after tax profit.

Another problem envisaged by this study is internal company policy restricting subsidiary borrowing capacity within a group. This policy restrict companies within a group not to borrow above a certain margin, the essence is to enable management of working capital and reduce the accompanying problem of insolvency and litigation from creditors. The policy have the tendency of reducing interest on debt in subsidiary, hinder after tax profit to a reasonable extent, increase tax payable and rub companies of the prospective from thin capitalization strategy. When company is disqualified from being thinly capitalize as a result of restriction on internal debt arrangement, the rate of profit shifting will be reduced and group economic benefit of taxation is deprived.

Moreover, differential tax rate and flexibility in tax laws across countries constitute another major challenges to any transnational company using relatively high debts against equity. This is because, many countries of the world have realised that one of the difficulties confronting revenue authority from generating adequate revenue is the challenges of profit shifting and thin capitalization scheme which have the tendency of reducing tax payment. The tax avoidance practices have denied several governments revenue needed to provide citizens with social and infrastructural facilities. This necessitated countries to designed tax rules that restrict the use of thin capitalization by placing a ceiling on its application. The attempt is to discourage transnational companies from floating investment in countries, and could have a multiplier effect on both government and companies. In this manner, transnational companies could relocate from countries with stiff thin capitalization rule with adjoining negative implication on reduction of employment creation, technological development and skill acquisition and to invest in countries with favourable thin capitalization rule in attempt to maximize economic benefit of taxation. Against this backdrop, this study strive to examine the link between thin capitalization and tax burden of transnational companies in Nigeria.

1.3 Objectives of the study.

The broad objective of this study was to examine the extent to which thin capitalization affect tax burden of transnational companies in Nigeria.

The precise objectives of the study were to;

1. ascertain whether bank loans affect tax burden of transnational companies in Nigeria
2. determine the effect of lease transactions on tax burden of transnational companies in Nigeria
3. examine whether debenture loans affect tax burden of transnational companies in Nigeria.
4. investigate the effect of bond on tax burden of transnational companies in Nigeria

1.4 Research questions

Arising from the problem and the objectives of this study, this research answers the following questions.

1. what is the effect of bank loans on tax burden of transnational companies in Nigeria?
2. how significant is the relationship between lease transactions and tax burden of transnational companies in Nigeria?
3. to what extent does debenture loans affect tax burden of transnational companies in Nigeria?
4. what relationship exists between bonds and tax burden of transnational companies in Nigeria?

1.5 Statement of hypotheses.

1. H₀: bank loans do not significantly affect tax burden of transnational companies in Nigeria.
2. H₀: lease transactions have no significant effect on tax burden of transnational companies in Nigeria.
3. H₀: debenture loans do not significantly affect tax burden of transnational companies in Nigeria
4. H₀: bonds have no significant effect on tax burden of transnational companies in Nigeria

1.6 Significance of the study.

The research work would be significant both in understanding theory and practice of thin capitalization. On theoretical ground, it will contribute to existing literature on thin capitalization in both advanced and emerging nations. The work would also serve as a reference material to researchers and students of accounting in particular and management science in general. To the corporate managers of multinational companies and other

companies that are yet to adopt thin capitalization, the study findings will assist them in understanding tax avoidance option given the loopholes in countries tax law so as to enable improvement in profit and shareholders wealth maximization.

1.7 Scope of the study.

The study looked at thin capitalization strategy and evaluated how it enable tax planning to affect tax burden given the financing options available to transnational companies in the years 2011-2020. This study is concentrated on transnational companies operating in the oil and gas sector, Breweries, Conglomerate, pharmaceutical companies, Industrial and domestic product and Food, Beverages and Tobacco industries in Nigeria.

1.8 Definition of terms.

Thin capitalization:

This is a situation where a company is heavily financed by debt as against equity for the purpose of gaining income tax advantage.

Debt:

Debt used in the study refers to any kind of financial instrument on which interest or similar charges is made that are permissible as a deduction during the computation of taxable profit.

Tax burden:

Tax burden this refers to the amount of tax a tax payer would pay from carrying out economic activity.

Tax Planning:

This involve having understanding of tax legislation to enable adequate arrangement in their financial affairs so as to reduce tax payment.

Bank loan: Is a credit given to a company by bank to facilitate their economic activities which is subject to repayment with specific interest.

Debenture: Is a long term unsecured interest yielding debt instrument issued by a company to investors in order to finance their operations.

Lease transaction: An arrangement in which the owner of an asset (lessor) conveys to another (Lessee) the right to use an asset for a series of rental payment which is subject to an interest over the life of the lease.

Bond: Is a long term secured interest yielding debt instrument issued by a company to investors in order to finance their operations.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL FRAMEWORK.

2.1 Theoretical framework.

2.1.1 Theory of Planned Behaviour (TPB).

The theory was propounded by Ajzen in 1985. The theory upholds that three core mechanisms which include subjective norms, attitude and perceived behavioural control, together form an individual's behavioural intents under certain circumstances. Ajzen, (1991) opined that subjective norm is characterised as a universal view of public force which may be comply with or not. Trafimow and Finlay (1996) also contended that the dimness in the subjective norm element emanates from a few individuals whose activities are motivated principally by perceived public power. Perceived power is the presence of influences that may expedite or obstruct behavioral performance. Ajzen (1991) maintained that intents are presumed to arrest the motivational influences that enable a behaviour and to specify how difficult people are eager to or how great effort people would employ to implement the behaviour. Within the context of this study, Attitudes is considered as the degree to which a company exhibit negative perception towards tax payment as a result of government inefficiency in the utilization of tax revenue. Subjective norms is the belief that company is entitled to pay tax from every legitimate economic activities while perceived behavioral control consist of the use of government policy to restrict the rate at which interest yielding debt instruments are used by companies as a strategy of paying minimum tax. The surrounding circumstance in this context is high tax rate in most countries of the World which impinge company's ability to maximize needed profit.

However, the theory was primarily concentrated on psychology, it has since been used effectively in other fields of medicine, healthcare, political science, business, government and international relation (Bandura, 2006). From business perspective, the theory is intended

to take advantage of ambiguities in an established laws regulating business model. The attitude about the probability that the planned behaviour will produce anticipated result that would be beneficial to individual or organization in terms of cost savings and performance enhancement. Oakland and Taner (2007) suggested that, creating sufficient readiness to adapt to plan behaviour will often lead to positive or negative oriented change implementation. Ogbodoakum and Norhasni (2017) posited that the theory of planned behaviour, suggests that when an individual demonstrate optimistic boldness towards an act, is braced and inspired by related associate, and is self-assured that undertaking the act would yield a positive outcome. Grizzell (2007) further urge that, for perceived behavioural control to be effective, the belief of self- effectiveness is paramount and individual and organization ought to have develop the aptitude to involve in the action.

Theory of planned behaviour has penetrated in to the field of taxation, this is because some empirical researches prove that subjective norm, and perceptual behaviour and perception of tax payers to the government have certain consequence on the intention to fulfil the tax compulsion (Damayanti et al, 2015). Every corporate establishment is design for the purpose of maximizing stakeholder's wealth. To enable the actualization of this critical objectives, transnational companies are conscious of the application and combination of capital in financing policy to improve after tax profits. Thin capitalization constitutes a planned behaviour by the transnational company, conceived out of creativity from experts in accounting, law and other financial areas with the understanding of the tax implications of debt capital against equity. This is because the scheme is within the ambit of the tax laws which allow corporate tax shield for companies that finances its operation with high debt. The tax buffer comes during the computation of company assessable profit, where interest paid on borrowed fund is treated as tax deductible expenses. By implication of the tax law, the greater the debt level of a company, the higher interest it pays and the lesser the tax payable. Therefore, it is in the behaviour of transnational companies to plan

the deployment of more debts in their financing policy so as to reduce tax payment and enhance shareholders wealth maximization.

2.1.2 Theory of tax planning.

The theory was propounded by Hoffman & William in 1961. This theory explains tax payer's ability to organise his economic undertakings in a manner that it will suffer a lowest expenditure from taxes. According to the proponents, tax planning intend to prevent cash that would have usually move to institution responsible for tax collections to the company. The thus recognising the optimistic association amongst tax planning activity of firm which are depended on taxable income other than company returns and performance. Tax planning has been acknowledged as the suitable choice around the influence of the tax legislation which enable the reduction of tax burden. This is realised through the divergent of tax rates between individual tax authorities and economic undertakings, and many other tax inducements under tax laws (Fallan, et al 1995). Scholes et al (1992) posited that a prosperous company is one that adjust suitably to its tax system. This is because, tax planning framework point out the necessity for corporate organisations to involve in tax planning. Desai and Dharmapala (2009) see tax planning as an essential investment for stakeholders due to its ability in the reduction of tax burden which constitute a significant constraint that to companies and stockholders. Besides, tax planning consist of positive and negative affect on firm value and growth in prospect. Inger (2012) maintained that the scope of tax planning theory neglect the issues surrounding changes in market performance of firm. The reason is that as capital markets improve and the ownership structures became dynamic, so also control mechanism amongst companies is enhanced, hence given room to broad tax planning theory. Desai and Dharmapala (2009) buttressed that difficult tax avoidance practices provides organization with the implements and defences for unscrupulous administrative behaviours, such as incomes management, transaction with connected persons, and other resource-diverting undertakings.

Tax planning activities are necessary to a reasonable point as it help to decrease the amount to pay as income tax, without foregoing accounting earnings. The impression is to strengthen economic undertaking that would decrease taxable income without unintended connection on accounting income. The theory underpins the study of thin capitalization in that, transnational companies arrange their financing policy with high debt instruments which give rise to interest payment as tax deductibility expenses during tax computation against equity instruments which give rise to dividend payment to equity holders as non-tax deductible expenses. The tax relief on interest paid enable transnational companies to pay minimum tax and further enhance performance. However, the research is moored on tax planning theory given its significance to the study.

2.2 Conceptual Framework.

Independent Variables Dependent Variable

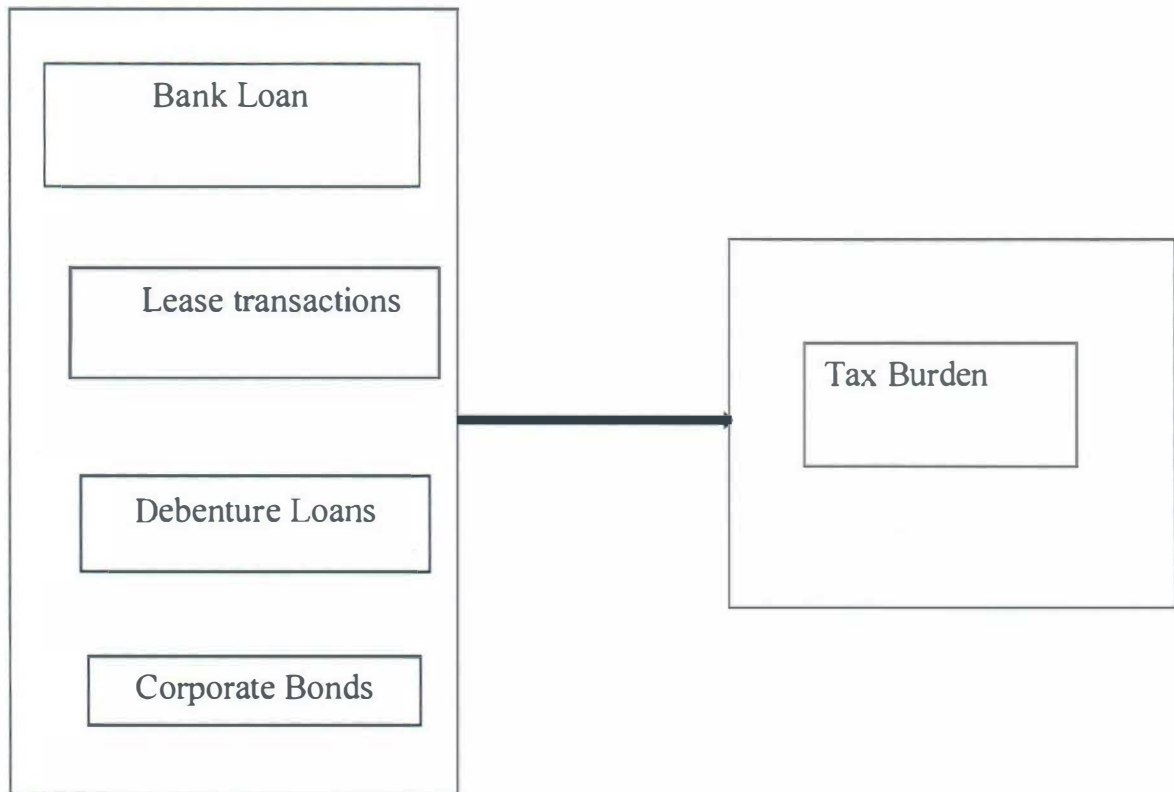


Fig 1: Conceptual model of thin capitalization and tax burden of transnational companies in Nigeria.

Source: Researcher's compilation

2.2.1 Concept of tax burden

Tax burden is the weight of a specific tax on the financial performance of an organization. In economics point of view, individual who eventually suffer the tax burden and those on whom tax is primarily imposed are not the same. Tax burden measures the true economic encumbrance of the tax, indicating the difference amongst actual incomes or utilities before and after tax imposition, taking into cognisance how tax causes changes in price. A high tax burden have the tendency of putting additional financial burden on company, because a company who refuse to pay their tax would risk being fined by the tax authority, and would also increase their tax burden through cash outflow which dampened financial capacity. This can constitute a problem to a company if the tax payment schedule relates with a period where the company is suffering low cash flow. Having a negative cash flow could create additional operational problem to company because it will hinders their financial capacity to transact future economic activity. More so, when a company is being taxed at effective marginal rate above the market average, it could also affect it productivity and growth. Duranton, et al (2011) maintained that, the idea behind marginal effective tax rate (METR) was established to analyse how investment choices of firm hindered by boundless amount of provisions of the business and individual income tax systems that affect the incentives to invest.

From theoretical point of view, the corporate tax has a multi-dimensional approach. First, it analyse how tax impacts on decision-making of corporate economic activities with respect of labour force (Chen, et al 2014). The second aspect of approaching the corporate tax is built on its influence and the way companies are financed, specifically on the borrowed capital (Gordon & Hines, 2002). Company's choice of finance is motivated by their policy concerning the cost produced by the type of the funding source, which is, own sources and borrowed sources. Whatever is the choice of funding, company will usually suffer a cost represented by dividends, if finance from own sources, or interest, if they chose borrowed

fund (Hassett & Hubbard, 2002). In this regard, the management's choice on the nature of the funding source need to take into consideration tax matters and the consequence it will have on the financial performance of the company.

2.2.2 Concept of thin capitalization.

In 1989, the United State of America (USA) introduced earnings tripping rule whose purpose was to reduce repatriation of profits by transnational companies in USA. This was followed by subsequent changes to its tax code to allow the application of internal debt as a tax saving mechanism to companies in 1997, and gradually introduce thin capitalization rule that enable revenue authority to regulate the use of debt instrument amongst US domestic companies. The thin capitalization rule has been replicated by many countries across the globe as a way of regulating interest payment on debt capital in company capital structure (Blouin, 2012). With the restriction on the use of debt capital by countries tax laws, there exist economic conditions that have created aggressive rivalry amongst firms, this rivalry made it very essential for transnational companies to device means of locating countries with high tax rate so that interest paid on borrowed fund which is a relief to them in compliance with countries tax laws can be shifted to improve their overall profit and other favourable economic conditions as factors before trade are negotiated and investment established. For this purpose, debt is habitually considered as more effective technique of finance than equity. Transnational companies habitually arrange their financing affairs in order to maximise the benefit of taxation. For this purpose, transnational companies are not only capable of achieving a tax effective combination of debt and equity in borrowing countries, but they are also able to overcome challenges surrounding tax policy of the creditor which obtains the accrue interest.

The assumption of most tax expert and economists is that business activities should not be driven exclusively by tax reduction objectives. Jones (2006) posited that, a business

deal ought not to be tax driven except it has an opens business objective other than tax preventive technique. Huizinga, et al (2008) maintained that multinational's arrange their capital structure policy in such a manner that permits interest to be received in a tax authority that does not assess the interest into tax or otherwise, or which ensure that such interest is assess to a small tax rate. To enable corporate entity benefit from this interest income, there is need for them to thin capitalise their operations. Thin capitalisation denotes a state of affairs whereby a multinational corporation is funded via a moderately greater proportion of debt above equity source. Eytayo (2005) sees thin capitalization as tax escaping practice whereby transnational affiliates are financed mainly by borrowed fund from parent company as against equity capital which appear to be financially intensive. Ferrar and Mawami (2008) upheld that a firm is lightly capitalised if it capital arrangement constitute a larger proportion of debt against equity. Webber (2010) asserted that thin capitalization is a financial tactic employ by transnational companies use to make foreign direct investment. Blouin, et al (2014), also opine that thin capitalization is imperative in the understanding of changes in tax rate in capital structure studies and it is practice in a country with high tax rate. In his view, Schon (2011) maintained that thin capitalization is a foremost way of moving earnings from tax authority with high-tax rate to tax authority with low-tax rate through obtaining additional fund in high tax environment and fewer in low tax environment. Thin capitalization is a tax planning policy carryout by company having strategically evaluated country fiscal policy to suite its capital composition, activities which enable them to finance their operation relatively with high level of debt against equity for the purpose of gaining tax advantage.

Among multinational structure, financial composition is very important to transnational companies because it influences the amount of tax it will pay over the profit made in the end. Transnational company is entitle to a credit and deferment tax system at home and are often to operate one associate in a country with low-tax rate. After capitalizing

the associate, the transnational selects between direct dividend payments to the parent and additional real investment in the foreign associate. However, physical venture in the foreign affiliate, which may produce low returns comparative to venture at home, is only one of many options to through dividend deportations. The transnational company can be involve in a range of other approaches that have the consequence of realising the equivalent of deportation without incurring the local country tax on direct deportations of profit from low-tax income. Altshuler and Grubert (2003) maintained that plan that relates the operations of connected associates is one in which associate with low tax is firstly capitalized by an equity injection from a subsidiary or an upper-tier subsidiary experiencing a higher tax rate. Grubert (2003) posited that manufacturing affiliates in nations with effective tax rates less than ten per cent more often deport about seven per cent of their earnings.

2.2.2.1 Sources of finance

2.2.2.1.1 Debt capital as source of finance.

A good number of companies have put in place an aggressive means to withstand intensive competition. The competition made it worthwhile for firms to improve its performance so as to remain relevance in the foreseeing year. For firm to expand in midst of rivalry forces, it is essential that capital acquisition decision that would enhance the achievement of corporate objective be formulated. The decision should be directed toward financé sources that would encourage tax savings and frim expansion in a short run. Debt capital decision seem to be more appropriate for firm with desiring profit motive, as it is described as money employed in a company from external or internal sources for fixed period of time with coupon rate of interest. Ezekiel, et al (2016) see debt financing as a major phenomenon in the corporate literature across the world. This is because, it provides a tool of covering financing shortfalls of businesses that do not have adequate in-house financial capacity required to finance their investment and operating activities. Debt might

be obtained in numerous ways, and be classified based on its maturities period. It could be short-term, long-term and convertible debt. Debt capital are line item found under company's statement of financial position.

A firm with high debt financing would majorly enjoy two benefits. One of the benefits is the tax shield deducted from profit during tax computation as a result of interest payable made by the firm which has an effect on reducing the amount of cash flow available to firm (Fama & French, 2005), thus, the debt has the prospect of increasing firm value over time. Graham (1996) posited that owing to tax advantage of debt, a company with greater marginal tax rates are prospect to issuing debt instrument than equity. Issuing debt capital could be considered as a pointer that managers have assurance that the company possess the capability to refund its liability as they may fall due. The second benefit a firm with high debt would stand to enjoy is financial discipline (Jensen, 1986). In this, manager are expected to give the debt holders thorough information concerning monitoring of investment process (Frank & Goyal, 2003). Debt is the tax-deductible expense so they are low-cost source of finance as compared to equity (Adesina, et al, 2015). Shireen (2019) posited that the association between Debt and earnings per share is a vital financial discussion that needs the thoughtfulness of an expert grounded with financials matters in daily policy making and implementation. Studies by Baker and Haslem (1973) show that huge amount of debt is associated with high risk thus increasing profitability.

2.2.2.1.2 Equity source of finance

2.2.2.1.2.1 Retained earnings as source of finance

The essence of taking up investment is to earn profit. Most often, companies invest in stock with greater expectation that the return would be reasonable enough to be distributed to owners or retained for the purpose of re-investment. Horkan (2014) in his

study described retained earnings as quota of income after deduction of incidental expenses that organisation reserve to fund future economic activity and to repayment of debt. In a like manner, Merritt (2014) pointed that retained earnings symbolise amount "locked up" in the business undertaking, which do not symbolise cash on hand but can be hypothetically allowed to the shareholders in the event liquidation after discharge of debt holders. In other word, retain earnings is the amount of net income available for corporate entity after payment of dividend to equity holders. The purpose for retention often varies among firms, it could be for maintenance, to take up another investment prospects and growth expansion of the company. Given the nature of business operation across the World, management of corporate entity need competent and effective skills to manage resources, take reasonable decision relating to investment growth, put up adequate plan to manage its finances, and enhancement of future cash flow. As internal source of capital, retain earning refers to funds generated from within an entity as a results of success recorded through enterprises activities. Success of every corporate entity is assess by profit potentials and the utilization of same over time. Often time this profit is disburse to shareholders to encourage their patronage and commitment to the dream and aspirations of the entity, but it can also be reinvested into the business to enable growth and expansion. Retained earnings have a significant relationship with firm market performance, because experienced investors look at stock prices of companies in the stock market to value firm operating performance. Thuraniira (2014). Dinayak (2014) sees retained earnings as part of trading earnings which is not shared as dividends but is reserved by the company for impending growth and is item under stockholders' equity on the balance sheet. Retained earnings denote the percentage of income after deduction of permissible expenses not distributed as dividend to equity holders but retained by an organization for further investment purpose (Chasan, 2012). Organisation may have several business ideas that need financial support, retained earnings helps company to actualized the objective as it make financing decision very fast, possible and

reliable without additional cost. It serve as a significant in-house financing that organization obtain with no cost (Mohamed, 2010). Khan and Zulfiqar (2012) posited that company growth is not influence by the amount of retain earnings but other firm specific variables also consist a major component.

2.2.2.1.2.2 Share capital as source of finance

Share Capital is one of the important facets which drive company's growth and enable the maintenance of liquidity and long term survivability. A company share capital is the percentage of a company equity that has been acquired through share issued to shareholder, more often for cash. More often shares are allotted in exchange for non-cash consideration, this usually occur when company A buys company B for shares. Share capital is the unit of ownership and asset of Limited Liability Company. Company raises money through issuing of share from the general public and guaranty their participation in the ownership of the company. Prices of share vary from company to company and are depended on the rapid changes in the demand and supply chain. Ramadhani (2019) classified changes in share price into historical and market changes. According to him, historical changes in prices of share portrays the rate at which prices of share in the previous year are value in the market due to uncertainties in the security market. Almarar and Nobanee (2020) maintained that if the price changes for the stocks are reasonable and generally stable, investor's will perceived it as having lower volatility and safe. But when there is intensive deviation in prices, the volatility in the price of the stock would reduce the investment potentials. Gabaix, et al (2005) Observed that performance of company in the market has significance influence on the trading capacity and share returns. Accordingly, optimistic news concerning the firm's activities may stimulate trades, encourage other prospective investors to trade. This is reason, Almarar and Nobanee (2020) in their study admonished companies to develop and implement a suitable business program, as news of any negative or positive practices may enhance their image and increase their stock prices.

Share capital is one of the instrument traded in the capital market. As capital market across the globe are consider as major pillars of economic growth and development. Increase in the market value of public limited liability company have a strong tendency of encourages expansion foreign investors while also improve market value of firm.

2.2.2.2 Interest as tax allowable expenses

Interest expenses in the income statement represent borrowing cost incurred by a company to meet up its short or long term obligations, acquire assets and increase inventory so as to meet competitor struggle in the market. As current liabilities, interest expenses accrued but not yet paid usually appear on the statement of financial position. However, interest expenses paid in in the future would be recorded as current assets as prepayment. Interest payments are tax-deductible expenses that reduces tax liability and improve cash savings of company. They serve as a motivation to firm and therefore enable their policy direction in financing with more debt than equity, because financing with debt has some element of benefit permitted under the tax laws. This imply that firm that finance its operations with high debt will be advantageous in rolling with tax benefits mostly in states where tax rate is high. The tax benefit will decline, if firm suffers losses in the cause of business transactions. But, if firm operating capacity are large enough to accommodate accompanying interest expenses, then firms will be of advantage in tax deductibility of interest expenses (Tariq & Hijazi, 2006).

Webber (2010) maintained that high debt against equity restriction are not always active enough to prevent firms from repatriating accounting earnings from one jurisdiction to another. This has posed much concerns amongst scholars in the study of thin capitalization. The essence is that if the multinational company is capially sufficient, it can introduce high debt over equity into the subsidiaries across countries, comply with high debt against equity restrictions set by them and still repatriate earnings. Multinational company in a bid to expand its scope across border lines, ensures that shareholder wealth is maximize

and capital structure policy that will enhance internal debt flows within multinational enterprises is encourage. Huizinga, et al (2008) submitted that multinational companies are faced with complicated choice of determining their overall indebtedness from subsidiaries but derive benefits through reflection of corporate tax deduction.

Thin capitalization rule as applicable in many countries of the World restrict the rate of debt capital in firm capital structure that can increase to interest deductible expenses for the aim of computing taxable profit. The interest on any amount of debt above that limit is not tax deductible as shown in tables 1, 2 and 3. As a result, countries have taken measures to ascertaining the percentage of debt that can increase interest deductible expenses for tax purpose.

TABLE 1

Proposal to restrict a Controlled Foreign Corporation (CFC's) tax-deductible interest expenses by the World wide enterprises, ratio of interest expenses to earnings before interest, tax, depreciation and amortization (EBITDA).

Financial measures	World-wide enterprises	Financial measure	CFC financial
	financial result		result/Limit
Total trade interest expenses	\$ 15 million	Limit of tax deductible interest expenses to EBITDA	7.5%
World-wide EBITDA	\$ 200 million	CFC EBITDA	\$ 10million
World-wide ratio of trade interest to EBITDA	7.5%	Tax deductible limit for trade inter-company interest expenses	\$ 750,000

Source: OECD Tax data base, 2012

For instance, German tax law provides that consolidated firms are exempted from interest deduction rule. In Japan thin capitalization rules permit companies to employ the debt-to equity percentage of a related Japanese company to ascertain the higher amount debt-to-equity proportion. The Dutch guidelines restrict affiliate's debt-to-equity proportion to global transaction. In New Zealand's also, the law restrict affiliate's debt-to-equity proportion to 110 per cent of the combined business activities. There is no universal rule for debt to equity application in firm capital structure, numerous nations enact thin capitalization laws that recognize the debt level of the global economic transaction of company.

Table 1 above showed global company interest expenses proportion that would be subject to tax deduction from affiliate entity. The above table further showed that, global business economic transaction of companies exerted \$15 million in trade interest expenses, and EBITDA of \$200 million respectively. Thus, the proportion of interest expense to EBITDA is 7.5 per cent, while affiliate earned \$10 million. The controlled foreign corporation tax-deductible interest payment is ascertained by multiplying the 7.5 per cent amount by its EBITDA of \$10 million, which become \$750,000. This imply that any Interest expenses up to \$750,000 is consider as tax deductible expenses, whereas interest expenses above that figure are usually disallowed.

2.2.2.3 Income taxes and corporate performance

Taxes are consider as mandatory payments imposed on income, wealth, and physical assets of individuals, partners in business, executorships and firms by the government. It is paid by corporate organisations and individuals to government at the federal, state and local governments, and constitute most productive revenue source of government. As company look to realise and maximize value for her shareholders, it will also pursue profit maximization through adequate tax planning. This is because, high tax rate would leads to reduction in the profits margin of company and also adversely affect Company through

reduction of investment potentiality or disinvestment. Olaleye, et al (2015) observed that one of the major thing that eat deep into company cash flow is tax, this is so because, it increases out flow of company financial activity deeper than any other element. Hence, companies are confronted with the choice of dealing with issue of tax obligation in a manner that associate burden is minimize so as to avoid unnecessary outflow that will impinge after tax profit. More so, decision bothering investment opportunity surrounding corporate entity could be affected to a greater extent by amount of corporate taxes its pays. Reason being that, high taxes paid by company as result of high tax rate in a country would result to low profits and a restriction expansion potentials of company. In so doing, foreign investors will speedily assemble their investments portfolio and abscond to other nations with favourable and good tax system (Koranteng, 2014).

Financial performance of company operating in high tax environment is driven by manager's ability to understand the country's tax law so as to avoid tax payment. This is done through proper planning of financial affair geared towards maximizing after tax profit and encouraging reinvestment of excess funds into productive venture. De Mooij, et al (2013) observe that when company profitability rises, the returns from the manufacturing and process would be high, therefore, the firm would have enough resources to return. Salam (2013) maintains that the more corporate profitable a company appears, the more investment capital it could get in either debt to carry out its operations, the more interest repayment from debt that reduces tax payment. The amount of after tax profit is often considered a notable indicator of measuring firm's performance and also serves as an indicator to measuring going concern in business (Agha, 2014). Moullin (2007) pointed out that performance evaluation is a critical tool which helps companies in evaluating and recognising areas that require support, attract staff stimulus, cultivating communication pattern and solidification of corporate accountability.

2.2.2.4 International tax Laws regulating transnational companies.

International organisation such as Organization for Economic Co-operation and Development, United Nation Organisation and the European Union has been in active promotion of trade and removing of barriers to trade posed by taxation issues amongst its member nations. The essence is to ensuring that developing countries get their share of the tax on profit of multinational companies operating within their territory. Organization of Economic Co-operation in 2012 defined the concept of thin capitalization as a circumstances whereby firm finances its operations via moderately high level of debt against equity. Huang (2013) opines that international tax system allowed countries to impose tax on world-wide and within national boundary. Under the world-wide, countries tax business's total income whether such income is generated in that country or not, the national system permit countries to assess income generated within the country into tax leaving other countries to assess income generated in their country into tax until they are repatriated. This means that international organisation is aware of earnings tripping policy of thin capitalization by multinationals, therefore tax authorities is on the heel to fighting thin capitalization through restricting associate interest payment by placing a ceiling on its application. Rixen (2010) opine that international tax consists of a complex patch work of functional jurisdictions interacting with one another.

Jones (2006) maintained that most tax authorities assumed tax payment should be centred on principal business materiality, other than the legal arranging of a transaction. Lessambo (2009) posited that the substance over form principle be contingent on the foundation that taxes are collected on the ground of substance rather than its mere legal framework. This principle is often applicable in thin capitalization guidelines. For example, to repatriate proceed of transaction from one national boundary to another, transnational company may spread an intercompany loan across nation where it operate. Tax rules in

recent time has prevented this kind of arrangement through by putting restriction to rate at which should carry intercompany debt in its statement of financial position. Transnational company may also structure a loan from a third party, but in real term the parent permits such transaction.

Taylor and Richardson (2013) maintained that the unnecessary application of debt instrument in method of thinly capitalized arrangements by affiliate companies situated in complex tax authorities (unlike in Nigeria where 30 per cent is applicable) carry's an essential global corporate tax avoidance practise by multinational companies. The unnecessary use of debt instrument to finance subsidiary firms situated in complex tax environment consist a vital international corporate tax avoidance mechanism used by transnational firms (Shackelford, et al 2007; Taylor & Richardson, 2013). Martins (2012) maintained that tax authorities often attempt to limit the use of debt instrument by transnational firm, usually end up restricting the sum of interest payment by the associate. Organization for Economic Co-operation and Development (2012) explained that thin capitalization laws are generally gear toward ascertaining the higher sum of debt on which interest payment are deductible and ascertaining the higher sum of interest subject to deduction with regards to the percentage of interest payable.

International income tax is centred on the division of tax revenue among taxing jurisdictions for the purpose of avoiding double taxation of trans-border earnings streams and tax avoidance. The crux of international taxation is the matter of whether and to what magnitude a country would exercise power to tax a person or a company who is subject to two more national tax laws. International tax system basically considered two principles in the assessment of corporate bodies and individuals. These are source based and residence based tax principle. The source based principle, nation is entitled to assess income of non-residents earned within its boundaries. Residence based approach look at tax jurisdiction to assess the global income of its residents regardless of source. International taxation look at

the divergent between resident individual who reside in one state but received income or gains emanating from another state. From a country's viewpoint, the countries in question will permit the collections of taxes that are recognise by law, but from a taxpayer perception, this situation may lead to double taxation (Lund, et al, 2008). Schon (2011) observed that several nation of the world today have entered into mutual agreements with other nations which intention is to delineate which nation a taxpayer will be categorised as resident for the purpose of taxation and how taxes on diverse sources of earnings and assets are to be shared amongst the two nations having the right to tax such income.

However, International tax laws provide better explanation on who should be consider resident in trans-broader transaction. It further ensure that there is a common atmosphere in the treatment to business activities and income tax administration to reflect the principles of equity for multinational companies. There serve as source of resolving litigation between tax payers and tax authority, most specifically it application could be interpreted in different ways across countries. Recent empirical research offers opinion that differences in international tax laws hindered transnationals' financial arrangement in a manner that is in agreement with general objective of minimizing the amount to pay as tax (Grubert, 2003; Mintz, 2004). If capital structure of multinationals from different research evidence is thinly capitalised, therefore, multinational companies is suspected to pay lower taxes compared to national operating companies. To avert the repatriation of income to low tax country while leaving the host country with little to services the activities of government, many countries have enacted thin capitalization law whose purpose is to reduce payment of interest on related party transaction. See table below lists of all countries specific limitations in their corporate tax laws in 2005.

TABLE 2
Countries with thin capitalization laws

Country	Safe heaven debt-to-equity ratio	Debt in Colum refers to
Australia	3:1	Total debt
Belgium	7:1	Related party debt
Bulgaria	3:1	Total debt
Canada	2:1	Related party debt
Croatia	4:1	Related party debt
Czech Republic	4:1	Related party debt
Denmark	4:1	Total debt
France	1:5:1	Related party debt
Germany	1:5:1	Related party debt
Hungary	3:1	Total debt
Italy	4:1	Related party debt
Japan	3:1	Total debt
Latvia	4:1	Total debt
Lithuania	4:1	Total debt
Luxembourg	5.7:1	Related party debt
Mexico	3:1	Total debt

Source: Buettner *et al* (2009).

Countries thin capitalization laws

Country	Safe heaven debt-to-equity ratio	Debt in Colum refers to
Netherlands	3:1	Total debt
New Zealand	3:1	Total debt
Poland	3:1	Total debt
Portugal	2:1	Related party debt
Romania	3:1	Total debt
Slovakia	4:1	Related party debt
Slovenia	8:1	Related party debt
Spain	3:1	Related party debt
South Korea	3:1	Related party debt
Switzerland	6:1	Total debt
Turkey	2:1	Related party debt
UK	1:1	Total debt
USA	1.5:1	Total debt
Indonesia	4.1	Total debt

Source: Buettner *et al* (2009).

Thin capitalization rule is not universal as most countries of the world including Nigeria are still suffering from the negative consequence of the tax avoidance mechanism. Ireland and Spain have recently abolished the thin capitalization law but Ireland split its corporate tax rate which had been in force transnational tax treatment. This decision resulted to European Commission in 2007 announced to take coordination of action against solely artificial arrangement employ to split profit between institutions.

Table 2 and 3 show list of countries other than Africa countries under the Organisation of Economic Corporation and Development treaties with thin capitalization rule. These tables shows safe heaven debt to equity ratio which explains the percentage of debt to equity a company can accommodate in its capital composition as allowed by the various countries tax legislation. In this, excess of permissible ratio will be subject to full tax using appropriate tax rate existing in the country. However, debt in Colum refers to debt arrangement in company transaction, it could be ratio of total debt incurred by the company or ratio of related party debt. This is to say that, if a country's thin capitalization rule recognises only a ratio of related party debt, any debt incurred by the company must come from related party transactions, otherwise the debt component will be subject to the applicable tax rate. Some countries as seen on the table allow total debt as reported in company's statement of financial position. This gives transnational companies prominence to use debt capital over equity in their financing structure as to enable the reduction of tax payment and maximization of shareholder's wealth.

2.3 Nature of Transnational companies and their operations.

As the global economy is expanding with divergent in institutional framework posing restriction to foreign transaction, good road network and communications system, flexibility in fund transfer, etc., foreign entity are being motivated to invest in risk free environment where they can earn profit so easily. Before now, developing nation see the

presence of foreign entity as a threat to their development and are often consider to be loss of sovereignty. It is now understood that transnational companies are purely a part that enable corporate integration and economy harmonization as against the narrow reasoning of most people in developing nations. Onuoha (2005) stated that, one foremost academic contentions on global political economy has been on the motivation of transnational Company in developing countries. This was reinforced by institutional framework developed by Organization for Economic Co-operation and Development which has been very active in promoting trade and removing of barriers to trade posed by taxation issues amongst its member nations (Richard, 1998). The essence is to ensuring that developing countries get their share of the tax on profit of transnational companies operating within their territory and well as enhance efficacy in trans-border trading. The framework allow flow of economic resources amongst member countries in bilateral understanding and exchange of technology between organisations. The reason could be that if economic activities are restricted within the shoreline of a country, sensitive information relating to technology and economic expansion will be hampered. Therefore, bilateral understanding amongst nation has the opportunities of unlocking economic downturn of any nation, and as such transnational organisation are bent to critically evaluate the country tax policy, political and economic amongst other rules as elements of trade. Transnational Corporation could be describe as any trade that has productive undertakings in two or more countries. In essence, they retained a single head office in state other than the state of operation with enough assets and capacity to exploit profitably in different markets.

Despite the fact that transnational organisation decreases unemployment rate in a country, Feldstein and Horiaka (1980), points out that holding everything constant including domestic savings, transnational companies reduce domestic investment by significantly less than one for one. When transnational companies initiate commerce in another nation outside its economy boundary, the branch in that nation is often called a subsidiary. The investments

in the subsidiary needs to be funded through equity or debt, to facilitate acquisition of assets and support expansion for the maximization of shareholders wealth. Feldstein, et al (1995) opines that investment decision of transnational companies is determined by home-and-host Country taxation and variation amongst nations in tax matter connected to debt and equity finance. Fuest, et al (2011) suggest that transnational companies have among them a characteristic that the group arrange a high debt capital against equity in the capital structure and also provide loan to affiliate in low tax jurisdiction. Both loan and debt finance has interest element and are deductible items during the computation of company tax liabilities as permitted by countries tax laws. This tactic permits the transnational companies to transfer taxable incomes from high-tax jurisdiction to low-tax jurisdiction, for the purpose of reducing the group tax weight.

The concept of transnational companies and its influence on the economic advancement of countries, specifically in Nigeria cannot be overemphasis as seen in the work of Andabai (2006), Awolusi (2012) and Otokiti (2012). Odogbor (2004), in his work also observed that Nigeria is a developing country and shares the same features with others developing countries of the world such as Brazil, Mexico, Malaysia, Russia, Philippines etc such as low industrialization, low level of debt, level of savings, investment etc. Andabai (2006) maintained that, transnational company is a company owned and managed in two or more nations. Transnational companies could also be corporation with headquarters situated in advanced nation and affiliate spread in a number of other nations (Omotola, 2006). Barnet and Muller (2004) see transnational companies as a machinery for the economic advancement and transmission of capital resources from developed state to underdeveloped state. Ake (1990) in his own view agreed that transnational companies are good citizens of the country they operate only if they remit taxes to government like other indigenous companies, as taxes increase revenue base of government and facilitate a ground for government to provide social amenities and infrastructural development to citizenry.

**THIN CAPITALIZATION AND TAX BURDEN OF TRANSNATIONAL
COMPANIES**

BY

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ACC/Ph.D/17/008**

**A DOCTORATE OF PHILOSOPHY DEGREE (Ph.D) THESIS CARRIED
OUT IN THE DEPARTMENT OF ACCOUNTING
FACULTY OF MANAGEMENT SCIENCES,
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Nwankwo (2002) also maintained that multinational corporations in Nigeria assist government in reducing unemployment rate and development of skills needed for industrial advancement.

Muller (2003) in his work, analyzed the function of transnational companies in developed nations. He contended that, most initial capital used by transnational companies are sourced from host country economic transactions and not from their country of origin. Sherlock (2007) stated that, transnational companies are selfish and self-centered because their profit motive is place above host country development and growth. This imply that the net contributions of multinational companies in terms of foreign direct foreign investment to the host country is undesirable. Andabai et al (2006) assumed that, transnational company's contributions stimulate domestic development of economic activities, but such contribution indicates no proof of success, rather exploitation of natural resources. Odunlami and Awolusi (2015) observed that, transnational companies are exposed to fluctuations in exchange rates, tariffs, duties, and restrictions on trade which more often affect their trade. Ozoigbo and Chukwuezi (2011) opine that TNCs enviously protect the technical knowledge of their skills in a manner that they tactically refuse to make use of experienced staff. The TNCs instead prefer to use people without adequate skill in production process and are used to assemble what they knew not how it was manufactured. By implication staff from host country may not learn well the intricacies involving the production of the product.

TABLE 3

List of transnational companies operating in Nigeria.

S/N	COMPANY	YEAR OF INCORPOATION
1	7-Up bottling company	1960
2	Lafarge cement construction	2012
3	UACN FMCG Multinational	1997
4	MTN Telecommunication multinational	2004
5	Airtel Nigeria	2004
6	Stanbic IBTC Banking Multinational	1989
7	Addax oil and gas multinational	1994
8	ENI oil and gas	1991
9	DHL logistic Multinational	1978
10	IBM Technology	1961
11	Shell Petroleum development company	1958
12	Mobil oil and gas	1955
13	Total oil and gas	1956
14	UNILEVER	1976
15	Julius Berger	1991
16	Etisalat	2007
17	Cadbury FMCG Multinational	1965
18	Google Technology	1998
19	Cocacola	1929

Source: Field study, 2021

List of transnational companies operating in Nigeria.

S/N	COMPANY	YEARS OF INCORPORATION
20	PZ Cusson	1948
21	P & G FMCG Multinational	1937
22	Guinness FMCG Multinational	1962
23	Glaxosmith Klinne Pharm	1999
24	British American Tobacco	1997
25	Schlumberger Oil & Gas	1962
26	Baker Hughes oil & gas	1907
27	Price water house cooper Consult	1998
28	Chevron oil & gas	1879
29	Nestle Nigeria	1997
30	Halliburton Energy oil & gas	1924
31	KPMG Consulting	1987
32	Julius Berger construction	1970
33	Accenture Consulting	2009
34	Standard Chartered Bank	1859
35	MAERSK grow conglomerate	1928
36	Volkswagon group	1972
37	Samsung group	1938

Source: Researcher compilation, 2021

2.3.1 Transnational companies' financial strategies.

Financial policy formulation is one of the major company consideration of a typical financial controller of any corporate enterprise. This has to do with fund acquisition and allocation, but the major of them is acquisition of fund that require careful evaluation before decision is taken. Firm chose between debt and equity financing is strategy in nature, chosen debt has both tax and non-tax. A non-tax implication suggest that overall debt obligation of company should be moderate in order to enable the chance of costly insolvency at minimum level (Huizinga et al 2016.). Similarly, debt finance has the privilege of reducing the free cash flow of a firm and help to discipline over spending managers. The disciplining properties of debt finance would clarify debt level of transnational companies and its subsidiary could keep to curb the descending effect of bankruptcy on the company. These situation give rise to an ideal overall capital structure transnational company would maintain for non-tax purpose.

Countries tax system provided for interest to be deducted from tax base on debt finance instrument while return such as dividend accrue to equity instrument are regarded as non-tax deduction item. The unequal treatment of different finance sources available to investors and accompanying ultimate incentive, motivated the reliance on debt capital as a better finance source against equity. For transnational companies the incentive will guarantee their consciousness on surrounding opportunity in the use of debt instrument and internal debt to transfer profits from one tax region to another. Recently, research works have proof evidence of the differential effect of international taxation and transnational financial choice (Armstrong, et al 2012, Adesina, et al 2015 & Clausing, 2015). These researches proved that financial choice is dependable on the benefit of tax reduction, hence transnational company roll on the opportunity to float investment abroad. Moreover, transnational companies indulge in profit transfer using different avenue such as transfer

pricing, thin capitalization and hybrid mismatch arrangement to management tax rate differential amongst nations so as to reduce tax payment (Grubert, 2003; Mintz, 2004).

Apart from using thin capitalization strategy to reduce tax liability and transfer profit from country with high tax rate to country with low tax rate, transnational companies also make use of transfer pricing to transfer profit from one tax territory to another. Existing empirical evidence that centred on OECD have identified different avenue which corporate entity transfer income to include distortions of transfer prices, thin capitalization, and the setting of assets without substance (Clausing 2003; Huizinga, et al 2008). Though transfer pricing has been consider as one major instrument of earning shifting within the international tax system and as where often referred to as potent strategy of allocating profit. Otusanya (2013) have argued that when two companies carryon business under mutual possession, they do not project price for individual company rather ensuring that value is created for the overall interest of the transnational company. Companies often share the profit between affiliates companies in a manner that will reduce the amount paid as tax from high-tax jurisdiction, this will erode share of tax due to jurisdiction where those profit s were never generated specifically low-tax jurisdiction (Lee, 2017).

However, Eyitayo (2005) have pointed out some main elements considered by transnational Company before the establishment of branches in different parts of the world are; Location of Corporate head office: Multinational Company often consider its corporate head office very important in business structure because of the variation in tax rate existing between countries. For this reason, they will decide to situate its head office in a nation where the tax rate is grossly low.

Location of subsidiaries: Multinational structure requires different affiliates from different territories with great consideration to the tax rate existing among this countries. It may choose to locate an affiliate in a state or country where it is not tax or is tax at a very

minimum rate like the Cayman Island, Bermuda or Switzerland. This is to enable them secure tax advantage that would help in the reduction of tax payment.

The group structure: Another element very important is the composition of the group structure. Multinational company often isolate for company with high debt profile so that it will not crash with the existing debt outstanding. The reason for avoiding companies with high debt profile is to keep investor's confidence since trading with high debt could be interpreted by many as lacking adequate financial capacity.

Trade agreement: Multinational companies also consider trade suitability between group companies such as transfer pricing which constitute a planned strategy to lessen tax burden by putting price on goods and services in a parent company in a manner that it would not show the existence of arm's length operation so as to reduce tax payment.

Other considerations apart from the one listed above are, where would the company record its costs, market its product, location of assets, staff sourcing, fund acquisition, location of intellectual property etc. All these elements mentioned above have direct relationship on tax payment and are consider as major criteria for transnational companies investment policy formulation.

2.3.2 Thin capitalization policy in developed countries.

One of the tax avoidance practices across the globe is thin capitalization. Thin capitalization as tax avoidance strategy is often practiced by multinational companies due to it accruing benefit of tax payment minimization. The benefit obtained through tax savings enable company to increase their investment capacity when put together would also assist to increase shareholders wealth and corporate benefit of management. Several of such strategy are considered to be hostile, instead of being cautious. Thin capitalization laws are vital source of understanding difference in tax rates in the study of capital structure. Webber (2010) asserted that many countries have enacted related tax regulations that avert tax payers and consultant from placing elegant tax business activities that serve no corporate purpose

other than minimizing tax commitment. As shown in table 2, they are relatively tax laws in developed countries where transnational company found a safe haven in floating their investment. For example, in Australia the tax rule on thin capitalization is 3:1 and 4:1 in Indonesia. In U.S.A corporate tax rate as at 2013 is 35 per cent, US government provided bench mark for debt-to-equity ratio of 1.5-1 figure as safe harbour in their thin capitalization rule. Therefore, if the debt-to-equity ratio is above 1.5-1, the portion above 50 per cent is not tax deductible. Moreover, German tax law also restrict related party loan shift without exclusion to domestic and international owners of German firms. Rossi (2005) maintained that Italy tax law under the thin capitalization mechanism are so difficult and possibly risky for ill-advised tax payer due to its complexity which subjects resident corporation, joint stock companies, partnerships, sole proprietorships and permanent organisation into tax. Despite the tax restriction rules habitually practice in many part of the world, most developing countries such as Nigeria is creeping with the challenging of tax injustice resulting from avoidance machinery perpetuated by transnational companies which results to revenue shift to home country and deprived the government of the much needed revenue for growth, a benefit that stand to improve on the company's profit.

Thin capitalization policy differs amongst countries with numerous main dimensions. First, thin capitalization is differ in meaning in terms of higher debt percentage from where interest is charged. The meanings of the higher value of debt is categorised into two key groups; restriction of total amount of debt or limitation of debt from related party transaction. Second, thin capitalization law also vary in the handling of extreme interest on debt above margin. Third, they is difference in the implementation of thin capitalization laws amongst nations. In most nations, the law allow treatment of interest expenses involuntary as disallowance so there is no biasness in the thin capitalization law. While in some countries they allow company to use some decision in the application but control the company level of indebtedness so as to ascertain whether interest deduction is restricted.

Transnational companies often use internal capital markets instrument to overwhelm the weaknesses connected with external credit markets, internal financial policies for the purpose of decreasing their overall tax burdens (Desai et al., 2004). In a situation where transnational company is functional in tax jurisdiction where tax is high or low, it is expected that associate company located in high tax jurisdiction would have to obtain loan from affiliate in the low-tax jurisdiction to remain in the same margin of profit. Interest paid on debt instrument are generally consider as deductible expenses from the corporate tax base, hence the divergence in country tax law regarding tax rates decides the possible gain company would enjoy (Buettner & Wamser, 2005).

To protect corporate tax bases, many countries have enacted and placed restriction on the use of debt equity in firm capital structure. For instance, thin capitalization law was enacted in Germany in 1994. After several amendment, the law was replaced and titled earning stripping rule in 2008. This law limits subtraction of interest if a company's internal debt-to-equity ratio surpassed a definite margin. Buettner, et al (2012) buttressed that if the internal-debt to-equity ratio of a firm is more than the margin enshrined in the deductibility rule, only interest costs for the internal loan above the permitted margin would be treated as non-deductible expenses. Apart from Germany and USA other nations that are troubled with tax effect of debt-equity financing are Poland, Switzerland, Turkey, Denmark, Netherlands, UK, Mexico, France, Italy, Canada, Japan and New Zealand. These countries have developed regulations that require critical attention in the restriction of interest due to their economy size and population. Most specifically, Denmark, Netherlands, and New Zealand. Lund, et al (2008) opined that Denmark thin capitalization rule is harsh and complicated. Denmark used three approaches to limit interest deductions that consecutively diminish tax-deductibility interest expenses. The first restriction is on interest deductibility expense on related party debt. The second restriction is on the value placed on qualifying asset and the

third is the margin placed on net financing expense based on firm's earnings before interest and taxes.

Van-Saparoea (2009) maintained that for Asian and American firms, specifically Netherland have a long history as preferred jurisdiction for investment opportunity. Netherlands on their own efforts to stability the rival objectives of improving tax revenue and promoting an eye-catching environment for investment growth have been faced with the challenges of earning transfer which resulted to the amendment of their tax law to 10 per cent. Numerous transnational companies have derived substantial tax benefits from Netherlands given their internal economic policy, these effort has contributed to declining tax burden across the globe. The present thin capitalization rule in Netherland became effective from 2004 and was structured to identify whether interest expenses are tax deductible or firm should allow equity figure of at least €1 (Blouin et al 2014).

Sporken (2008) maintains that the first choice for debt-to-equity ratio of the taxable entity may be 3:1 at most. If the debt-to-equity ratio is higher than the margin, the accompanying interest expense is not tax deductible. The second choice is to allow the global company's debt-to-equity ratio. Van-Saparoea (2009) maintained that if the taxpayer chose the group ratio, its surplus debt value held by the average debt-equity ratio should be used as ratio of the group. But if taxpayer operate in more than a group, the maximum debt-to-equity ratio relates. To avoid manipulation and preserve constant tax proceeds, the Dutch tax law also recognise a number of precise circumstances which make interest non tax deductible expenses. Sporken (2008) maintained that interest is deductible expense only if such expense is not considered as business expense. Conversely, the rules offer two exemptions to these restrictions. First is that the loans should be taking for the purpose of doing business, second the income should be assess into tax at 10 per cent reasonable level (Van Saparoea. 2009).

Conversely, New Zealand developed a rules to restrict earnings transfer activities in 1996. Smith and Dunmore (2003) maintained that the introduction of the rules was to complement the existing transfer pricing. They assumed that the absence of any formal earning stripping law will fortify the tax net and enable revenue authority to generate revenue and eliminate the opportunities for tax avoidance scheme while also encourage foreign investment. Thin capitalization rule in New Zealand's specifically apply to company that meet ownership test, tax payers residing in the country and non-resident tax payer with equity ownership of 50 per cent and above (Smith & Dunmore, 2003).

2.3.3 Thin capitalization policy in Africa.

The principal duty of revenue authority is the generation of revenue for government and ensure that those revenue remitted to the government appropriate authority. In most countries of the World, Africa in particular, a greater percentage of their revenue is derived from tax. This is one of the several reasons why policies are enacted to encourage trade and growth of businesses. Given tax rate differential and flexibility of tax system in Africa continent, Nigeria in particular. They seems to be unilateral rule restricting capital composition of companies operating in Africa region by Africa countries. This restriction has open many companies eyes to navigating a better avenue that would enable improve profit maximization through payment of low tax. Therefore to achieve entrepreneurial goal, companies are bound to maximise higher profit through the use of any legitimate source of capital to float investment with the objective of reducing tax return.

The major effect of thin capitalization on a company's financial statements is the cost of debt which company have to pay to the debt holder. The cost of debt is interest which tax laws recognise as allowable expenses in the computation of tax liability is often subtracted from the adjusted profit before tax is deducted (Wen-Sheng, et al, 2014). The interest paid on debt instrument is regarded as finance costs and is a tax deductible expense

which often enable reduction of corporate income tax payable. Therefore, for a company, debt incurred has no income tax burden and would facilitate profit maximization for resident company while further enable profit shifting from one tax jurisdiction to another. Thin capitalization rules were introduced in most Africa countries to empower government in the restriction of possible revenue leakage with respect of taxation, a situation where investors roll on the ambiguity of the tax system to remit minimum tax. This practice is often referred to as tax avoidance scheme perpetuated by corporate entity due to it legitimate before the law. Most countries in Africa have enacted laws to deal with the issue debt-equity capital composition by placing a ceiling on debt/equity ratio while some depends on their country's transfer pricing laws to regulate debt/equity mix. From a policy point of view, inability facing tax laws of countries to block unnecessary interest payments to related enterprises and affiliate give transnational companies high tax advantage over domestic trade's activities.

TABLE 5
List of African countries with thin capitalization laws

Country	Safe heaven debt-to-equity ratio	Debt in Colum refers to
Kenya	3:1	Total debt
South Africa	3:1	Related party debt
Ghana	3:1	Total debt
Egypt	4:1	Related party debt
Tanzania	7:3	Related party debt
Nigeria	3:1	Related party debt
Republic of Cameroun	2:1	Related party debt

Source: researcher compilation from various countries finance Act. 2021

Table 4 show list of Africa countries with thin capitalization rule. This table shows safe heaven debt to equity proportion explaining the percentage of debt to equity a company can accommodate in its capital composition as allowed by the various countries tax legislation. In this, excess of permissible ratio will be subject to full tax using appropriate tax rate existing in the country. However, debt in Colum refers to debt arrangement in company transaction, it could be ratio of total debt incurred by the company or ratio of related party debt. In Nigeria, section A (15) of the Finance Act of 2020 introduces a new tax legislation which comprises of provisions disallowing 'high interest' (more than 30 per cent i.e 3:1 of EBITDA of the Nigerian company) payment on a foreign loan with a related party (other than those in banking or insurance industry). The law provide that such interest expense should not be carried forward for a period more than 5 years from the year the excess interest was first acquired. This is to say that, if a country's thin capitalization rule recognises only a ratio of related party debt, any debt incurred by the company must come from related party transactions, otherwise the debt component will be subject to the applicable tax rate. Some countries as seen on the table allow total debt as reported in company's statement of financial position. This gives transnational companies prominence to use debt capital over equity in their financing structure as to enable the reduction of tax payment and maximization of shareholder's wealth.

2.3.4 Transnational tax policy in tax heaven countries.

Corporate organization across the globe have mounted intensive machinery to lessen the weight associated to tax payment so as to enable increase in stakeholder's returns. For this purpose, they develop a practice of locating a saver environment where their investment can be secured without unnecessary disturbance from both internal and external business variables such interest rate, political uncertainty, strike and protest, violence, war and other social cultural indicators. Though, it quite difficult in this 21st century to have well secured

environment where business would strive without seemingly interruption but government of different nations have cultivated vigour to ensure that economic activities are not interrupted in spite severe challenges. The reason is that when economic activities are interruption as a result of environmental and social issue that government would have control, businesses would likewise be affected which could result to depletion of profit and loss of revenue on the part of government.

In recent time, many nations of the world with better regulation and affluent such as Switzerland, Luxembourg, Ireland and Netherlands have used their domestic tax policy to capture several global companies and market economy. This is so because, companies operating in these countries do not pay tax or pay taxes at low rate, hence, most transnational companies prefer to invest in such environment. Tax haven is a region or country where certain taxes are charged at a very low rate or no tax at all. This attract corporate entity to establish subsidiary for the purpose of reducing overall tax burden associated with investing in high tax countries. It became more paramount that corporate entity have chosen to be very efficient in their practices gear towards reducing tax expenses and strategies on a better environment to invest. In attempt to achieve business efficiency and minimise payment of taxes, companies that are involve in tax planning strategy with the purpose of increasing corporate value and expansion through savings. Today, tax planning activities of these manner are encouraged provided they do not harm the system or not being engage vigorously for the detriment of the host country. Chen, et al (2014) establish that tax avoidance is adversely related with firm value, but increases firm value when the firm is among the most transparent. In doing this, companies often locate a state or region where certain taxes are charged at little rate or not at all. Investment in such countries are floated through personal or corporate residency where wealthy individuals and companies operating in jurisdiction with higher tax rate sought to relocate themselves to low tax jurisdiction since in most countries of the world residency is the primary basis of taxation. In most cases,

through holding asset in a region in high tax region and changing the ownership of the assets into an entity where they is no tax or low tax so as to maximise the benefit in that region. Johansson, et al (2016) sees tax reduction strategy as separation between profits and economic activity from which the profit is generated. It involve a circumstances where the effective tax rate of transnational company is hollowly reduced compared to that of related local companies as a result of manipulation of tax systems concerning ambiguities in tax systems. Kawor and Kportorgbi (2014) admitted that tax reduction strategy has a positive relationship with accounting profit.

2.3.5 Thin capitalization and company performance.

Organization performance is measure in many form such as profit measure, growth in term of expansion, effectiveness in services delivery etc. Echekeba & Ananwude (2016) suggested that performance is the blue print of the financial affairs of an entity which reveal how firm prospered. Company's return on investment basically show the solvency and performance of a business concern. They emphasize how company can effectively manage their profitability and how the company performs at generating revenue from the investment. Return on capital employed (ROCE) and return on assets (ROA) are more often used among other performance indicators, because they access the competency of company to generate profit from its capital employed and also give manager, stakeholders and forecaster insight on how efficient organisation could be in the utilization of available asset to produce incomes. There is no how performance improvement will be conceivable without assessing the outcome. Therefore, organizational performance enhancement needs evaluation to detect the position under which the use of organizational capitals have bearing on corporate performance (Gadenne & Sharma, 2002). According to Modigliani & Miller (1958) "firm's value is unaffected by the way that it is financed be it debt or equity". But as

soon as the hypothesis of the absence of taxes is realised, company's value is said therefore to be determined by the utilization of its asset on capital employed. Apparently, company financial policy can affect its performance and should be considered more significant taken both the tax shield and the financial distress cost into account. Jensen and Meckling (1976), opines that increase in leverage teaches self-control in managers as they will be careful of exposing the firm to insolvency. Akhtar, et al (2012) examined the relationship between financial leverage and financial performance of fuel and energy sector in Pakistan. The study established existence of optimistic connection among leverage and the financial performance. In his study, Ojo (2012) maintained that financial leverage results to changes in the returns of shareholders, thus, adds financial risk. Alcock, et al (2013) investigated firm's performance by evaluating the importance of financial leverage of private equity funds. The study showed that moneys over all are incapable to provide substantial performance on the foundation of management expertise that is unconnected to the disclosure of the disparity in the fundamental market. Enekwe, et al (2014) examine the effect of financial leverage on financial performance of pharmaceutical companies in Nigeria. The result shows that interest coverage ratio is confidently associated with recurrence on asset while debt ratio and debt-equity ratio is adversely associated with recurrence on asset. Armstrong, et al (2012) buttressed that tax savings improves the financial performance of corporate entity because they enable further investment into profitable ventures; while Kawor and Kporgbi (2014) maintained that tax savings does not reflect firm growth but it could reduce tax payment.

Several studies were carried out in Nigeria, these studies show consistent results on firm performance and firm's capital choice. For instance in the study of Simon-Oke and Afolabi (2011), using panel data regression model to investigate five quoted firms from the static trade-off and agency cost theory point of view. The study found existence of negative relationship amongst company's performance and debt financing. Semiu and Collins

(2011), employed descriptive statistics and Chi-square analysis to investigate firm capital structure and firms value using sample size of 150 respondents and 90 firms. The study found optimistic substantial association occurs between a company's choice of capital structure and its market value.

2.3.6 Transnational company tax evasion and avoidance.

Tax avoidance could be describe as a circumstance where tax payer organises his financial activities in a manner that would reduce income tax payment to a minimum level. For instance, value added tax can be avoided by refusing to buy the goods and/or taking the services on which value added tax is charged. Apart from not buying the goods or services, tax avoidance mechanism are perpetrated after a serious assessment of the tax legislations. Difficult tax avoidance activities often provide protection for managers to take advantage of themselves devoid of governance controls (Yee, et al 2018). The tax authority and countries government generate reasonable revenue from taxes and they are often use to provide citizens with social infrastructures. Hence, taxpayer would often devises mean to exploit ambiguities in the tax laws so as enable them pay minimise tax. To a reasonable level, tax avoidance is permissible once it is carried out within the confines of the tax laws. While there are several cases of defilements in the tax law, the visionless description of tax evasion as unlawful and tax avoidance as lawful by lawyers and economists has been branded as a hasty deduction because the legitimacy of any tax behavior could not be determined effortlessly (Weisbach, 2003).

However, tax reduces profit and performance of corporate company and individual who engage in trade and economic transaction, this give rise to company's management and individuals to plan their financial activity in other to pay lesser tax. Tax avoidance has no universal definition in accounting literature but many scholars and authors have attempted to examine it differently. Mochamad and Obsatar (2019) see tax avoidance as a range of tax

planning schemes, including activities that are flawlessly permissible. Many researchers and authors are of the view that corporate tax evasion activities are most time wrongly define (Desai & Dharmapala, 2009). This may be connected with the fact tax avoidance is seen as a legal practice that when perpetuated by company will not amount to an offence. Hanlon and Heitzman (2010), explain that tax avoidance reduces unambiguous taxes per dollar of earnings before tax. Dewi and Jati (2014) says that the issue of tax avoidance and technique to employ is wholly company management decision. Desai and Dharmapala (2009) holds that tax avoidance increases after tax profit of transnational company, and it is carried out through transfer pricing mode such as royalty payments and improper purchase of raw materials and sales for the purpose of transferring taxable profits from one country to other countries.

Taxes denote substantial costs to a business and subsequent declines in its profit margin. The information concerning corporate tax fierceness is not new given that they exist both in developed and developing economies. Frank, et al (2009), Richardson and Lanis (2012) contend that tax evasion is the descending exploitation of taxable income via tax planning which may be consider as dishonest activities. Chen, et al (2010) view it more clearly, that tax planning scheme is legal provided they are conducted under the permission of the tax law. Dalu, et al (2012) maintained that tax avoidance distort investment opportunity resulting to individual and companies to underestimate it growth and performance as whereas given low attention to the worth of it asset over a certain time frame. Tax evasion could as far as possible reduce transnational morale, ethics and initiative of maximizing profit as they will focus more basically on the loopholes in the tax laws instead of providing other measures advertising, rebranding etc to enhance profit. Transnational companies repeatedly use affiliate to avoid payment of income taxes, and there are capture by effective tax rate. This transferring of accounting returns from a high tax authority to a low tax authority minimize transnational company's global effective tax rate (ETR). The

global ETR is minimized since the denominator has been the same, while the numerator is lesser than estimated. Generally, firms that evade income taxes through reduction of taxable income while retaining their financial accounting income will have lesser ETRs as measure of effective tax planning.

2.4 Thin capitalization and tax burden of transnational company.

Thin capitalization practice enable companies to arrange their capital by aggregating more debt against equity (Martin, 2012). Debt instrument has greater percentage of interest, so, the greater the amount of debt, the greater interest the company would remit, and the lesser taxable income. Besides, thin capitalization scheme might also assist transnational companies to fund its subsidiary through intercompany credit facilities. The subsidiary company may be situated in a country where the tax rate is lower and could decide to give loans to its affiliate situated in another country where its tax rate is high. In this manner, the affiliate tax liability can lower because interest paid on borrow fund represent an expenditure which allowable deduction in the computation of tax liabilities.

In recent time, many countries across the world have try to respond to the negative consequences of thin capitalization scheme by developing a policy often referred to as thin capitalization law. This rule restrict payment of interest expense beyond a certain debt margin. Many developed nations have existing rule while most developing nations are still faced with the problem of thin capitalization rule. Besides effort made by developing countries to issue thin capitalization rule, government also have a greater responsibility to raise investment by making available financial resources for local investors and inviting foreign companies to invest so as to improve country's economic development. When that is done, government tax net will increase and have more revenue for the servicing of the economy. Though, taxation serve as the most essential revenue source of government, it contribution is quite larger compare to other sources. Moreover, to enable government

finance public infrastructures, it need to increase tax revenue. The enactment of thin capitalization law by countries is projected toward improving government income base, by reducing possible tax avoidance scheme of all forms especially that which has to do with interest deductible debt instrument. Overesch and Wamser (2008) posited that tax benefit ascending from debt instrument is observed not only on the local perspective, but also on the foreign countries, where tax payer are residents of more than one tax authorities.

In general sense, there is no evil in arranging financial activities for the purpose of gaining tax advantage if carried out within the permission of the relevant tax law. Hoffman's (1961) tax planning model affirmed this assertion. He posited that it is quite impressive for companies to comprehend the enabling tax legislation and use same in a way that guarantees tax minimisation. Scholes, et al (1992) maintain that a prosperous firm is one which correctly adjusted its operation to the available tax system. Tax planning policy highlights the need for corporate organization to engage and achieve corporate objectives of profit maximization through application of tax legislation that enable reduction of tax burden.

2.4.1 Bank Loan and tax burden of transnational companies.

Bank credits enable efficient and effective performance of the manufacturing sector of any economy, hence Government across the globe has made laws and policies that aim at achieving economic growth. A bank loan is just like a credit given to individual or corporate entity for a particular period of time with a fixed interest on repayment. Payment of bank loan may be paid on instalment basis or in full depending on the loan arrangement. Management of company need to ensure that the loan is repaid with the principal at the appropriate time to avoid confiscation of collateral and declaration as non-performing loan. Caprio and Klingebiel (1999) described non-performing loan as that which does not produce income over a specific period not less than three months. Ajayi (2000) maintained that bank loan is a credit which serve as an assurance by one person or group of person to pay another

for money lent or goods and services acquired. Bank credits to the manufacturing are mostly referred to as business loan or advances. Business loan provides financial assistance for either small businesses that are in dire need of capital or large ones that need additional funding for expansions (Sanusi, 2010).

Bank loan is considered to be a very lucrative credit advance of bank and importance source of capital for corporate institution because most business operate on credit. This credit need to be properly managed and company also need to ensure that they do not take excessive loan that will be above their capacity on repayment. When company take too much loan, it will be challenging for company to trade effortlessly and could exposed them to bankruptcy and insolvency. It worthwhile to note that manufacturing and other sectors exert a decisive responsibility in the improvement of modern economy because, they are involved in the manufacture of goods and services via collective deployment of raw materials and other production factors. They need loan and support from banking system to enable the facilitation of economy activities for the benefit of consumers. One common feature of loan is that it has an agreed term of repayment of principal and interest. When bank grant credit facilities to individual and corporate institutions, the credit and subsisting interest consist a cash flow from the organization and could reduce profit after tax consideration. From tax authority perspective, the amount paid as interest is tax allowable expenses which relief company from the burden of taxation.

2.4.2 Lease and tax burden of transnational companies.

A lease consist an agreement in which a party possessing an asset (lessor) handovers the right to use the asset to the user (lessee) over a specific agreed term for financial consideration (rentals) with or without a further payment. International Financial Reporting Standard (IFRS 16) defined lease as an agreement whereby the owner of the asset (lessor) transfers to another (the lessee) with the expectation that they will be payment or series of payments in regard to the right to use an asset for an fixed period of time. In lease

arrangement, the use of an asset is obtained through a number of predetermined payments over a period of time. Leasing has been agreed as one of the foundations of contemporary source of finance and area of critical decision for company worldwide (Salam, 2013). Kampumure (2009) maintained that leasing is one of the remarkable arrangement of financing because it is flexible. Gallardo (1997) posited that leasing is concentrated on the ability of lessee to make more cash from the business activities as to make repayment quite convenient since legal ownership of the asset is retained by the lessor. Leasing enhances financial performance of a company by inducing the cost of capital as the free cash can be capitalised in project that can generating cash and enable effectiveness in application of the assets (Tarus, 1997). Ezzell and Vora (2001) found that leasing decreases external costs of finance as a result of information irregularity. Brick William and Marti (1987) contended that, primary motive of engaging in leasing is the variance tax effect company and individual would stand to benefit from holding the assets. In this context, a company with relatively profit margin may not be able to earn the complete benefit of quicker devaluation in the use of the asset, but a company or individual with high income tax may be able to realize such. In this event, the former may have the capacity to grape reasonable percentage of the complete tax benefits by leasing of asset as against purchasing such asset. Competitor amongst lessor may trigger tax benefit to be passed on the lessee in a manner that will result to low lease payment.

2.4.3 Debenture and tax burden of transnational companies.

Debentures serve as a long term form of finance to a company and it is cheap to obtain. It is suitable to companies which have regular earnings to service the debt and for those who fixed asset proportion is high which provide cushion to security and serve as motivator to investors during depressed market conditions. Debentures as a source of long term debt enable company to grow faster because it is less cost-effective compare to other forms of lending. Debentures holders are entitle to a fixed rate of interest and it is paid before

consideration is given to equity holders during event of liquidation. The interest paid to debenture holders is tax deductible during computation of corporate tax liabilities, this fixed interest payment to the individual or corporate entity may leave a larger percentage of earnings available for equity holders (Kaufman, 1948). The use of debentures by corporate entity should ensure pecking order for the repayment of capital to the creditor. Pecking order, as contended by Myers (1984), is one of the method of avoiding transfer of wealth to outsiders and adverse effect in issuing equity capital. However, company financing its operations with debenture loans have the privilege of benefiting from tax savings arising from the interest payment which enable reduction of tax burden during computation of tax liability.

2.4.4 Corporate bonds and tax burden of transnational companies.

Market participant and patronage of corporate bond has improve in recent time and have become bigger in term of coverage over the last period. It has nearly tripled in size since 2000 and has inflated as a percentage sum of global company funding in recent time (Nzau, etal 2019). Corporate bond market is seen as a vibrant item in economic progression, stability of money in circulation and economic recovery. The market provide a basic capital funding that flow to corporations which enhances corporate expansion, modernise, and afford employment, products and services for the people (Kapchanga, et al 2018). Onyuma (2017) see corporate Bonds as long-term debt instruments issued by the private sector due for one year and above. A bond is regarded as a corporate debt instrument, which is subject to negotiated and is a common source of funding in capital market. Corporate bonds are hard to trade and the probable transaction cost is higher compare to the primary unpredictability of the asset class (Harris, 2015). The bond could be those that bear interest

or corporate safety that necessitates the issuer of bond to pay the bondholder an identified sum of money in a common way, habitually at specific time frame, and to repay the prime amount of the loan at maturity. In the face of insolvency, bondholder has a right to receive interest before equity owners, but has no corporate ownership privileges, as shareholders do. An interest is paid to a bondholder on annual bases depending on the arrangement between the bond issuer and bondholder upon the presentation of the bond titles. A secured bond is supported by warranty which may be purchase by the bond owners to satisfy claim that bond issuer fails to pay interest and the amount borrowed as they fall due. This Interest paid to bondholder by the bond issuer constitute tax deductible expenses during the computation of tax liabilities, and provide succour to company by reducing tax burden that would have eaten up profit in each year.

2.5 Review of empirical literature.

The concept of thin capitalization has stock a strong contention amongst scholars in recent time due largely to its influence on income shifting and tax repatriation strategy employed by Multinational Corporation. Waluyo and Caturida (2018) conducted a study on factors affecting tax avoidance via thin capitalization, with objectives of examining how multi-nationality hinders tax avoidance via the policy of thin capitalisation, the use of tax havens to stimulate tax avoidance and whether Institutional ownership effects tax avoidance. The study obtained data from 122 transnational companies using their reports and accounts, the companies were those quoted on the Indonesian Stock Exchange. The study employed purposive sampling techniques for sample determination and data was analysis using path analysis. The results shows that multi-nationality and the use of a tax haven exerted optimistic effect on thin capitalisation, while institutional ownership exerted adverse effect on thin capitalisation. The study recommended that governments should make necessary

effort to understand tax evasion scheme and improve on tax evasion prevention rules base on the circumstance.

Agus and Ety (2019) examined effect of intra group transaction, thin capitalization and executive characteristic on tax avoidance with multinationality as a moderator. The objective of the study was to investigate the issues surrounding tax avoidance in business and corporate groups in Indonesia, specifically those in property industry. Variables used in the study was company size, profitability, incorporeal property and debts capital was used as control indicator. The research sample was drawn from companies in property sector and the real-estate sub-sector and data obtained from the Indonesia stock exchange covering five years period using purposive sampling technique. The study employ panel regression method and ordinary Least Square method for data analysis and the results indicated that variables of intercompany economic activities and executive characteristics exerted optimistic and substantial influence on tax avoidance, while thin capitalization exerted no non significance influence on tax prevention. The study recommended that directorate general should innovate a tax compliance techniques so as to improve taxpayer compliance in both individuals and companies.

Darmansyah and Bambang (2018) did a work on analysis of transfer pricing, thin capitalization and tax heaven utilization against tax avoidance, with objectives of examining whether the application of transfer pricing has an influence on tax evasion, whether thin capitalization has an effect on tax evasion, whether tax haven operation has an effect on tax evasion and whether the transfer pricing influences tax avoidance. The result was moderated by corporate social responsibility. The study employed purposive sampling method and data was obtained from 63 manufacturing companies listed on the stock exchange during the period of three years period. Panel regression and descriptive statistics was used for the analysis of data collected and the result revealed a substantial effect between transfer pricing and tax avoidance, while thin capitalization and tax haven operation showed no substantial

influence on tax avoidance. It was recommended that government should provide a stiff policy to regulate incidence of transfer pricing amongst inter group.

Huizinga, et al (2008), carried out a study on capital structure and international debt shifting, with the objectives of examining how transnational company financial arrangement and international tax system impact debt/equity ratio in Europe, and whether the studied firms are parents or a subsidiaries of a multinational or a domestic firms, and offer information on tax structures of all the location where the transnational carried out its activities. Data set for the study was obtained from the Amadeus database, the data consisted of ten (10) years data for both holding company and subsidiaries, and parent year observation of about 38,736 subsidiary were used for the study. It was found that company debt strategy do not only reveals changes in domestic company tax rates but also modifications in international tax systems affect debt shifting. The study recommended that government should upsurge domestic tax rate and strengthen policy on fund repartition as measure of improving revenue base.

Blouin, et al (2014). Conducted a study on thin capitalization rules and multinational firm capital structure. The objectives of the study was to investigate the impact of thin capitalization law on the capital formation of the overseas associate of US transnationals. The sample size of the study consisted of 56,596 affiliates and data obtained from five benchmark years observations. Descriptive statistics and correlations were employed for the investigation and the result showed that thin capitalization rule affect firm's value and reduce aggregate interest expenses within the multinational. Furthermore, the study found that thin capitalization rules exercised a significant effect on the capital composition of transnational companies. It was recommended that revenue authority should improve enforcement of thin capitalization rule to enable revenue multiplication.

Heckemeyer and Overesch (2017) studied multinational profit response to tax differentials: effect size and shifting channels. The objective of the study was to examine

profit-shifting behavior of transnational company, the study used sample of 27 MNEs' profit response to international tax rate differentials, data were collected from the sampled firms and was analysis using meta-regression analysis. The result showed that a device for unnoticed heterogeneity in profit transfer prospects across companies is connected with considerably minor tax effects on stated profit. The study recommended that national governments and tax administrations should design an approach to reduce anti-avoidance tax scheme.

Johannesen, et al (2020). Investigated whether under developed countries are exposed to transnational tax avoidance. The objectives of the study was to ascertain whether tax avoidance by transnational companies is more predominant in under developed countries. Data were drawn from 210,000 corporations in 142 countries. Data obtained from the studied multinational corporation were analysis using regression method and percentages method. The result of the study indicated that the feeling of informed profits to transferring motivations is adversely associated to the rate of economic and institutional development. The study recommended that developing countries should make reasonable step on legislative advances to reduce larger exposure to profit shifting.

Yoo and Lee (2019). National culture and tax avoidance of Multinational Corporations. The study objective was to ascertain the purpose of national culture in tax avoidance by transnational companies. Four cultural dimension was used to measure differences in countries cultural practices; they includes vagueness avoidance, individuality, masculinity, and power distance. The sample comprises of 36,235 observations located in 31 nations covering the period between 2008 to 2015. This study uses data obtained from Bureau van Dijk's Orbis database, and regression and were analysis using descriptive statistics, regression and correlation analysis statistics. Findings shows that the cultural characteristics of subsidiary nations are vital factors of tax avoidance by transnational companies. The study recommended that policymakers in each nation should take into

consideration the cultural characteristics of their nations when drafting and forecasting the anti-avoidance laws. Policy makers should also introduce guidelines limiting cultural characteristics of companies that are associated to tax avoidance.

Clausing (2009). Multinational firm tax avoidance and tax policy. The study objective was to consider the challenges of tax policy of both real and financial forms of international tax avoidance, focusing on U.S. transnational companies over the period 1982–2004. Data was obtained from Bureau of Economic Analysis reports in U.S. The data were analysis using descriptive statistics and regression method. The results indicates that US tax rates have been relatively constant that led to loss of revenue and increase income shifting incentives of US tax base. The study recommended that government should construct a formula to minimize the distortion in tax rate and disincentives associated with US residence.

Boateng and Vitenu-Sackey (2019) carried out a study of Corporate Governance Variables Influencing Thin Capitalization in Ghana. The objective of the study were to; evaluate the effect of corporate governance on thin capitalization in Ghana, identify corporate governance variables and determine the extent at which corporate governance hinder thin capitalization. A sampled comprises of 42 registered firms quoted on the Ghana stock exchange was used for the study. Data was obtained from annual reports and accounts of the study firms, the data was analysed via correlation matrix, least square while co-integration tests was conducted on the data set. It was revealed in the study that corporate governance exerted a substantial influence on thin capitalization thus the engagement of external auditors ought to have account for accurate activity of companies and directors disclosure. The study recommended that good corporate governance policies should be develop among all corporate bodies.

Buettner, et al (2012). The impact of thin-capitalization rules on the capital structure of multinational firms. The objectives of the study was to analyses the efficiency of restrictions

on the amount of tax deductibility of interest expenses for transnational companies. The study sample size estimation consist of 41 European countries from 42,950 observations. The study used panel regression technique for the analysis of data obtained and it was revealed that thin capitalization rules efficiently decrease the benefit accompanying the use of intercompany loans for tax planning but increasing benefit arising from the use of external debt. It was recommended that revenue authority should strengthen the enforcement of thin capitalization policy to enable revenue multiplication

Using data set of German multinational firms, Fuest, et al (2011) conducted a study on international profit shifting and multinational firms in developing economies. The purpose of the study was to examine whether intra-group loans of associate company operating in tax heaven region respond more considerably to taxation in emerging economy than those in advanced economy. Sample size of the study consists of 27,750 associate companies residing in 22 developing countries. The study used panel regression technique and descriptive statistics for the analysis, the result indicated that associates of transnational companies situated in countries with low tax rate provides loan to associates situated in high tax countries. The study further revealed that minimal changes occasioned by effect of a tax rate in emerging economy is double as high as in advanced economy. The study recommended stiff policy to reduce tax ceiling on inter party loan arrangement of companies.

Wen-Sheng, et al (2014) carried out a study on the Impact of Anti-Thin Capitalization Rules on Capital Structure in Taiwan. The objective of the study was to investigate whether anti-thin capitalization law on company capital arrangement after the promulgation of the anti-thin capitalization laws in Taiwan. A sample of 23 registered companies was used for the study, and panel regression method was used for the analysis. The empirical results indicated that company's overall debt-to-equity ratios reduced considerably after thin capitalization laws was enactment while provisions restricting capital

dwindling was found to be effective. The study recommended the enactment anti-thin capitalization rules for non-debt tax shields, research and development as to drive investment growth opportunities.

Pratama (2017) conducted a study on does corporate governance reduce thin capitalization practice? the case of Indonesian multinational companies. The objectives of the investigation was to examine corporate governance-related variables in driving the practice of thin capitalization. Board of commissioner's size and proportion of independent commissioners was employed as representative for corporate governance. The study used 31 firms and 93 observations for the period three years. For the data analysis, multiple linear regression was employed and the result indicated that the board size of commissioners adversely influence thin capitalization activity. The study recommended that regulatory institution and corporate entity should evaluate and support the monitoring instrument of corporate governance put in place by management structure.

Ebaid (2009) examine the impact of capital structure choice on firm performance: empirical evidence from Egypt. The study specific objectives was to examine the effect of company financial arrangement on company's performance in Egypt. The sample of the study comprises of 26 non-financial quoted companies in Egypt, where data were acquired from the firm's financial statement for the period of nine (9) years. The study observed a fragile connection between firm's performance and debt structure of Egyptian firms. It was further revealed that the link amongst the substitutes of the debt capital on the return on equity is substantial. Whereas aggregate debt to assets and the short term debt has adverse and substantial influence on the firm's return on asset.

In Malaysia, Ong and Teh (2011) examined capital structure and firms performance of construction companies. The study specific objectives were to; evaluate the nature of connection concerning capital structure and corporate performance of companies in building

segment pre and post crisis (2005-2008), classify the interdependence concerning capital structure and corporate performance of companies in construction segment before and during crisis (2005-2008) and investigate the stability of the companies' capital composition in the building segments pre and post the crisis (2005-2008). The study used long term debt to capital, debt to asset, debt to equity market value, debt to common equity, long term debt to common equity to represent capital structure whereas company performance was measure in the study using returns on capital, return on equity. The study used 49 construction companies and they were separated into big, medium and small sizes according to their capital base. The study obtained four (4) years data from the annual reports and accounts of the companies, and ordinary regression technique was used for the analysis. The result indicated the existence of a subsisting association between capital composition and company corporate performance. Basically, the study shows that long-term to common equity exerted straight influence on corporate performance of intermediate enterprises but other capital structure variables exerted no effect on performance. The study recommended that future policies on capital structure compositions should be made with precaution.

Lawal, et al (2014) study effect of capital structure on firm's performance using manufacturing companies in Nigeria as case study. The objectives of the study was to; evaluate the relationship existing amongst total debt and returns on assets and investment, investigate the relationship concerning the use of debt and equity and returns on assets and appraise company capital composition and performance in Nigeria. The study sample comprised of ten (10) listed companies on the Nigerian Stock Exchange. Ten (10) years data obtained from financial statement of the companies was used for the study, descriptive and regression methods was used for the analysis and the result found that overall debt and debt -to-equity percentage has adverse correlation to firm performance. The study recommended the use of debt other than equity in financing business activities, in as much that debt capital improved company performance.

Bambang, et al (2012) examined the company policy, firm performance and firm value in Indonesia. The objective of the study was ascertain whether company financing policy influence firm value. Company policy is proxied by debt ratio, bond and stock while performance was presented by return on asset. Sample of the study include all manufacturing companies quoted on the Indonesia Stock Exchange. Purposive sampling method was employed and two (2) years data was gotten from annual financial report of the firms. The technique of analysis used in the study was regression method and the result indicated that the mixture of debt and equity has a substantial adverse influence on performance, and exerted a substantial optimistic influence on firm value. The study recommended that management should carry out a policy that would exploit the use of debt instrument in capital outlay to enable increase in company value.

Wamser (2008) investigated impact of thin-capitalization rules on external debt usage: a Propensity Score Matching Approach. Specific objectives of the study was to; carefully ascertains how transnational companies restriction response rate on interest reductions acquired for internal borrowing affect transnational behaviour. The study used 3309 observation drawn from companies operating in 21 European countries as sample size. Ex-po facto research was employed, and the study used both descriptive statistics and ordinary regression model for analysis of data gathered from annual financial reports of the companies. The outcome indicated that restriction on internal debt are related with increases in external debt, showing a replacement connection amongst companies. This imply that companies, to certain category, are able to substitute external for internal debt. The study recommended that policy maker should carefully scrutinise thin capitalization policy so as to secure corporate tax revenue.

In a similar, Chandrasekharan (2012) examines determinates of capital structure in the Nigerian listed firms. The study used firms' tangibility, size, growth, profitability and age on the leverage as variables for the study. The study sample consist of 87 firms listed

on the Nigerian stock exchange covering the period of ten (10) years. The sample selection process used in the study was convenience sampling technique. The study used panel regression method for the data analysis. It was found that company size, growth and age are substantial with the debt ratio of the company, while, profitability and tangibility are not. The study recommended for company to embark on debt financing policy, food, beverages and tobacco firms, must organize and correctly extent variables like size, age, growth, lucrativeness and tangibility of the company.

Prepeh, et al (2016) investigated effect of debt policy on firm's performance: empirical evidence from quoted manufacturing companies on the Ghana stock exchange. The objectives was to assess the influence of debt policy on firms' performance. The study data was obtained from five (5) manufacturing firm quoted on the Ghana Stock Exchange (GSE). Panel regression technique was employed to ascertain the significant relationship amongst the debt ratios and the performance indicators. Findings from the study indicated that quoted manufacturing companies in Ghana employed the mixture of debt and equity capital in its composition but the proportion of debt capital was higher than that of equity capital. It was recommended that manufacturing companies should increase the equity component of their capital mix so as to exploit the advantages surrounding the use of leverage.

Dube (2013) investigated the impact of debt financing on productivity of small and medium scale enterprise: SMEs in Masvingo Urban as case study. The purpose of the study was to examine the influence of debt financing on the activities of SMEs in Masvingo. The study developed questionnaire instrument to obtained sample from 80 SMEs, and secondary data were also obtained from the SMEs records. The study used ordinary regression method for the analysis of data and the findings revealed that debt finance exerted an optimistic effect on efficiency of SMEs. The result also indicated that companies received suitable funding from banks loan to expand their output. The study further showed that benefit of

interest payment enable companies to borrow suitable amount of debt to finance investment opportunity. It was recommended that financial institutions such as bank should give long-term debt to SMEs as to qualify them keep track of investment opportunity, acquire capital equipment and increase construction in future as well reducing of interest rates to stimulate SMEs growth.

Karuma, et al (2018) examined effect of debt financing on financial performance of manufacturing firms in Nairobi, with objective of ascertain whether short-term debt, long-term debt, interest rates and income tax rates affect performance of companies. The study population covered all the quoted manufacturing companies on the NSE from 2013 to 2017. Multiple linear regression technique and descriptive statistics was used for the analysis, and findings indicated that debentures was exerted substantial association with ROA, it was revealed that bank loan and interest payments stood non-significant to ROA. The study recommended that manufacturing firms need to issue long term debt instrument such as debenture and should be careful with the interest on tax as measure of improving after tax income.

Nwaobia, et al (2016) studied tax planning and firm value: evidence from Nigeria consumer goods industrial sector. Precise objective was to investigate the association concerning tax planning and company value. Variables used in the study were total asset, debt, preferred stock and market value of equity as control variables. Sample size for the study consisted of 80 manufacturing companies quoted in the Nigeria stock exchange but 10 companies in the consumer goods company were used for the study. The study period was 5 years covering 50 firm-year observations. The study data was drawn from annual reports and accounts of the companies and panel regression techniques was used for the analysis. The result of the analysis indicated that tax planning influence company value but the magnitude of the influence is contingent on the variables used as tax planning indicator. It was recommended that companies should not concentrate their value boosting instrument

on tax planning only since the study to explain differences in tax planning indicator as measure of firm value positioning.

The study of Rohaya, et al (2010) on corporate tax planning: A study on corporate effective tax rates of Malaysian listed companies, with the objectives of examining the degree at which company effective tax rates affect authorised assessment tax scheme and self -assessment tax scheme (2001-2006), and to examined the elements of effective tax rates (ETR) of Malaysian public quoted firms during both tax regimes. The sample comprises of firms from nine areas registered on Bursa Malaysia. The data sample covered a period from 1993 to 2006, and the study used descriptive statistics and univariate analysis why sectorial analysis was conducted for each sector. The result indicated that current-based ETR was absolutely correlated with scope during both the official assessment system (AAS) and statutory tax rates (SAS) regimes. The result imply that bigger companies encountered greater income tax burdens. It was recommended that revenue authorities should assume tax appraisal and examination to trace illegal tax planning doings.

In Nigeria, Ogundajo and Onakoya (2016) examine tax planning and financial performance of Nigerian Manufacturing companies. The key objective of the study was to carryout in-depth evaluation on the influence of tax planning on firm financial performance. A sample of 10 companies was used out of 28 listed consumer goods companies, data were obtained from these companies' annual reports and accounts. Generalized Least Square (GLS) regression model was employed for the analysis, Hausman's model estimation test was also carried out for the study. The study found that companies in Nigeria have not fully utilized the loopholes in the tax law and taking advantage of several tax incentives and thin capitalization scheme to reduce tax burden. It was recommended in the study that manufacturing companies in Nigeria should make tax planning a critical strategy and engage the services of tax and finance professionals in tax related issues as to facilitate the maximization of tax benefit.

Kariuki (2017) examined the effect of corporate tax planning on the financial performance of listed companies in Kenya, the study objective was to ascertain whether corporate tax planning have impact on corporate performance. Tax planning was represented by income tax, liquidity was represented by current ration, firm size and leverage while performance is presented by return on asset. A sample of 64 registered firm on the Kenya stock exchange, where data was obtained from annual reports and accounts of the study firms. Descriptive statistics and regression method was employed for the analysis and the result showed that corporate tax planning and liquidity exerted optimistic and statistic relationship while leverage exerted negative relationship. The study recommended that companies should put adequate measures to enhance and raise performance of companies through corporate tax planning.

Fazliza and Natrah (2019) examined the determinate of corporate tax avoidance strategies among Multinational Corporation in Malaysia. Tax return data from Inland Revenue Board Malaysia (IRBM) was used for the study. Tax avoidance was represented by effective tax rate (ETRs), tax payable, total sales, total assets, profit before tax, debt, fixed assets, purchases, ETR, firm's size were variables of the study. A sample of 1,187 multinational categorized as high risk were selected for the study. The results indicated that firm's size, profitability, size of overseas branch and capital strength are the elements of the tax avoidance of transnational companies in Malaysia. The study recommended tax enforcement should be implemented efficiently in a manner that would minimise administrative and compliance costs of tax collection.

Olabisi, et al (2019) investigated corporate tax planning and performance of Nigeria listed, with the objective of examining the association amongst tax planning and performance of Nigerian quoted oil and gas companies. The study used effective tax rate, firm size, firm age, financial leverage and Return on Assets as variables. Descriptive research design was adopted and six years (2012-2017) data set was obtained from annual

reports and accounts of the study firms. The study employed descriptive statistics and pooled ordinary least square regression method was used for the analysis. The result indicated that effective tax rate, firm size, and firm age exerted substantial association with return on asset of the study companies. The study therefore recommended that companies in Nigeria should integrate tax planning scheme into their financial policy for enhanced performance.

Imad (2013) carried out a study on debt-performance relation: evidence from Jordan. Debt was presented by long term debt, short term debt while measurements of profitability ratio were proxies by return on asset and return on equity. A sample of 77 Jordanian companies was used for the study, the covered a period of ten years 2000 to 2011. Data for the study was collected from the company's financial reports and accounts, and was analysed using unbalanced pooled cross-sectional time series regression technique. Findings indicated that debt component reported as long-term, short-term, and total borrowing exerted a substantial effect on asset yield. The study recommended that firm should not depend heavily on external funding.

Prempeh et al (2016) conducted a study on effect of debt policy on firms' performance: empirical evidence from listed manufacturing companies on the Ghana stock exchange. The study objective was to empirically investigate the impact of debt policy on firms' performance. Gross margin profit, return on assets, short-term debt, long-term debt and total debt were measure of variables. Data for the study was obtained from five quoted manufacturing firms on the Ghana Stock Exchange using ten (10) years financial statement. Panel data regression technique was employed for the analysis and was found that debt exerted adverse impact on firms' performance. The study recommended that quoted companies should decrease the rate of equity finance and exploit the advantages of leverage

Kwadwo, et al (2016) conducted a study on effect of debt policy on firms' performance: empirical evidence from listed manufacturing companies on the Ghana stock exchange. Specific objectives of the study was to empirically examined influence of debt

policy on company's performance. Ten years data was obtained from five quoted manufacturing firms' annual reports and account, this firms were listed on the Ghana Stock Exchange (GSE). The study employed panel regression method for the analysis, the result indicated that manufacturing company in Ghana used 14% equity and 86% debt in their capital structure. The debt structure was found to constitute about 49% long-term and 37% short-term. The study recommended that government should take adequate measure to grow a capital market that will permit businesses access to long-term capital given the benefit surrounding debt capital.

In their work, Ezekiel, et al (2016) examine effects of debt financing on businesses firms financial performance. Study objectives were to; determine the association amongst debt ratio and financial performance of selected quoted firms in Kenya, investigate impact of short term debt ratio on company performance and examine the how long term debt ratio affect company performance. Short term debt ratio, long debt term ratio and return on asset were variables of the study. Population of the study consist of 60 companies from where sample was drawn. The study data was collected from annual financial statement of the firms for the periods of 2009- 2012. Regression technique was used for the data analysis and the result revealed that a unit rise in short term debt decreases return on asset by one but the result concerning profit margin ratio exerted a diverse result. The study recommended that a thin based investigation on particular sector or company be conducted so as to find out the effect of firm financial composition on performance.

Sohail and Ulfat (2019) examine effect of debt financing on firm performance. The objective aimed at ascertaining whether debt financing affect performance of non-financial sector of Pakistan. The source of data was secondary, obtained from a sample of 360 firms quoted on Pakistan Stock Exchange secondary data obtained. The study used Panel least square for the analysis and Hausman test were also conducted on the data set. The results shown that debt financing exerted adverse but substantial influence on company's

performance. It was recommended that firms should not depend only on internal source of finance because of low-cost involving the acquisition to neglect other sources of finance that create participation in corporate policy formulation.

Shireen (2019) conducted a study on effect of Debt ratios, and total assets on the earnings per share in Arab Bank and Housing Bank. The study objectives was to; ascertain the impact of debt ratios on company earnings, examine the impact of total assets on company earning, determine whether there is a statistical substantial association amongst debt ratios and bank earnings. The study population was 13 commercial banks quoted on the Amman Stock Exchange for the period of 14 years. Data for the study was obtained from annual financial statement of the banks, descriptive analytical method and ordinary least square method were employed for the analysis. The result revealed that there is no substantial link among debt ratios of Arab Bank and Housing Bank. Findings also revealed that there is no association existing between debt and earnings per share in Jordanian Banks. It was recommends that stakeholders should invest in banks with viable assets to enable increase in earnings per share and reduction in risk return of the investment.

The study by Korkmaz (2016) examined the effects of profitability ratios on debt ratio: the sample of the Istanbul stock exchange manufacturing industry. The study objective was to measure the relationship amongst debt and profitability ratios of firms quoted on the Istanbul Stock Exchange. Variables used were asset growth ratio, current ratio, leverage ratio, cash rate, new borrowing rates, total financial liability/total liability ratio as measure of debt ratio while return on equity and return on asset represents profitability. Sample size comprises of 86 manufacturing firms between the years 1994 and 2015. The study used panel regression technique for analysis of data, and the result revealed that real growth and return on equity exerted optimistic and substantial influence on new borrowing rate. The study recommended that companies operating within the manufacturing sector should take

financial policy formulation seriously to enable its stabilization given benefit accruing from the use of debt capital.

Zaidi, et al (2019) studied influence of debt financing on firms performance: A study of consumer product industry in Malaysia. The main objectives was to; examine the link between account payable (AP) and company performance, ascertain the association amongst short-term debt (STD) financing and performance of company. The study used return on asset to represent performance while payable (AP), short-term debt (STD), long-term debt (LTD), and firm size were used as debt financing. Data of the study was obtained from consumer product companies listed on the Malaysia stock exchange. The study covered fifteen years from 2001 to 2015. Out 131 firms, a sample of 99 firms were used as sample. From the data obtained, the study employed ordinary regression method for the analysis and the findings indicated the existence of substantial link amongst short term debt and long-term debt on the performance of consumer product companies. It was recommended in the study that companies should consider composition of debt and equity capital in their financing policy resolution to secure leverage benefit and performance enhancement.

Mandeep and Pooja (2016) carried out a study on effect of lease structure on financial statements and performance of companies. The study objective was to; investigate how operating and finance lease affect the financial performance of companies. The study considered 72 manufacturing firms quoted on the Indian stock exchange from 2010 to 2015. Data for the study was obtained from annual financial statement of the company's for the various years. The study used descriptive statistics and regression model for data analysis. Finding shows that current ratio was greater in operating lease than financial lease this means that firm operating via operating lease are generally having good short term financial capacity. The study recommended that firm should consider operating lease so as to enable

them secure the benefit accruing to the use of operating lease to boost good short term financial capacity.

Marwan (2014) examine impact of leasing decision on the financial performance of industrial company. The objective of the study were to; examine whether leasing enhance the financial performance of the Jordanian industrial companies, investigate whether leasing intend to achieve profits for Jordan's industrial companies, whether leasing affect the risks of Jordan's industrial companies, whether leasing have an effect on the liquidity of the Jordanian industrial companies and what are the factors and variables affecting the leasing decision of Jordan's industrial companies. Study sample consist of the 163 Jordan industrial firms quoted at Amman Stock Exchange (ASE) during the period (2001 - 2011). The study obtained data from annual reports and account of the study firms and ordinary least square method and Pearson correlation method was used for the analysis. Finding shows that lease financing represented by lease index exerted substantial link with the liquidity of companies. The study further revealed that lease financing represented by lease index also showed a positive substantial influence on companies profitability represented by earnings per share. The study recommended that companies that use lease financing should to compare between the lease expense and amortization rate before embarking on a rental asset.

Akinbola and Otokiti (2012) conducted a study on effect of lease option as source of finance on the profitability performance of small and medium enterprises in Lagos state. The study purpose was to identify if there is optimistic effect on leasing on organisational performance and if leasing is an option the can be consider by other firms. The study employed cross sectional survey using multiple-stage random sampling, and questionnaire instrument was used to draw sample from the population. The study used a sample of 300 respondents who were managers of SMEs in Lagos. The study used frequency tables, simple percentage, and analysis of variance and correlation method was employed for the analysis. The findings indicated that lease option have optimistic effect on profit of SMEs. The study

recommended that leasing companies should come up with leasing solution that SME can easily afford as to increase productivity.

Umar, et al (2016) did a work on impact of lease financing and financial performance of oil and gas companies in Nigeria, with the objective of examining whether finance lease impact financial performance of oil and gas companies. Return on asset company size (log of total assets), debt (debt to total assets) were variables used for the study. The study obtained data from annual reports and account of 6 sampled companies in the oil and gas industry. The data were analysis with the aid of ordinary least square regression method, and the results indicated that finance lease exerted a substantial influence on the return on asset of the companies. The study recommended that oil and gas companies should embrace finance lease as a better lease option other than operating lease.

Odunayo and John (2019) study corporate tax planning and financial performance in Nigerian non-financial quoted companies. The study objective were to; examine the link amongst corporate tax planning and companies financial performance. The study sample consist of 47 non-companies, data was obtained these companies published financial statement from 2007 to 2016. The data collected was analysis with the aid of panel vector autoregressive method for analysis. The result shows that saving from tax expenses exerted a substantial link with company's financial performance while tax avoidance showed contrary association with financial performance. The study recommended that companies should identify others viable tax avoidance technique that will enable greater tax savings through interest deduction in boosting after tax company financial performance.

Kawor and Kportorgbi (2014) investigated effect of Tax Planning on Firms Market Performance: Evidence from listed firms in Ghana. Specific objectives of the study was to; examine tax planning of firms in other to establish the linkage amongst tax planning and companies performance in the stock market. The study make use of 22 non-financial companies quoted on the Ghana Stock Exchange, 12 years data from companies financial

activities was obtained and used. From the data obtained, panel regression technique and ordinary least square method was employed for the analysis. Findings show that firms' penchant to involve in aggressive tax planning scheme decreases once tax authorities keep corporate income tax rate low. It was also revealed that tax planning has unbiased influence on firms' performance. The study recommended that investors should establish a systems that would guarantee tax planning benefits replicate meaningfully in their pockets.

Stefan (2018) used ordinary least square method to examine whether tax planning effects profitability. The objectives of the study were to; investigate expenditure on capital assets affect tax planning, examine whether tax planning affect performance of small enterprises, assess how tax planning through advertisement expenditure impact performance of small enterprises. Variables used in the study are effective tax rate (ETR), logarithm of total assets, debt ratio, asset turnover ratio (ATR), return on asset (ROA) and return on equity (ROE). The study sample consisted of 23 companies was used for the study, the companies were those listed on the Belgrade Stock Exchange. The study adopted a descriptive survey method, and questionnaire instrument was used to elicit information form respondents from the sample. The study was survey in nature and data were obtained with the aid of structured questionnaire instrument. The data was analysed using descriptive statistics, frequency distributions and measures of central tendencies. The result found that tax planning exerted substantial and optimistic influence on SME's profitability but has no effect on SME's market value. The study recommended that small scale enterprises should to seek professional guidance from expert on issue relating to tax planning and utilize the opportunity surrounding tax planning benefit to secure tax advantage.

Adebisi and Okike (2015) investigated impact of non-performing loans on firms' profitability of banks in Nigeria. The main objectives were to; examine the linkage concerning non-performing loans (NPL) and return on assets (ROA) of Nigerian banks and assess the extent of the linkage amongst non-performing loans (NPL) and return on equity

(ROE) of Nigerian banks. The study obtained data from annual financial statement of banks and Nigeria deposit insurance corporation (NDIC) annual report from (2006- 2012). Content analysis approach was used for data sorting. Data collated were analysed using the regression statistical tools and was found that non-performing loan do not exert significant influence on return on asset while substantial association was found amongst non-performing loan and return on equity. The study recommended that for banks in Nigeria to overcome the challenges of non-performing loan, banks should confirm that customers has viable means of repayment.

Chude and Chude (2014) examined implication of non-performing loan on economic growth in Nigeria. The study objective was to specifically examine the consequence of non-performing loan on economic growth in Nigeria. Sample size comprises of all registered banks operating from 1992-2009. The data for the study were collected from annual financial statement of the banks. Data analysis was analyse with the aid of quantitative technique and ordinary least square. The study found a long run linkages among non-performing loan and economic growth while substantial affiliation was found between rate of inflation and non-performing loans. The study recommended that banks should make concrete effort to develop maturity profile that would accommodate matching of their assets and liabilities.

Amahalu, et al (2017) studied loan management and financial performance with a focus of deposit money banks in Nigeria. Specific objectives were to; ascertain the extent of linkage between loan management and return on asset of quoted bank in Nigeria, examine the level of the association amongst loan management and earnings per share (EPS) of quoted bank in Nigeria and ascertained the extent of association amongst loan management and dividend per share (DPS) of quoted bank in Nigeria. In the study, loan management was represented by non-performing loan and deposit while performance was measured return on asset and earnings per share. Study sample size consist of fifteen (15) commercial banks,

and data were gathered from six (6) years published financial statements of the study banks. The study employed Pearson co-efficient of correlation movement and regression technique for the analysis. The result showed the existence of optimistic and statistically substantial association between loan management and performance. It was recommended in the study that banks in Nigeria should improve on policy issue surrounding credit analysis and loan management.

Ebele and Iorember (2016) studied effect of commercial bank credit on the manufacturing sector output in Nigeria from 1980 to 2015. Bank credit was represented by inflation rate, interest rate, loans and advances and broad money supply. Sample size of the study consist of all listed banks in Nigeria from 1980 to 2015, data was obtained from the banks web site and Nigerian stock exchange fact books. Data gathered were analyse with the aid of ordinary least square techniques (OLS), the result indicated that inflation rate and interest rate exerted negative influence while loans and advances and broad money supply showed constructive influence on manufacturing company's productivity in Nigeria. It was recommended that government should formulate and implement rules that will necessitate reduction and stability of both inflation and interest rates to encourage radical growth in manufacturing sector while effort should be made to growing lending rate and general money supply.

Eburajolo and Aisien (2019) examined the effect of commercial bank sectorial credit to the manufacturing and agricultural sub-sectors on economic growth in Nigeria. The objective of the study was to; establish whether financial sector development enlarge commercial credit to real sector in the Nigerian economy. Variables used for the study were real GDP, bank sectorial credit to manufacturing and agriculture subsectors, monetary policy rate and financial market development. The study used annual data acquired from Central Bank of Nigeria statistical report from 1981 to 2015. The result indicated presence of substantial short and long run connection amongst bank credit to the manufacturing and

agricultural subsectors economic growth in Nigeria. The study recommended that Central Bank of Nigeria should develop a thoughtful policy that will encourage commercial banks credits awareness to manufacturing and agricultural subsectors of the economy.

Ronen, et al (2018) examined common factors in corporate bond returns. The study was based on a comprehensive panel of U.S. corporate bonds firms between January 1997 and April 2015. The study firm comprises of all residents' bank of America Merrill Lynch investment-grade (U.S. Corporate Master) and high-yield (U.S. High Yield Master) corporate bond indicators. Sample size includes 274,665 unique bond-month observations issued by 4,296 unique firms and data obtained from US data base. Cross-sectional method was employed for the collection of data while cross-sectional regressions and Universe statistics technique was employed for the analysis. The study found that defensive and value explained substantial part of the cross-sectional difference in corporate bond excess returns. The study recommended that investors should put momentum strategy to maximise better performance arising from issuing of small liquid bonds by unscrupulous companies.

Chordia, et al (2017) conducted a study on capital market anomalies common to equity and corporate bond market. The study objective was to; examine whether financial statement indicators and other variables used for forecasting equity returns are also used to forecast corporate bond returns. The sample consist of 50 firms which shows unstable panel of around 925,000 bond-month return observations with 18,850 bonds issued. Data was obtained from the study firm with the aid of TRACE data covering the period between 2002 to 2014 financial years. The data obtained was analyse with the aid of cross-sectional regression and descriptive statistics and it was found that the rate at which prices follow risk-reward pattern is contingent on the business holding a security. The study recommended that investors should sought for information from stock market aggregates to enable them take advantage of predicted bond market prices.

Che, et al (2007) studied corporate yield spreads and bond liquidity. The study used 4000 U.S. corporate bonds and hypothetical grade classifications over a nine year period. Data for the study was obtained from Compustat annual industrial database for both active and inactive companies to reduce any subsistence preference in the liquidity factor and yield spread. The data used in the study was obtained in the previous year before the yield spread estimation. The study employed ordinary least square techniques for the analysis of data and the research finding shows that liquidity costs are evidently greater for hypothetical rating bonds than for investment rating bonds as liquidity plays an important role in corporate bond valuation. It was recommended in the study that companies should look at liquidity quality in bond returns which afford stimulus to evaluate liquidity's influence on complementary the tax benefits of debt.

Hotchkiss and Ronen (2002) conducted a study on the information efficiency of the corporate bond market: An intraday analysis. Specific objectives of the study were to; examine whether stocks lead bonds in replicating company explicit information, ascertain whether the speediness of adjustment to company explicit information vary from bond and stock prices and whether methods of market quality differ from bonds than for stock. The study sample of 99 observations, which comprises of 34 bonds obtained from 26 firms quoted on the New York Stock exchange was used for the study. Data for the study was obtained from National Association of Securities Dealers (NASD), and regression techniques was employed for the analysis. The results found that the low-rating bond market quality is has no significantly diverse than the market for those firms' stocks. It was further showed that there is no substantial causality between the firm's bond and stock prices. The study recommended that companies should focus on relative in formativeness of bond that yield greater prices rather than the structure of the dealer market for corporate bonds.

Nzau, et al (2019) investigated effect of bond issuance on financial performance of firms listed on Nairobi security exchange. The main objective was to; examine the influence

of debt (bond issued) on financial performance of listed companies. Data was obtained from annual report and account of six (6) quoted companies on Nairobi Securities Exchange (NSE) while consumer price index (CPI) were gotten from the Kenya National Bureau of Statistics (KNBS) Economic Surveys. The firm used in the study was those that had issued bonds in batches and additional debt instrument for the period 2008 to 2017. The study used regression technique for the data analysis and the result shows that almost 75.4 per cent of variations in financial performance of the study might be cause by bond issuance as categorized by bond price, bonds rate of interest and bond yield to maturity. The study further found bond yield to maturity exerted a geometric influence on company's financial performance. It was recommended that for company to enhance their financial performance they must take into consideration variation that characterised bond issued and bond maturity period.

Ammann, et al (2006) carried out a study on new evidence on the announcement effect of convertible and exchangeable bonds. Specific objective of the study was to; examine pronouncement and issuance impact of offering convertible bonds and exchangeable bonds with data obtained from the Swiss and German market. The study sample comprises of companies that issued convertible bonds and exchangeable bonds from 1996 and May 2003. As at when the study was carried out, a total of 203 convertibles and exchangeable bonds were identified after which 120 securities were eliminated leaving a sample 83 convertible and exchangeable bonds for 60 companies. Data for the study were obtained from Swiss Performance Index (SPI) and Composite DAX (CDAX) for the Swiss and German sub-sample respectively. The employed ordinary least square (OLS) regression and cross-sectional regression for data analysis. The result revealed that announcement effects are more significant for Swiss securities than for German securities. The study further found that adverse irregular returns are considerably more obvious when prior

market returns was negative. The study recommended that companies should stimulate the announcement effects of convertible bonds but not of exchangeable bonds.

2.6 Research Gap

Several researches have been conducted in thin capitalization mostly in advanced countries and just few in developing economy. Majority of these study were not sector base, some concentrated on the rule governing thin capitalization, financial choice, capital structure and international debt shifting but no mention was made on tax burden that thin capitalization intend to reduce. For some studies conducted in advance country than Nigeria,

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However, empirical review of the researches above showed that some of the studies were conducted in countries such as USA that have functional thin capitalization rule and their work were tailored toward strengthening the policy especially on debt shifting while some other rely on the passage of finance bill to enable implementation. This study captured subsidiary operations from developed and developing countries where thin capitalization policy were recently adopted through the amendment of the finance Act in the countries which now restrict the use and rate of internal and external debt amongst multinationals.

This study used lease transaction, bank loans, corporate bonds and debenture loans to measure thin capitalization while corporate income taxes (INTX) to measure tax burden of transnational companies as against the inconsistency observed in other researches. Based on this premise this study seek to investigate thin capitalization and tax burden of transnational companies in Nigeria. Over the years, researchers have examined the disparity of the tax treatment of debt on corporate financial policy in developed countries. However, to the best of the researcher knowledge, no study has examined the effect of thin capitalization on tax burden of transnational companies. In attempt to fill the gap created by other studies, this study seek to contribute to literatures in the study of thin capitalization and also investigate thin capitalization and tax burden of transnational companies in Nigeria.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Research design

The study adopts ex-post facto research design to examine the effect of thin capitalization on the tax burden of transnational companies as well as impact subsisting between variables in the hypotheses. The choice of ex-post facto research design was informed due to the fact that data series on the variables of the study are already in existence and hence would not provide opportunity for manipulation.

3.2 Population of the study

To show the effect of thin capitalization on tax burden of transnational companies, the population of the study includes thirty seven (37) transnational companies, based on their reporting pattern and financial structure which consist of more debt than equity. The study covered ten years consolidated financial statements from 2011-2020. This is to guarantee uniformity in financial reporting amongst the units of analysis. The table below described the population of the study:

TABLE 5

List of transnational companies operating in Nigeria.

S/N	COMPANY	YEAR OF INCORPOATION
1	7-Up bottling company	1960
2	Lafarge cement construction	2012
3	UACN FMCG Multinational	1997
4	MTN Telecommunication multinational	2004
5	Airtel Nigeria	2004
6	Stanbic IBTC Banking Multinational	1989
7	Addax oil and gas multinational	1994
8	ENI oil and gas	1991
9	DHL logistic Multinational	1978
10	IBM Technology	1961
11	Shell Petroleum development company	1958
12	Mobil oil and gas	1955
13	Total oil and gas	1956
14	UNILEVER	1976
15	Julius Berger	1991
16	Etisalat	2007
17	Cadbury FMCG Multinational	1965
18	Google Technology	1998
19	Cocacola	1929

Source: Researcher compilation, 2021

List of transnational companies operating in Nigeria.

S/N	COMPANY	YEARS OF INCORPORATION
20	PZ Cusson	1948
21	P & G FMCG Multinational	1937
22	Guinness FMCG Multinational	1962
23	Glaxosmith Klinne Pharm	1999
24	British American Tobacco	1997
25	Schlumberger Oil & Gas	1962
26	Baker Hughes oil & gas	1907
27	Price water house cooper Consult	1998
28	Chevron oil & gas	1879
29	Nestle Nigeria	1997
30	Halliburton Energy oil & gas	1924
31	KPMG Consulting	1987
32	Julius Berger construction	1970
33	Accenture Consulting	2009
34	Standard Chartered Bank	1859
35	MAERSK grow conglomerate	1928
36	Volkswagon group	1972
37	Samsung group	1938

Source: Researcher compilation, 2021

3.3 Sample size and sampling technique

The study sample consists of twenty nine (29) transnational companies operating in Nigeria, based on their reporting pattern and financial structure which consist of more debt than equity. The study covered the period of ten (10) years from 2011-2020, and simple random sampling technique was used for the study since the population is already known. This technique provide all member of the population an equal opportunity to be selected in accordance with companies financing structure of more debt against equity for the purpose of gaining tax advantage. The study sample are;

TABLE 6

Sample size of the study.

S/N	COMPANY	YEAR OF INCORPORATION
1	Lafarge cement construction	2012
2	UACN FMCG Multinational	1997
3	MTN Telecommunication multinational	2004
4	Airtel Nigeria	2004
5	ENI oil and gas	1991
6	DHL logistic Multinational	1978
7	IBM Technology	1961
8	Shell Petroleum development company	1958
9	Mobil oil and gas	1955
10	Total oil and gas	1956
11	UNILEVER	1976
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25	Accenture Consulting	2009
26	MAERSK grow conglomerate	1928
27	Volkswagon group	1972
28	Samsung group	1938
29	Baker Hughes oil & gas	1907

Source: Researcher compilation, 2021

3.4. Sources of data and method of data collection.

The study employed quantitative research technique to assemble appropriate data for analysis. The quantitative data were collated and recorded from secondary source, published in the audited annual report of the companies. Audited annual report are readily available, reliable and accessible through their respective website. The study covered the period between 2011 to 2020 financial year and the study companies were carefully selected from oil and gas sector, Breweries, Conglomerate, pharmaceutical companies, Industrial and domestic product and Food, Beverages and Tobacco industries in Nigeria.

3.5 Delimitations of the study

The major delimitations of the study was differences in imprecise measurement of the variable and the sample size that were not as large as expected. Many authors may have different views on the structure and concept of thin capitalization as it affect tax burden of companies which could result to differences in research findings. This theoretical gap in its own could be problem to any research as different models are used to interpret the concept, it could conflict data figures from the one used here.

3.6 Model Specification

As shown in this study, multinational company's performance generally is reflected by profitability that is exaggerated by leverage because fixed charges capitals can be gotten at a cost lesser than the company's rate of return on net asset. The model used in this study disclosed the company's value by the current cost of the debt tax buffers. Rational managerial attribute in the management of resources has necessitated corporate institutions in the construction of capital acquisition decision. From tax planning theory perspective, it is understandable that management will devise means of making higher profit from the sources of capital available to her disposal thereby chose between equity and debt, and ensure that such decision do not merely reflect growth in prospect but that which will

enhance shareholders wealth maximization through careful tax reduction mechanism. The dependent variable in the regression line would be corporate income taxes paid by transnational companies as measure of tax burden in the application of thin capitalization. The independent variables constitute critical information in the financial statements of which companies could exercise high power to reduce tax remittances in countries with high tax rates. The variables are explained in detailed in the model explanation, they include bank loans, lease transactions, bonds and debenture.

Thus, model is specified as follows:

$$TB = f(TCS) \text{-----} (1)$$

Where,

TB = Tax burden (measured by corporate income taxes (INTX))

TCS = Thin capitalization (Measured by BNL, LES, DEBL, BND)

$$INTX = f[TCS] \text{-----}(2)$$

$$INTX_{it} = \beta_0 + \beta_1 BNL_{it} + \beta_2 LES_{it} + \beta_3 DEBL_{it} + \beta_4 BND_{it} + \mu_{it} \text{-----} (3)$$

Where:

TB = Tax burden

INTX = Corporate income taxes

TCS = thin capitalization

BNL = Bank loans

LES= lease transactions

DEBL = Debenture

BND = Bonds

μ_t = error term

β_0 = Constant

β_1 to β_4 = regression coefficient.

3.7 Model explanation.

The dependent variable (tax burden) used in the study is corporate income tax often reported in the published financial statement of the companies. Independent variables use here consist of debt and equity composition in the financial statement of the company are bank loans (BNL), lease transactions (LES), corporate bonds (BND) and debentures loans

(DEBL). Thus, big size companies may have access to credit at ease than small size companies. Therefore, the study observed credit behaviours of multinational companies, a benefits that would row on the shoulder of favourable international tax policy undertaken by multinational companies to boost revenue by spreading investment across nations. B_0 = Coefficient of thin capitalization (independent variable). The regression model is design to infer whether tax payment of multinational companies decrease as a result to thin capitalisation.

3.8 Techniques of data analysis

The study employed the Panel Least Squares regression method because the data set from the twenty nine (29) transnational companies from different industries has both cross-sectional and time series attributes. The panel least square regression combine the properties of time series and cross sectional data. When dealing with firms drawn from a population as is the case with this study, the assumption of random effect model has greater appeal. The Hausman test identifies whether the fixed effects estimation would be almost as good as random effects and enables a choice between a fixed or random effects specification. It involves two sets of estimates, one of which is reliable under both the null and alternative hypothesis, and another that is stable only under the null are employed. The Hausman test is a test of H_0 : that random effects would be stable and efficient, versus H_1 : that random effects would be unstable. Thus, the null hypothesis stipulates that the preferred model is the random effect if the Hausman test statistic exceeds the relevant critical value (p-value is greater than 0.05). Finally, the outcome of the Lagrange Multiplier Tests for Random Effects that is a test of no random effect determines the choice of best model between pooled OLS and random effect. If the Breusch-Pagan Lagrange Multiplier test is less than 0.05, reject the null hypothesis of random effect is inefficient. However, before estimating the model, some regression diagnostic tests such as cross-sectional dependence test and test of endogeneity were carried out on the variables

CHAPTER FOUR

RESULT PRESENTATION, INTERPRETATION AND DISCUSION OF FINDINGS

4.0 Introduction

The main goal of this study is to examine the pattern of effects of thin capitalization among transnational companies in Nigeria on their tax burden over a period of time. This Chapter concentrated on the empirical evaluations of the study on the basis of the data obtained from selected transnational corporations (TNCs) operating in Nigeria. The analysis in this Chapter involves the presentation of data as well as analysis and interpretation of the estimated equations and results based on the methodology outlined in Chapter Three. The goal is to estimate and analyse the specified equations using appropriate techniques and draw valuable outcomes for testing the hypotheses of the study, and also to draw valid conclusions. In conducting the empirical analysis, both econometric and statistical methods were employed. The initial characterization of the data is done using the statistical techniques, while the estimation of relationships and other parameters for testing the hypotheses is done using econometric techniques. Given that both within-firm trend and heterogenous firm-specific characteristics can influence the outcome of the analysis, both cross-sectional and time series properties of the variables employed for the empirical inquiry were also examined.

4.1 Description of Data

The pattern of data characteristics is initially highlighted by presenting trends in relevant variables and the related summary statistics. Figure 2 shows the trend in corporate tax liabilities among the selected companies in Nigeria. The trend shows the log values of the corporate tax liabilities and indicates that MTN exceeds other multinationals in terms of

tax liabilities over the period. Other companies with large corporate taxes were Lafarge, Samsung, UACN, Glaxo, and Julius Berger. Interestingly, these companies are in diverse sectors of the economy, which shows that large tax-paying multinational corporations in Nigeria are not concentrated on a particular sector in the economy but are generally widespread. The companies with the least taxes in Nigeria are DHL, Sclube and Coca Cola. This is interesting, given the long period of operation of Coca Cola in Nigeria, compared to other companies.

Corporate income taxes of companies

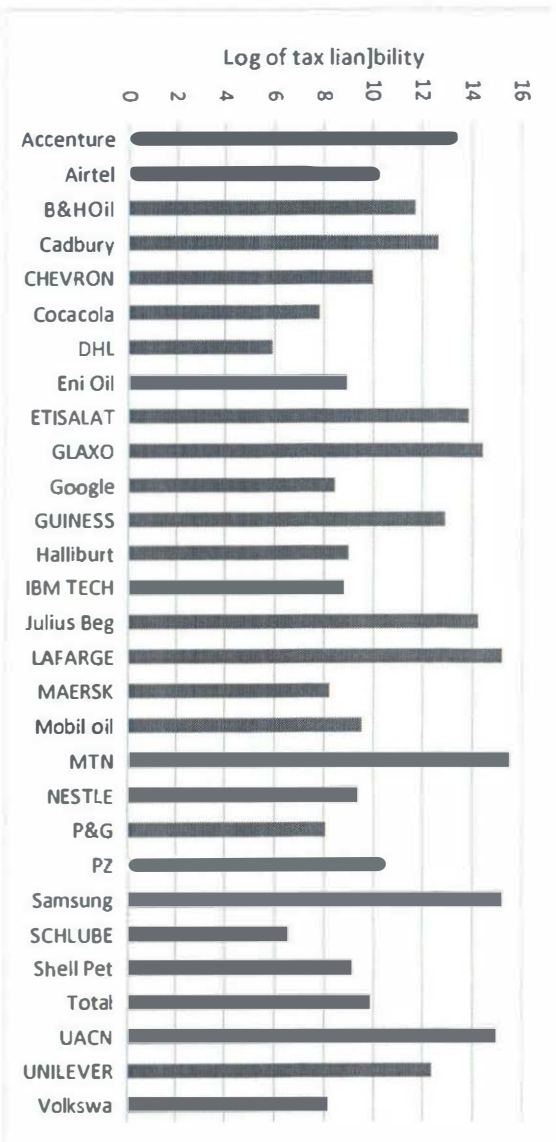


Fig 2

Source: Author's computation

The trends in tax obligations by selected companies in the study are also reported in Figure 3. From the Chart in figure 3 below, it can be seen that only MTN experienced a relatively steady rise in its tax obligations, all other companies had tax payments that were generally not rising over time. Indeed, tax liabilities for the oil companies, Shell and Mobil have declined steadily since 2012, suggesting the weakening of the contributions of the oil sector to the tax base in Nigeria. Other companies like Lafarge, Unilever and Volkswagen had highly unsteady tax regimes that exerted regular increase and fell over the period of the study. The tax liabilities of Coca Cola has however began to increase rapidly after the 2017 period. These charts indicate that there is generally no well-defined pattern of tax obligations among the multinational companies in Nigeria.

Trends in Corporate taxes for selected companies

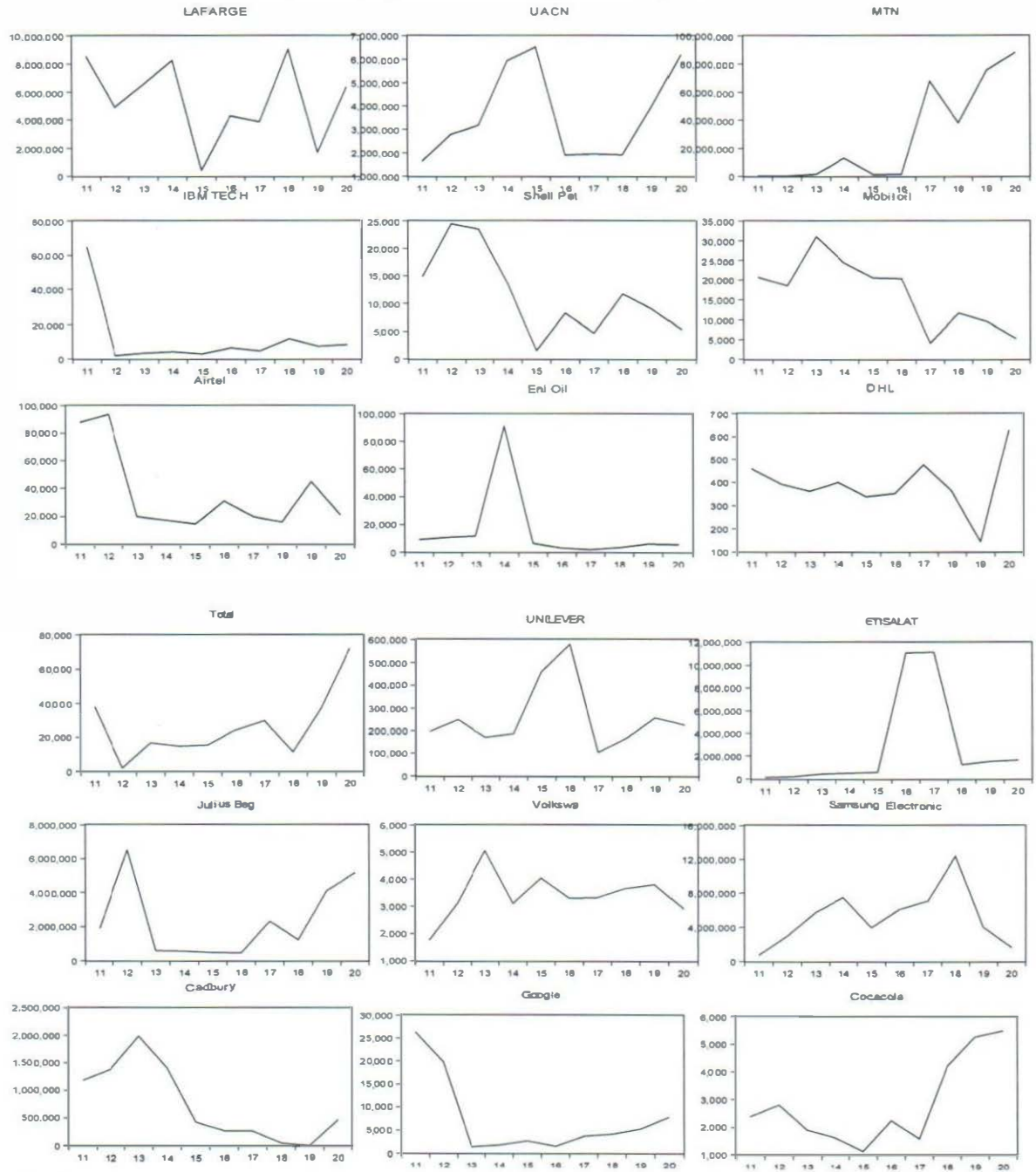


Fig. 3
Source: Author's computation

Descriptive statistics explains the summary of data and other basic elements within the series. The summary of annual statistical changes of the core variables in the study are presented are reported in Table 7 below. The descriptive statistics are reported in this manner because, the values for the general variables are large and may not present much information about the characteristics of the datasets. From the Table, average annual changes in tax liability for the companies is 187.23 per cent, although the maximum value of 18097.2 suggests that there were companies with terrific annual changes in their tax obligations over the study period. This is also established by the standard deviation value of 1298.32 which is much larger than the mean value, suggesting that the tax liabilities of the companies are not evenly spread across the reported mean value. Indeed, the skewness value of 11.42 suggests that most of the actual annual changes in tax payments by the companies are less than that of the reported mean value. There are large outliers that are pushing up the mean value. Average annual changes in bonds obtained by the companies is 97.76 per cent, which is less than average tax liability changes. Also, average changes in bank loans by the banks each year is 148.81 percent, while average growth in debentures was 147.56 per cent. The Table also indicated that on average, the leasing component of the companies' capitalization has increased by 135.87 per cent annually over the period. All these average annual changes are large and indicate that the multinational companies experience quit rapid annual transitions in terms of thin capitalization in Nigeria. The Jarque-Bera statistics for all the variables are substantial at the 5 per cent level, which shows the absence of normality in their respective data distributions. This outcome is to be expected since a panel of different companies was adopted for the datasets. Hence, the result shows that firm-level characteristics may be exerting strong heterogenous influences for the datasets. This is a strong basis for providing a panel-form analysis in the regression process for the study. The initial descriptive statistics report that company-specific factors vary across the firms, and these factors strongly influence the characteristics of the datasets (based on the highly significant J-B test values for the variables).

TASBLE 7

Descriptive Statistics for Annual Changes in Variables

Variable	Mean	Max.	Min.	Std. Dev.	Skew.	Kurt.	J-B (prob)
GINTX	187.23	18097.2	-99.39	1298.32	11.42	147.83	23895.5 (0.00)
GBND	97.76	3836.0	-99.29	435.24	6.48	49.52	25261.9 (0.00)
GBNL	148.81	10149.5	-98.73	754.80	9.86	122.38	15864.9 (0.00)
GDEBL	147.56	14496.4	-96.61	1024.20	11.67	154.52	25460.9 (0.00)
GLES	135.87	6966.0	-96.77	673.25	7.23	61.61	39476.9 (0.00)

Source: Author's computation

The summary statistics for the key variables in the study are presented for the sampled companies since this will offer more nuanced background evidence on the dataset. These indicators are reported in Tables 8 below. There is clear evidence that MTN (with N28,676,349.0) had the largest tax obligation on average among the companies, while DHL had the smallest average tax liability (N391.1). Essentially, the tax obligation of MTN dwarfed those of other companies given that the closest company in terms of tax remittances (Samsung Electronics) had a tax liability of N5,211,829.0, which is less than 20 per cent of the average tax liability of MTN. Cadbury however had the highest average annual change in tax obligations at 1982.81 per cent. These large annual changes among many of the companies generally indicate that tax payments are very unsteady among multinational companies in Nigeria. In terms of usage of bank loans, Lafarge has the largest value of N7410287.0, while DHL also has the smallest loan of N3100.3, indicating that DHL tends to have minimal interactions with institutions in Nigeria. Lafarge however appears to be reducing its loans over the years, given that a negative mean annual change in its loans is reported. On the other hand, Julius Berger, which has the second largest average loan value also has the highest annual changes in loans at over 1400 per cent on average. In terms of leasing, MTN has the largest mean value of N3772406.0, while Schlube has the least average value in terms of leasing as a capitalization strategy.

TABLE 8

Averages of variables in each company

Company	INTX		BNL		LES	
	Amount	Av. change	Amount	Av. change	Amount	Av. change
Accenture	867,233.9	32.66	13574.4	2.82	51873.3	-4.41
Airtel	36,590.7	9.52	1241537.0	172.62	89762	33.00
B&H Oil	126,806.7	-0.28	217141.0	7.22	77558.7	124.71
Cadbury	742,986.9	1982.81	2569539.0	39.37	111148.3	74.46
CHEVRON	107,688.7	1073.92	127454.3	224.68	3541.4	773.94
Coca Cola	2,858.8	22.68	30589.9	25.35	3286.1	72.98
DHL	391.1	28.93	3100.3	92.87	1382.1	592.65
Eni Oil	14,914.4	74.20	20187.5	-0.39	2467.4	-6.38
ETISALAT	2,842,231.0	214.81	89404.6	40.27	70422.8	62.25
GLAXO	2,275,632.0	74.76	258325	26.43	7325.7	218.21
Google	7,441.2	16.40	66695.2	701.74	4870.2	136.38
GUINNESS	464,659.5	0.07	5583732	56.41	192573.2	10.53
Halliburt	11,726.0	116.93	10008.8	282.97	2305.8	13.99
IBM TECH	11,541.7	22.11	39508.4	65.09	8917.6	37.94
Julius Beg	2,336,077.0	81.65	2680422.0	1415.89	144432.1	445.41
LAFARGE	5,385,724.0	138.37	7410287.0	-6.32	375780.4	34.67
MAERSK	12,460.9	-15.84	108725.9	-11.99	2084	70.26
Mobil oil	16,589.9	7.20	38597.4	172.82	3355.3	42.13
MTN	28,676,349.0	711.83	262639.7	21.15	3772406.0	15.55
NESTLE	82,038.6	314.74	19713.7	43.27	6348.2	147.40
P&G	3,202.2	-2.35	16516.4	136.26	320.8	13.62
PZ	248,322.4	230.05	144340.1	71.77	17271.6	42.10
Samsung	5,211,829.0	42.99	2401409	319.26	254463.8	425.80
SCHLUBE	879.7	10.76	14938.1	222.40	300	23.14
Shell Pet	11,711	45.89	53351	48.16	1164.1	19.06
Total	26,214.0	112.96	45524.4	32.74	31899.2	25.42
UACN	3,598,283.0	30.29	5029608	47.60	892493.6	141.82
UNILEVER	259,487.1	22.16	451501.9	43.09	32134.33	-11.40
Volkswagen	34,09.2	11.47	26809.9	3.33	846.4	348.75
All companies	1,840,872.0	187.61	999144.2	148.17	213132.2	135.87

Source: Author's computation

In Table 9 below, the average debenture accumulation among the companies is shown and it is seen that Lafarge also has the largest debenture accumulated over the period at N1128407.0 and Samsung Electronics (at N976286.6) comes at a close second. On the other hand, Halliburton, with a value of N425.2 had the least debenture obligation among the companies. Like in the case of bank loans, Julius Berger again has the highest rate of increase in debenture accumulation among the companies. Average bond values for the companies indicate that UACN, with a value of N3702492.0 has the largest bonds, while Halliburton also has the least bonds in its capital portfolio. The general outcome of this descriptive statistics is that larger multinational companies in Nigeria are also the ones with larger thin capitalization in all considerations.

TABLE 9

Averages of variables in each company

Company	DEBL		BND	
	Amount	Av. change	Amount	Av. Change
Accenture	17875.2	179.66	53984.1	-6.78
Airtel	85487.8	90.20	130727.5	34.77
B&H Oil	128336.5	-16.32	68487.6	225.41
Cadbury	252631.3	128.44	181750.3	178.25
CHEVRON	16054.3	131.51	584.1	69.27
Coca Cola	6677.6	42.90	15953.9	73.27
DHL	5472.8	10.80	4478.2	19.05
Eni Oil	6127.0	-0.28	5155.1	32.51
ETISALAT	33454.7	12.41	31901.9	23.59
GLAXO	26226.9	18.06	849.8	450.09
Google	4236.1	19.10	13400.4	148.77
GUINNESS	491072.4	36.01	334830.3	14.76
Halliburt	425.2	40.26	203.7	18.56
IBM TECH	7432.3	13.19	14689.6	395.97
Julius Beg	856134.6	1599.70	11150.6	79.37
LAFARGE	1128407.0	110.43	35541	55.84
MAERSK	2879.5	-7.63	16171.3	-7.77
Mobil oil	38274.4	20.53	8870.8	49.67
MTN	199413.9	40.91	94888.8	440.49
NESTLE	261033.1	550.04	1611.2	103.28
P&G	9058.2	82.30	2430	24.26
PZ	23120.2	53.26	2791.2	36.14
Samsung Electronic	976286.6	180.50	246366.8	-17.95
SCHLUBE	2479.3	59.54	479.6	41.76
Shell Pet	28715.4	2.34	6381.4	1.50
Total	176380.3	644.02	21988.1	270.10
UACN	832910.4	108.23	3702492.0	5.77
UNILEVER	368659.1	67.72	15142.8	53.75
Volkswagen	44261.1	43.20	17716.5	8.62
All companies	207914.6	146.93	173828.2	97.32

Source: Author's computation

The patterns of relationships among the independent variables (thin capitalization variables) in the study are evaluated with the correlation analysis shown on Table 10 below. The result showed a positive correlations among all the thin capitalization variables, although not all correlations are strong. The correlation between bonds and bank loans is positive and significant, as is also the case between bonds and debenture. This means that companies that procure more bonds are also the ones with bigger debenture portfolio and are also more prone to leasing as a capitalization strategy. Bank loans is shown to be highly positively correlated with debenture, suggesting that multinational companies with large loan obligations are also having large debenture issues in their balance sheets. This is to be expected, given that loans and overall debentures are generally expressive of similar dimensions of capitalization. The correlation between bank loans and leasing as well as between debentures and leasing are however insignificant. This indicates that companies that are increasing either bank loans or debentures in its share of thin capitalization do not necessarily also increase leasing.

TABLE 10

Correlation Matrix

	INTX	BND	BNL	DEBT	LES
INTX	1 -----				
BND	0.073 (0.219)	1 -----			
BNL	0.059 (0.315)	0.267 (0.000)	1 -----		
DEBT	0.059 (0.314)	0.189 (0.001)	0.350 (0.000)	1 -----	
LES	0.327 (0.000)	0.162 (0.006)	0.045 (0.445)	0.085 (0.149)	1 -----

Source: Author's computation

Another important means of observing the relationships among the explanatory thin capitalisation variables of the multinational companies is to plot the scatter diagrams among pairs of variables. We begin by considering the assumption that multinational companies with larger debentures tend to have bigger loan obligations to the banks. Figure 4 shows this relationship, where bank loans is plotted against the amount of debentures accumulation by the firms. A positive relationship is demonstrated by the scatterplot which proves that as the companies increase their loans, their share of debentures strategy in their thin capitalisation also increases. The accompanying equation of the regression line also confirms this correlation and suggests that every one per cent increase in bank loans by the multinational corporations, there is a 0.778 per cent rise in debentures among the companies. The relationship between bank loans and lease also shows a positive interaction. Moreover, based on the slope coefficient of the regression line, it is seen that a one per cent increase in bank loans leads to a 0.88 per cent increase in lease. Thus, once a company increases its loan structure, there is almost a 100 per cent chance that it will also increase leasing as a thin capitalisation strategy.

Scatterplots for relationships among thin capitalization variables

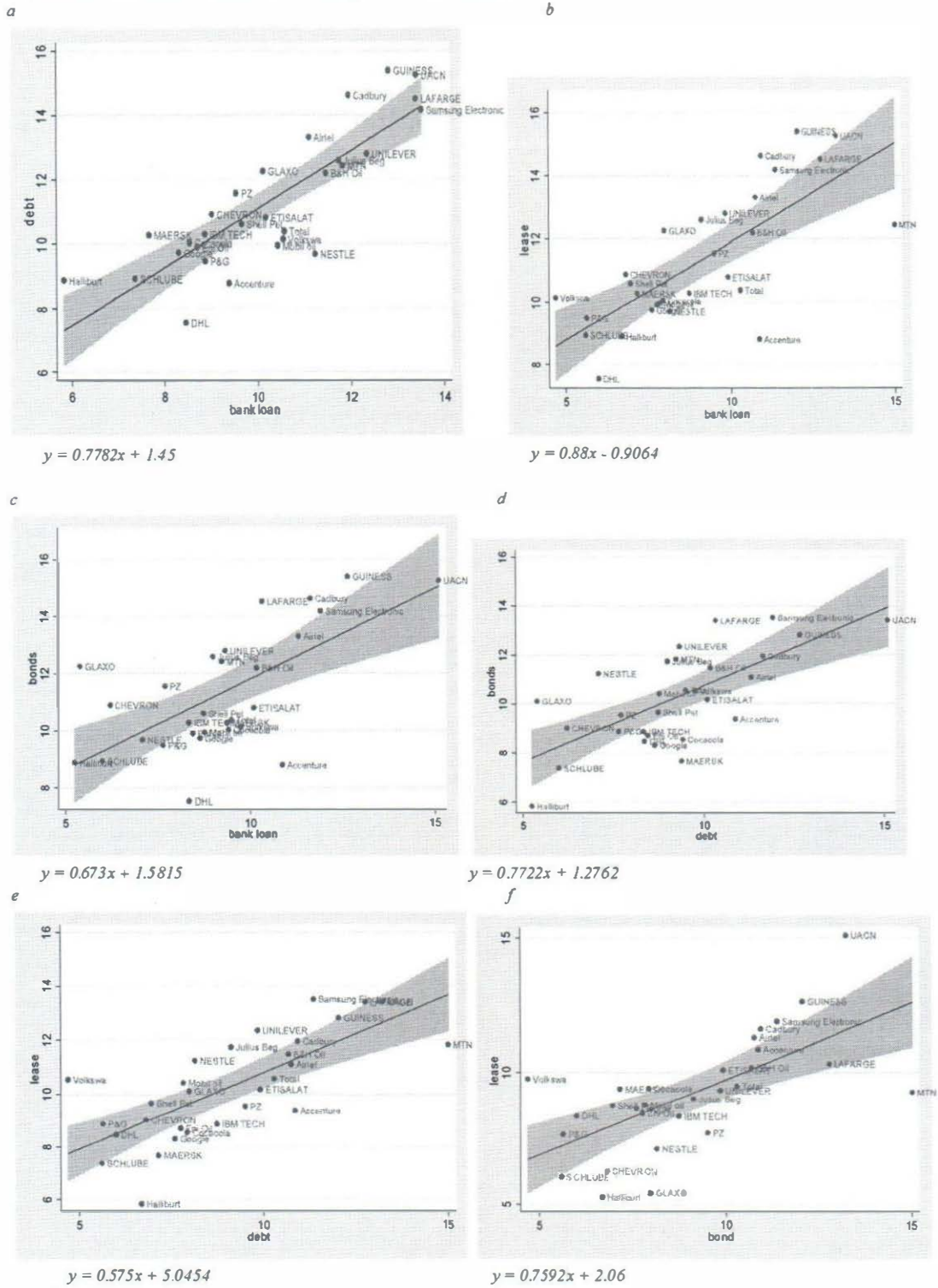


Fig. 4
Source: Author's computation

The relationship between bank loans and bonds is shown in Figure 4, where a positive relationship is also shown. The slope of the regression equation also reveals that bonds will increase for the firms by about 0.67 per cent for every percentage increase in bank loans among the companies. Panel *d* in the charts also reveals a positive relationship between debentures and bonds, suggesting that firms that are increasing debenture are also increasing bonds at a 1 to 0.77 ratio. The relationship between debenture and lease is also positive, like in other cases, although their interaction has the smallest slope coefficient (0.575) indicating that debenture and lease as thin capitalization strategies do not essentially go together among the multinational companies. The relationship between bonds and lease in Panel *f* of Figure 4 shows that every one per cent increase in bonds leads to a 0.75 per cent rise in leasing among the companies. Thus, multinational firms that accumulate bonds also engage heavily in leasing in Nigeria.

Histograms of probability distributions of the datasets

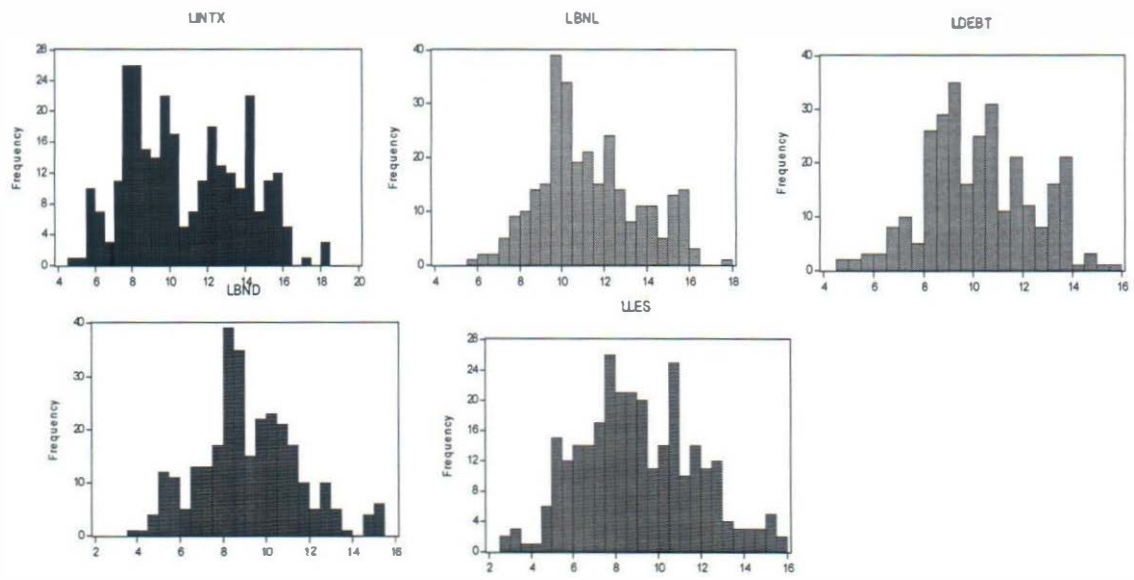


Fig. 5

Source: Author's computation

We further test for the distribution patterns of the density functions of the datasets for the study since the aim of the study is to investigate the interactive relationships. First, the concentration of the distribution of the datasets are demonstrated by the functions of the density distribution of the variables. The plot of the density functions in histograms (shown in Figure 5 above) presents the results of degree of normality amongst the variables. The distribution of tax obligations is quite unstable and indicates that it is non-normally distributed. Similar outcomes are reported for the other variables, given that they are not quite bell-shaped.

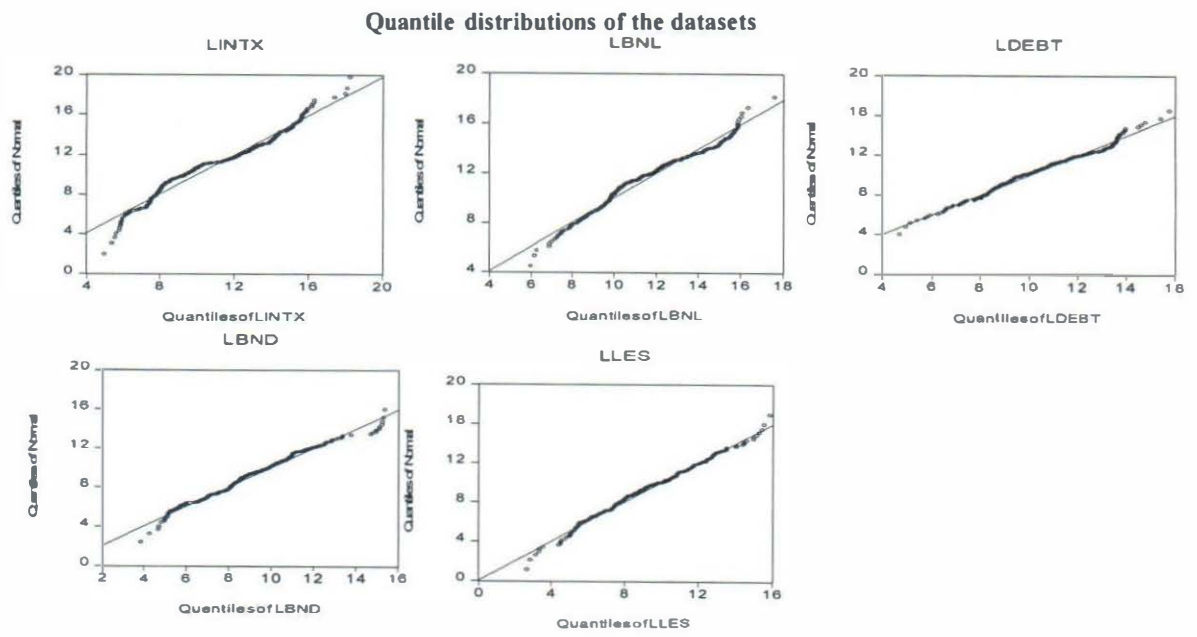


Fig. 6

Source: Author's computation

Another way to investigate the distribution of the residuals in data sequence is to plot the quantiles. In this study, the quantiles are plotted via the Quantile-Quantile (Q-Q) hypothetical plot as indicated in Figure 6 above. If the residuals are typically spread, the points in the QQ-plots must lie together with a straight line. For all of the datasets, the distributions do not lie on the straight diagonal at all levels. In each of the cases, the extreme ends of the distribution both on the left and right sides appear to vie off the lines. There may therefore be some non-normal form of the distribution that may occur at very high levels of the variables. The plots for all variables therefore indicates that, both great adverse and optimistic impact are motivating the movement from normality in each of the variables. This further confirms the results from the descriptive analysis as well as those of the distribution histograms shown above.

4.2 Tests of Panel and Time series Properties of Data

4.2.1 Cross-section Dependence Test

The panel structure of this study indicates that there may be heterogenous characteristics of the variables of the study that may present certain influences on the outcome of the estimation strategy. In particular, TNCs often demonstrate similar characteristics in terms of tax behaviour in a country, which may heighten the presence of tax-related agglomeration effects (Clausing, 2009; Blouin, 2012; Beer, de Mooij & Liu, 2018; Yoo & Lee, 2019). Also, these companies all operate in Nigeria with similar tax and operational environment may therefore likely exhibit similar responses to overall patterns of thin capital characteristics. The occurrence of this may present certain levels of interdependencies that are related to spatial autoregressive processes among that may reduce the efficiency of the estimates. It is therefore necessary to disentangle the cross-sectional features of the relevant variables in order to monitor the array of dependence. Given that the number of cross-sectional units (29 MNCs) in this study is more than the time period (10 years), both the Breusch and Pagan (1980) LM test and cross-sectional dependence (CD) test developed by Pesaran (2004) are employed for testing the cross-sectional dependence characteristics. This reported in Table 11 below.

TABLE 11
Cross-section Dependence Test Results

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	693.89	406	0.000
Pesaran scaled LM	10.103		0.000
Pesaran CD	0.975		0.329

Source: Author's computation, 2021

From the result in Table 11, it is seen that only the Peseran CD fails the significance test. It should be noted that the null hypothesis for this test is that there is no cross-sectional dependence, indicating that a non-significant coefficient is what is required in this case. Thus, only the Peseran CD test fails to reject the null hypothesis of absence of cross-sectional dependence in the block of variables. The other two tests are both significant and indicate presence of cross-sectional dependence. This implies that the results are generally not fully comprehensive and in order to fully understand the properties of the variables, there is need to further test for the long run characteristics of the data. This will further contribute to the efficiency of the estimation procedure especially as the estimation also allows for slope heterogeneity across panel units. We thus proceed by testing for the presence of cointegration among the variables in the study.

4.2.2 Unit root and cointegration tests

Particular features (individual heterogeneity) and joint (homogenous) features of the firms used in the study reflect in the data employed for this study. This is the reason panel unit root test was used to check for the stationarity of the data, in order to avoid incidence of “spurious” inference. In this study, the test developed by Levin, Lin and Chu (2002) was employed to assess the stationarity materials of the similar panel. These tests assume same cointegration vectors among the companies. However, each of the companies in the study is likely to exhibit differences in their capitalization and tax avoidance strategies. This means that the homogenous unit roots alone may not suffice for capturing the stationarity status of the data sets given that the joint unit root hypothesis may not be adequately accurate. To overwhelm this, the Im, Pesaran and Shin (2003) and the Augmented Dickey-Fuller tests (which permits for heterogeneity in the panel’s cross-section and undertakes a null hypothesis of no cointegration in the panel data) are also conducted. All the unit root test results are shown in table 12 below.

TABLE 12

Panel Data Unit Root Tests Results in levels

Variables	<i>Common unit process</i>		<i>individual unit root process</i>	
	LLC	IMP	ADF	PP-Fisher
INTX		-2.02*	87.28**	109.4**
BNL	-24.11**	-4.91**	109.1**	120.3**
DEBL	-33.01**	-6.39**	115.6**	118.1**
LES	-2.41*	-0.32	70.65*	79.29
BND	-2.68**	-0.44	68.45	127.9**

Note: ** indicate significant at 5 % levels respectively; IPS = Im, Pesaran & Shin; LLC = Levin, Lin & Chu

Source: Author's estimation, 2021.

Note that only the tests for levels variables are reported in the results since the variables are essentially stationary at this level. The table above showed that the coefficients of the test for all the parameters in their levels are stationary (in that the critical test values are greater than the test statistic). Given this condition, it is shown that the parameters are all joined of the same order zero. This implies that these variables will likely converge simultaneous in the same pattern, suggesting that cointegrated analysis can be carried out for the parameters with significant result.

As shown in the cross-section dependence test, two of the test outcomes indicated the occurrence of cross-sectional dependence among the errors of the relationships being estimated. This suggests the need to include a test for the long run stability of the relationships in the study in order to further establish the stability of the interactions among the variables. Moreover, the unit root results strongly indicate that the stationarity status of the variables are equal with each of the variables being the same order of zero. The long run conditions of the variable interactions can however be established to present a stronger background for a dynamic relationship among the variables. Table 13 displays the results of the Pedroni (1995) and Kao (1999) panel cointegration tests on both the panel and the group assumptions along with the various difference ratios and rho statistics (non-parametric tests).

TABLE 13

Panel Cointegration Test Result

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	-2.187	0.99	-2.863	0.99
Panel rho-Statistic	4.444	0.03	4.483	0.04
Panel PP-Statistic	-2.803	0.00	-4.432	0.00
Panel ADF-Statistic	0.615	0.73	-2.035	0.02
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.	Kao Test	
Group rho-Statistic	7.081	0.03		
Group PP-Statistic	-7.699	0.00		
Group ADF-Statistic	-3.577	0.00		

Note: the null hypothesis of no cointegration is rejected at the 0.05 level of significance respectively

Source: Author's estimation, 2021

The coefficients of the IPS and Augmented Dickey Fuller test statistics for both the panel and group assumptions are significant at the 5 per cent level. Thus, there is solid indication of panel cointegration according to both the ADF-t and non-parametric-t statistics. These results are complemented by the Kao (1999) panel cointegration test – which is a residual-based test. Based on the Kao residual-based cointegration test shown in Table 13 above, the null hypothesis of no cointegration can be rejected at the 5 per cent level for each of the equations. Thus, the cointegration tests results show that there is strong long run relationships among the variables in the study. The dynamic panel data estimation framework can therefore be employed in the empirical analysis.

4.3 Analysis of Regression Results

In this section, the results of the estimated models based on the specifications in the previous section are presented and analysed. The analysis of the regression results is interested in examining the effects of thin capitalization of transnational companies on their tax burdens in Nigeria. This is done by interpreting the estimated results for the goal of drawing relevant policy and academic conclusions. This is done by considering the estimated coefficients in terms of strength, significance and direction of effects on the dependent variables. As noted in the previous chapter, the nature of data used (small panel with $T = 10$ and $N = 29$) suggests that a dynamic panel data framework (based on the GMM estimates) may not generate efficient results in the estimated relationships. Hence the traditional Panel Data analysis procedure was adopted. The standard Hausman test for random effects is used for identifying the time-varying conditions of the panel data used in the study in order to determine the method of panel analysis to be adopted. The result of the tests are reported in the estimation Tables.

The preliminary results of the estimates are presented in Table 14 where the outputs from both the fixed effects and the random effects estimates are reported. The Chi-Square statistic

for the random effects argument fails the significance test for each of the equations at the 5 per cent level ($p > 0.05$), indicating that the null hypothesis holds, asserting that a random effect actually exists in the cross sections of the data. This effectively rejects the fixed-effects estimation procedure as the best method to capture the relationships in the panel and indicates that the Random Effects (RE) estimates are more appropriate for the analysis. We therefore focus on the result of the Random effects estimates. The diagnostic tests are generally impressive with a large R-squared value of 0.58 (even though dataset is a panel). This means that the variables BNL, LES, DEBL and BND jointly explain 58 deviations in the tax burden, leaving 42 per cent unexplained in the model. However, the R^2 Adj. of 579 per cent could also be interpreted explaining the co-movement between thin capitalization and tax burden. The F-stat value of 100.3 is substantial at the 5 per cent level and shows that all the thin capital variables combined have significant relationship with tax liabilities of the TNCs used in the analysis.

TABLE 14

Panel Data Estimation Results of the Relationship between Thin Capitalization and Tax Liabilities

Variable	<i>Fixed effect</i>			<i>Random effect</i>		
	Coefficient	t-Statistic	Prob.	Coefficient	t-Statistic	Prob.
Constant	0.036	0.06	0.96	0.102	0.16	0.87
LBNL	0.281**	3.75	0.00	0.275**	3.68	0.00
LLES	0.481**	8.01	0.00	0.485**	8.18	0.00
LDEBL	0.423**	5.07	0.00	0.422**	5.13	0.00
LBND	-0.111	-1.68	0.09	-0.114	-1.73	0.08
R Square				0.584		
Adj. R-sq	0.573			0.579		
F-stat.	30.82**			100.3**		
Hausman Test			1.873 (0.76)			
Heteroskedasticity LR Test			162.9** (0.00)			

Note: ** indicate significance at 5% level, respectively. Source: Author's computation

Source: Author's computation, 2021

The particular impacts of the thin capitalization variables on tax liabilities of the TNCs is ascertained by observing the coefficients of the explanatory variables in relations to signs and significance. A close look at the Random effects results reveals that three of the coefficients of the explanatory variables are significant at the 5 per cent level ($p < 0.01$). Only the coefficient of bonds (BND) fails the significance test even at the 5 per cent level. This result therefore indicated that bonds issue as a thin capitalization strategy does not affect the tax liabilities of TNCs in Nigeria. For the other variables, the coefficients are all positive, indicating that bank loans, leasing and debenture issuance by TNCs have significant positive impacts on tax liabilities of TNCs in Nigeria. The test heteroskedasticity test (based on the Likelihood Ratio outcome) reveals that there is the presence of heteroskedasticity in the errors of the estimated equation. This renders the efficiency of the estimates to become weak and the standard errors inflated. Thus, these results are generally unreliable.

In order to correct for the heteroskedasticity observed in the random effects estimates and to improve on the efficiency of the estimated relationships, the equation re-estimated using the Feasible Generalised Least Squares (FGLS) procedure. This method accounts for heteroskedasticity arising from either the estimated dependent variables or the heterogeneity of the datasets (Adegboye, 2020). This aims at evaluating whether the estimated coefficients from the random effects are robust to different estimation procedures. The outcomes of the FGLS estimation are stated in Table 15 below. In the result, the LR test for heteroskedasticity is reported at 1.09 ($p > 0.05$), signifying that the null hypothesis of no heteroskedasticity in the estimates is accepted. These estimates from the FGLS are thus more reliable for policy directions.

TABLE 15

Estimation Results of the Relationship between Thin Capitalization and Tax Burden (FGLS)

Variable	Coefficient	t-Statistic	Prob.
Constant	0.102	0.27	0.78
LBNL	0.275**	3.91	0.00
LLES	-0.485**	-6.45	0.00
LDEBL	0.422**	7.20	0.00
LBND	-0.114*	-2.31	0.02
Adj. R-sq.	0.579		
F-statistic	100.3**		
Heteroskedasticity LR Test	1.09 (0.28)		

Note: ** indicate significance at 5% level, respectively. Source: Author's computation

Source: Author's computation, 2021

In terms of the effects on tax liabilities, the result shows that all the coefficients of the explanatory variables passed the significance test at the 5 per cent level. Given that the FGLS results are efficient, the result shows that all the thin capitalization variables exert significant impacts on tax liabilities of the TNCs used in the study. The coefficient of bank loans is positive and shows that TNCs that increase their bank loan as a strategy for boosting thin capital actually tend to pay more taxes. This result shows that increasing bank loans may not essentially act as a form of shield for transnational corporations in Nigeria. Rather a one per cent increase in bank loans leads to a 0.275 per cent rise in company income tax liability of the companies. It appears that the TNCs do not efficiently apply their bank debts as a mechanism for tax shield. The coefficient of leasing is significant and negative, which shows that leasing as a form of thin capitalisation leads to reduction in tax liabilities of the transnational companies in Nigeria. For every 1 per cent rise in leasing, tax liabilities for the companies reduce by 0.485 per cent. The coefficient of debentures is positive and significant, which shows that debenture issues have a positive impact on tax liabilities of the TNCs in Nigeria. In particular, a one per cent rise in debentures leads to a 0.422 per cent increase in tax liabilities.

The coefficient of bonds is negative, which suggests that increasing debentures among TNCs tends to lead to reduction in tax liabilities. When debenture issue rises by one per cent, tax liability of the TNCs tend to reduce by 0.114 per cent. These results highlight that bank loans and debentures (which were initially shown to have similar dimensions among TNCs as thin capitalization strategies) both have similar positive impacts on tax liabilities of the TNCs. On the other hand, it is seen that increasing leasing and debenture issues by the company tend to effectively reduce tax liability of the companies. There is therefore evidence that leasing and debenture issues are the most effective thin capitalization structure that are employed by TNCs as tax shield.

In order to further improve on the robustness of the estimations, a further procedure is employed in testing the relationships. This technique internalizes any form of endogeneity in the relationships between the dependent variable and any of the independent variables. The dynamic panel data (DPD) procedure is a generalized method of moments (GMM) estimation for panel data. Essentially, thin capital structure and taxation may be endogenous in their relationship, given that more taxation may influence thin capitalization while thin capitalization application may also affect tax application by the tax authority. These outcomes were also observed by Buettner and Wamser (2013) and de Mooij and Liu (2021) in relation to the patterns of interaction between multinational companies' tax behaviour and thin capitalization. Hence, the results of the GMM estimates are also reported in this study.

In Table 16, the results of the dynamic estimates of the relationships using the GMM technique are reported. The diagnostic tests in the result are generally impressive, given that the coefficients of the over-identifying restriction test statistic (Sargan test statistic) for the GMM estimates possess the expected p-values (i.e., they are greater than 0.1). The p-value associated with the *Sargan test* therefore specifies that the tools employed in the estimation are effective and that the models were appropriately specified. The Arrelano and Bonds (AR) tests are used to identify any form of serial correlations among the errors in the estimates based on the instruments employed in the estimation. The second order coefficient needs to be insignificant in order to satisfy the AR condition. From Table 14, the coefficient of the second order statistic is not significant (in line with apriori expectation), suggesting that the model error terms are serially uncorrelated in levels. The constant value of the lagged dependent variable is substantial at the 5 per cent level – which also justifies the use of a dynamic form for the relationship. The coefficient is also positive, indicating the presence of mean reversion and long run stability in terms tax payments within among TNCs in Nigeria.

TABLE 16

GMM estimates of the Results for determination of tax burden

Dep. var. = intx	Coef.	t	P>t	[95% Conf.
Bnl	0.388**	8.41	0.000	0.297
Debl	0.324**	6.46	0.000	0.225
Les	-0.350**	-3.36	0.001	-0.555
Bnd	-0.488**	-5.39	0.000	-0.310
<i>Sargan test</i>	0.165			
<i>AR(1) (prob)</i>	-2.75**(0.006)			
<i>AR(2) (prob)</i>	-0.77(0.440)			

Note: ** indicate significance at 5% level, respectively. Source: Author's computation
Source: Author's computation, 2021

Table 16 showed the relative contributions of the thin capitalization variables to tax liability of the companies is also evaluated by observing the constants value of the explanatory variables in relations to signs and significance. It can be seen that the coefficients are all positive and they also all possess the same signs with the output from the FGLS estimates. The results confirm the evidence that both bank loans and debentures are not effective tax shield instruments for the TNCs, given that their effects on tax liabilities are significantly positive. On the other hand, the GMM estimates confirm that increasing leasing and bonds issuance by TNCs tend to lower tax payments for the companies.

TABLE 17
Causality test between thin capital and tax obligations

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LBNL does not homogeneously cause LINTX	2.63	1.82	0.07
LINTX does not homogeneously cause LBNL	1.18	-0.52	0.60
LES does not homogeneously cause LINTX	4.25	4.34	0.00
LINTX does not homogeneously cause LES	4.45	4.49	0.00
LDEBL does not homogeneously cause LINTX	2.26	1.22	0.22
LINTX does not homogeneously cause LDEBL	1.44	-0.10	0.92
LBND does not homogeneously cause LINTX	0.86	-1.03	0.30
LINTX does not homogeneously cause LBND	1.24	-0.42	0.67
LES does not homogeneously cause LBNL	1.29	-0.34	0.73
LBNL does not homogeneously cause LES	2.30	1.26	0.21
LDEBL does not homogeneously cause LBNL	1.40	-0.16	0.87
LBNL does not homogeneously cause LDEBL	3.03	2.46	0.01
LBND does not homogeneously cause LBNL	1.33	-0.27	0.79
LBNL does not homogeneously cause LBND	1.72	0.35	0.73
LDEBL does not homogeneously cause LES	3.61	3.74	0.01
LES does not homogeneously cause LDEBL	4.81	-4.09	0.00
LBND does not homogeneously cause LES	1.19	-0.50	0.61
LES does not homogeneously cause LBND	2.43	1.46	0.14
LBND does not homogeneously cause LDEBL	3.13	-2.91	0.03
LDEBL does not homogeneously cause LBND	3.21	2.94	0.04

Source: Author's computation using Eviews 10

Finally, we test causality among the thin capitalization variables as well as between the variables and the income tax payments by TNCs. The outcome of this tests will give backing to the argument of a possible reverse causality running from tax liabilities to thin capitalization among the companies. The result of the causality test using the Dumitrescu-Hurlin Panel Causality technique is presented in Table 17. From the result, it is seen that only the W-statistics for the null hypothesis of causality running from LES to INTX and from INTX to LES passed the significance test. This shows that the strongest reverse causality between thin capitalization and taxes by TNCs is the test between leasing and taxes. Thus, it is seen that leasing influences the behaviour of TNC's tax systems, tax

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4.4 Tests of Hypotheses

The hypotheses sated in this study are tested by means of the t-ratios from the panel regression results from the FGLS estimates in Table 15. The study adopted 5 per cent level of significance to conduct the test on the different hypotheses formulated.

Hypothesis One

Bank loans do not significantly affect tax burden of transnational companies in Nigeria.

The test of this hypothesis is done based on the coefficient of the BNL variable in Table 15. In the result, the coefficient of BNL was 0.275 ($p < 0.01$), indicating that is significant at the 5 per cent level. As a result of this evidence, the null hypothesis is rejected, which shows that bank loans significantly affect tax burden of transnational companies in Nigeria. In particular, bank loans significantly increase tax burdens of transnational companies in Nigeria.

Hypothesis Two

Lease transactions have no significant effect on tax burden of transnational companies in Nigeria.

For this hypothesis, the coefficient of LES is considered from the output in Table 15. The coefficient is -0.485 ($p < 0.01$). Since the associated p-value of the t-test for the coefficient is less than 0.05, it is demonstrated that the constant value passes the significance test at the 5 per cent level. Thus, the null hypothesis is rejected, suggesting that lease transactions have substantial adverse effects on tax burden of transnational companies in Nigeria.

Hypothesis Three

Debenture loans do not significantly affect tax burden of transnational companies in Nigeria.

The coefficient of DEBL in the regression result in Table 15 is 0.422 ($p < 0.01$). This shows that the coefficient passes the significance test at the 0.05 per cent level and hence, the null hypothesis is rejected. From this outcome, the null hypothesis can be rejected at the 5 per cent level. This means that debenture loans significantly affect the tax burden of transnational companies in Nigeria. The effect is actually positive in this regard.

Hypothesis Four

Bonds have no significant effect on tax burden of transnational companies in Nigeria.

For this hypothesis, the coefficient of BND is considered from the output in Table 15. The coefficient is 0.114 ($p < 0.01$). Since the associated p-value of the t-test for the coefficient is less than 0.05, it is demonstrated the constant value passes the significance test at the 5 per cent level. Thus, the null hypothesis is rejected, suggesting that bonds actually have substantial adverse effect on tax burden of transnational companies in Nigeria.

4.5 Discussion of findings

The results obtained in the empirical analysis of this study provides certain outcomes that are apt for discussion. First, the study shows that there are some forms of the application of thin capitalization for reducing tax burden or tax avoidance in Nigeria. This result therefore follows numerous studies that have found that companies that have high leverage of debt enjoy some form of tax shield (deductions on tax liabilities). From a theoretical perspective, this study confirms the Miller and Modigliani relevance theory that demonstrates the usefulness of debt by firms. Previous studies have demonstrated that thin capital is a fundamental strategy employed by international corporations for avoiding high tax burdens (Blouin et al 2014; Waluyo & Caturida, 2018; Darmansyah & Bambang, 2018). These studies all indicated that thin capitalization helps these companies reduce tax burdens by having a larger debt financing structure where interest on debts are non-taxed. The result from our study also confirms these previous studies, especially with regard to non-loan financing systems. The result from this study however is not in line with findings by Altshuler & Grubert (2003) and Agus & Ety (2019) who found no evidence of tax shield generated from thin capitalization among transnational companies. The finding of no effect may be due to the type of debt used. In our study that attempt to disaggregate debt structures for the firms has resulted in clearer outlines of the relationships.

The result from the study also shows that the most important thin capitalisation factors that can form strategic tax burden reduction for transnational companies in Nigeria are the non-loan debt structures. Thus, debt that are closer to loan types do not generate enough tax shield for TNCs in Nigeria. Thus, the thin capitalisation strategy among TNCs appears not to be paying off in terms of bank loans and loan-related debt. The rational for this outcome may lie in the nature of the banking system in Nigeria and the fact that a small

proportion of debt by TNCs is financed by local banks. The study shows specifically that loans and debentures had significant positive impact on tax burdens of the TNCs, indicating that these debt structures increase the debt burdens of the companies. The positive impact of loans in this study can be understood in two dimension. First is the realization that larger firms that report larger tax liabilities in the study may essentially be the ones that borrow more from the banks. If this is the case, a strong positive relationship will be observed between loan, thin capitalization and tax burdens among the companies. Secondly, research has shown that multinational companies are often able to arrange their financing activities to exploit interest-deductibility benefits in their tax obligations (Heckemeyer & Overesch, 2017; Johannesen, et al 2020). These firms do this by establishing tax-efficient debt acquisition in the countries where they borrow and then ensure that the lender institution (that receives interest) also gets favourable tax treatment. This can be done where the TNCs have significant influences on the financial institutions (Johannesen, et al 2020). This is however not too possible given the nature of the banking system in Nigeria, hence the tax burden-enhancing effect of loans on TNCs in Nigeria.

The result from the study therefore suggests that an important factor for thin capitalization and movement of financing into more external structures is the existence of an affiliate financial institutions in a low tax country. This finding are similar to those of Clausing (2009), Buettner and Wamser (2014). This implies that a more developed financial market in the country may pose significant risk for tax yields from TNCs in Nigeria since these international corporations will have more leeway for tax avoidance.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

In this study, the effects of thin capitalization on the tax burdens of transnational companies (TNCs) in Nigeria was examined. The study is centred on the realization that TNCs are easily prone to making decisions that generate tax savings given that deductibility of interest makes it attractive for these companies to adapt debt financing of their foreign affiliates in countries with high tax rate, while they apply equity financing for affiliates in low-tax jurisdictions. These decisions are considered by focusing on the debt (against equity) financing strategies of transnational companies in Nigeria. Four debt financing instruments are considered (including bank loans, lease finance, debenture loans, and bonds) in order to evaluate the respective place of each of these debt structures in influencing tax burdens for the companies. Thus, the study extends previous research in this area by disaggregating the debt components of the companies that make up the thin capitalization strategy. A panel of twenty-nine (29) transnational corporations were used in the analysis for the period 2011 to 2020. Moreover, a mixture of panel data analysis framework and a dynamic (GMM-based) procedure was devised for the panel data analysis. In general, the results from the empirical inquiry reveals that the loan-related debt instruments of thin capitalization do not constitute tax shield for the TNCs, while the non-loan thin capital instruments actually reduce tax burdens for the companies in the study. Precisely, the following findings were made in the study:

- 1) That bank loans significantly affect tax burden of transnational companies in Nigeria, suggesting that thin capitalization strategy with bank loans would increase tax burdens for transnational companies.

- 2) That lease transactions have significant negative effects on tax burden of transnational companies in Nigeria, suggesting that lease financing is an important tax shielding mechanism for transnational companies in Nigeria.
- 3) That debenture positively affect the tax burden of transnational companies in Nigeria, suggesting that the thin capitalization strategy with more debentures would likely increase tax burdens for transnational companies in the country.
- 4) That bonds have substantial adverse effect on tax burden of transnational companies in Nigeria. Suggesting that bonds as thin capitalization strategy constitute an important tax reduction mechanism for transnational companies.

5.2 Conclusion

It is generally agreed that transnational firms make sizable tax savings by adjusting both investment and income strategies. This is powered by the essentially distortionary capacity of taxes in firm undertakings. This study therefore complements to the prevailing literature that examines the implications of the welfare cost of corporate taxation systems as it affects firm investment and financing decisions. The argument in this study is that corporate taxes can distort firm investment structure and minimize foreign investment inflows to the country. For the part of the fiscal authority, it is imperative to integrate this aspect of distortion when assessing the general effect of corporate tax policy or proposal. This is where this study is relevant given that it has demonstrated that transnational companies in Nigeria tend to involve in thin capitalization so as to reduce tax burdens.

5.3 Recommendations

The findings of this study give rise to the following recommendations which are beneficial to both the managers and other market participants. The following recommendations are made:

- 1) Given the results of the study, it is recommended that transnational companies in Nigeria should minimize the use of bank loans and debentures as thin capitalization strategy since they do not enable the reduction of tax burden.
- 2) For the TNCs, the result from the study shows that thin capitalization is only efficient when a larger share of debt is in non-loan form. In particular, bond holding (which is easily obtained in foreign markets) and lease financing are the main debt structures that TNCs need to focus on
- 3) That thin capitalization rules should be intensified by the fiscal authority in the country. Essentially, thin capitalization rules deny interest deductibility above a certain threshold by considering either the payment on interest in relation to cashflow or the net debt-to-equity ratio of these companies. When these rules are well-designed, both financing shifting towards more debt and debt shifting by TNCs can be effectively reduced in Nigeria.
- 4) Furthermore, government needs to get the corporate tax rate right in Nigeria. This is because, the findings from the study have shown that debt shifting in the country is very sensitive to changes in the corporate tax rate. Thus, if tax rates are made specifically for the TNCs in relation to their capacity for thin capitalization, more TNCs may be willing to operate in the country. Tax administration can however achieve the desired results in Nigeria if tax rules are simplified and burdens that are related to rates are reduced in order to clarify issues of legal tax base and exemption packages.

5.4 Contribution to knowledge

This research has contributed to the existing literature in the concept of thin capitalization and concentrated on tax burden of transnational companies in Nigeria. It is hoped that this study will enable regulatory authorities and government provide a framework towards full implementation of the Finance Act of 2020 that place ceiling on the unit of debt

schedule which contains provisions disallowing excess interest. The study supported the position in Finance Act of 2020 that interest expenses should not be carried forward for a period more than five (5) years from the period the excess interest was first incurred. This attempt is geared toward discouraging company carrying forward excessive debt in their capital structure that could in future exposed its operations to insolvency, litigation and bankruptcy.

Furthermore, the study unveil to corporate organization the need to efficiently utilize non loan debt instruments such as lease financing and corporate bonds as a better thin capitalization scheme provided they do not emanate from related party as prohibited in thin capitalization rule in Nigeria. The work would also function as a reference material to corporate managers of multinational companies and other companies that are yet to adopt thin capitalization scheme the need to choose from several debt instruments for the minimization of tax payable.

5.5 Suggestions for Further Studies

The objective of this study was to examine thin capitalization and its effect on tax burden of transnational companies in Nigeria using twenty nine (29) transnational companies and ten (10) years consolidated financial statement of the study companies. These companies were carefully selected from oil and gas sector, Breweries, Conglomerate, pharmaceutical companies, Industrial and domestic product and Food, Beverages and Tobacco industries from 2011 to 2020 financial years. The researcher suggests that further studies should be made on:

1. Thin capitalization in services organizations in Nigeria
2. Thin capitalization in deposit money banks in Nigeria

3. Related studies should also be conducted in sectors not covered by this research so as to enable the generalization of the applicability of thin capitalization on the economic activities of corporate organization.

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APPENDICES

APPENDIX 1

Annualised data from various study transnational companies

	BNL	DBL	BND	LES	INTX
LAFARGE	45183312	2038951	21136	425021	8525000
	4038215	562329	19327	371091	4881000
	4384444	329214	17334	200624	6553284
	3710261	274257	36834	264011	8259421
	9585101	135465	75012	385321	387726
	3648829	680471	10863	467721	4284966
	3087827	748942	58351	419532	3857332
	115202	526665	48621	264013	9058929
	162481	5139600	33849	173586	1697180
	187193	848180	34083	786884	6352400
UACN	1620236	692034	3227011	261824	1642719
	7061996	477390	4812730	326482	2781593
	6409142	730664	4220761	277034	3182629
	5909680	492289	3806471	590313	5929810
	7737406	819158	3190472	771709	6526570
	8125644	1212770	4518266		1899944
	5751564	237079	4271923		1955014
	1329037	2704552	2510944	281040	1921733
	4500793	503570	2717236	360811	3959969
	1850583	459598	3749102	4554941	6182850
MTN	2401625	459598	3610528	278678	1023576
	195283	270488			229170
	235549	104622			193625
	217424	107906			1385383
	346640	113388	3223		12913764
	394701	137838	1057		1248790
	250479	863203	1258	7959833	1336185
	189783	100543	43541	1304108	67954967
	274920	119820	117347	2032530	37850862
	141529	143878	548425	2332238	75656747
Airtel	380089	32453	228770	3365400	87994000
	330551	190599	298180	5479800	93660000
	394000	49995	46630	547980	87994
	171401	118804	29000	27680	93660
	82338	58956	35038	27467	19813
	984082	31390	30673	43910	17318
	7271743	12510	62158	44050	14398
	591575	86680	204644	14048	30916
	892686	57238	395292	61742	19980
	896373	129442	368912	25933	15898

	544681	80680	65413	38990	44690
	586494	229183	69515	65820	21240
	629476	354128	513820	26472	76014
Eni Oil	20305	7478	1097	2997	9157
	23102	6495	3772	3045	10674
	19145	5047	5180	3440	11679
	20875	4685	5037	3678	91056
	19316	6575	5028	2655	6492
	19397	8396	6404	2205	3122
	20564	6675	6219	1672	1936
	20179	4528	6552	1684	3467
	20082	5783	6760	1820	5970
	18910	5608	5502	1478	5591
	21895	4791	5381	8763	2650
DHL	5644	4106	1659	175	458
	403	4004	4109	149	393
	1335	12100	5088	213	361
	486	12050	4290	210	400
	553	4255	4304	164	338
	1464	4292	4217	203	351
	8993	4402	5350	181	477
	2593	4432	5472	9859	362
	2916	2525	5467	1031	145
	6616	2562	4826	1636	626
IBM TECH	4037	3419	1327	13931	64600
	6018	6428	3302	23531	1890
	32856	6862	1885	8996	3363
	35073	5731	1881	1650	4234
	33428	6461			2847
	34655	7513			6461
	73870	11795	67899	12828	4695
	66690	10134	60988	7037	11715
	54102	8797	2124	1729	7316
	54355	7183	3725	1525	8296
	47283	6382	5281	2418	8640
Shell Pet	9237	100552	5900		14870
	7124	102659	4902		24475
	29921	7833	7506	750	23449
	38332	7208	5943	703	13584
	52849	5530	8483		1537
	82992	9480	7964		8299
	73890	11795	8163	2290	4695
	66690	10134	4993	653	11715
	81360	15064	5080	1525	9053
	91115	16899	4880	1380	5433
	72836	12074	3298	926	3793
Mobil oil	11082	51923		1047	20611

	89041	23106		3709	18494
	36532	79280	3430	2391	31045
	158081	68914	21255	3530	24263
	19925	17089	173754	6118	20532
	1669	41336	220538	10599	20333
	13830	28932	5346	1166	4066
	17930	24406	4198	1521	11741
	20578	26342	3826	1564	9532
	17306	21416	4615	1908	5282
	18561	21242	5350	1921	5632
Total	93847	10934		16440	37845
	12519	29186		14090	1914
	14535	29392	2881	27841	16747
	11193	34574	54470	18840	14767
	15682	4765	37640	58932	15424
	18587	10576	3273	36746	24483
	92197	16240	28176	36259	29852
	81895	932932		32644	11281
	74912	644801		40941	37710
	39877	50403	24056	36259	72117
	31047	83984	35853	31093	259732
UNILEVER	730809	46211			197123
	593410	38500		45222	249223
	756567	265637	3081	55845	169743
	749167	401056	3541	48921	185167
	120607	762602		564960	460892
	742654	591055		230765	578697
	205012	414275		5317	103453
	164628	796800	22709	5572	166701
	216504	323541	23391	5561	257523
	235661	46914	29348	3199	226349
	228440	44616	28187	2940	192318
ETISALAT	15136	17380	16274	18999	138246
	29187	15092	42541	167925	201157
	41629	16977	28962	304237	424117
	39274	29182	85217	136026	503193
	186194	36097	74953	52570	582711
	178805	41996	14608	6983	11088476
	182039	40747	14217	7070	11124486
	200351	46702	15112	5152	1245241
	14973	85524	15528	3273	1500239
	6458	4850	11607	1993	1614443
	7334	5823	12580	4838	1450709
Julius Beg	18729	129899	2481	2481	1923002
	16038	158211	3655	3655	6521140
	37263	74773		3311	601183
	48740	50977		2818	563570

	32017	34800		4880	489441
	3281590	24807		5632	466921
	465880	55833	10976	4760	2318763
	12950012	49834	38474	6991	1221620
	8135459	7273975	3873	39090	4095852
	1818494	708237	20199	1370703	5159277
	2310386	5503437	7364	1309390	2620369
Volkswa	37159	9437	11941	3138	1767
	44443	12162	11603	4090	3126
	14352	54060	16952	132	5056
	17177	59987	14614	14	3107
	18893	47836	21748	17	4040
	24613	55872	23755	23	3299
	28036	66981	23601	36	3315
	26291	37622	17877	28	3664
	28036	48774	15290	29	3804
	29099		19784	957	2914
	32645		19825	1100	2646
Samsung	550057	509267	995400	107101	759153
Electronic	2192987	1109966	647379	136854	2969694
	3433174	946660	125894	101771	5751665
	933495	2298712	106944	82402	7476087
	6996114	1198517	108275	92489	3960643
	5469187	1087641	159072	88596	6099929
	1100048	51758	104713	18599	7061911
	1604177	842880	114475	10925	12385744
	75671	855543	50315	50122	3990896
	1659177	861922	51201	1855779	1662569
	1847884	856229	48904	2202901	1370248
Cadbury	1962753	16947	62531		1183725
	2871631	56600	29183		1382467
	1736524	108267		189997	1987443
	6271653	299635		167925	1398258
	2517277	164258	153028	121535	424117
	1560729	726628	228714	17042	266468
	1228936	258271	635421	136026	266468
	1083642	104527	273901	52570	50319
	3726826	118562	141650	1873	2572
	2735418	672618	187263	6805	468032
	3450725	290157	267364	6867	523762
Google	49526		4172		26281
	41735		4481		19735
	3159	3990	5273	463	1409
	2699	5274	6381	522	1771
	3932	4418	1140	2576	2692
	1995	3225	1631	3415	1524
	66149	4222	2731	1171	3728

	357271	4772	3863	10941	4177
	4554	3183	50919	16482	5282
	135932	7341	53413	12211	7813
	107345	1837	28172	146724	68351
Cocacola	8100	1660			2384
	12871	1569	20995	1808	2805
	24353	3514	25583	2917	1890
	23774	7310	28347	3547	1625
	23073	3253	23597	4400	1124
	28311	13129	1173		2239
	29684	12498	9960		1586
	71189	10114		1024	4184
	78201	10222		8431	5260
	6343	3507	9261	2295	5491
	7114	1962	6715	6081	4830
PZ	172400	2401	413	9381	29100
	219300	4962	969	5511	28200
	25228				1768
	88717	8540			2329
	46237	10356	2891	4729	2580
	23284		3620	25418	19860
	128676		3103	27588	101830
	318364	72630	5982	32668	1124572
	234985	37712	3991	34785	386389
	186210	27836	3018	11984	786596
	23070	10475	2635	15519	745176
P&G	3830	1798	3284	264	4101
	1536	1024	3392	224	3392
	21080	8698		254	3468
	19111	12432	497	241	3441
	18329	12021	1272	249	2916
	18445	11653	1407		3342
	18038	11653	3271	843	3063
	20863	10423	3737	213	3465
	20395	9697	2400	166	2103
	23537	11183	2167	255	2731
	19263	28263	2873	4181	1524
GUINNESS	3507303			129865	625237
	4210672			133293	824903
	3272478	851305	661194	338492	616853
	8557059	879618	158992	387025	514514
	5236682	215999		352663	210808
	9875392	121188		118834	300020
	3390828	141646	277194	104292	331355
	1565957	102434	402647	133575	738361
	8116367	557295	481090	115906	322555
	8104582	508632	290330	111787	161989

	1209526	863148	287162	811231	130133
GLAXO	122030	29164	279	9500	2016370
	148090	26980	175	28000	3593850
	146710	36310	6888	13440	3087770
	154560	27890	49	777	1594530
	158410	29430	155	85	225780
	153240	13080	404	705	1188598
	146610	41290	153	9410	3293466
	282500	14264	194	2400	1667000
	579300	20271	74	6800	1535000
	691800	23590	127	2140	4553960
	372500	23425	381	1117	4350000
SCHLUBE	2214	381	222		890
	1041	336	250		1545
	1163	958	247	1618	1700
	1819	964	270	318	1848
	37180	759	368	441	746
	16463	3153	184		278
	14875	3324	850		330
	27881	3971	801	1180	261
	18368	5110	720	255	585
	28377	5837	884	491	614
	17360	4710	1147	380	583
CHEVRON	11966				384520
	19960				419967
	23960	37411	708	99	46792
	33584	1270	813	97	32400
	315934	3790	422	6854	1912
	33477	4928	310	8060	165516
	27171	10841	306	9350	1004
	364581	51926	374	9404	16370
	417380	5726	950	345	5715
	26530	32820	174	660	2691
	22183	1548	1173	450	1892
NESTLE	7519	10950		1847	1934
	6207	16100	127	6381	2555
	9009	18568	1012	3352	3201
	26471	947809	2774	1770	3789
	26354	824623	1839	2945	2095
	12530	171088	2985	1838	5585
	10384	401303	1095	1945	13623
	39816			2906	364493
	35715			37288	391608
	23132	14032	1176	3210	31503
	27928	12019	3167	2610	3365
Halliburt	3119		112	7126	8530
	4820			5182	14390

	4285	140		7222	12350
	7765	588	197	1834	12750
	14687	659	311	228	2740
	14687	170	184	381	6700
	12214	512	297	257	2180
	1043	714	150	171	25540
	27152	827	328	132	30180
	10316	110	169	525	1900
	9632	195	287	530	2650
Accenture	52162	1402			378127
	49192	1620			239072
	4419	22400			252533
	4762	6806	60825	51937	309999
	5933	38394	62819	578149	1121743
	1848	25587	54008	547206	1136741
	2773	24457	61413	539711	1253969
	2907	22163	47103	51662	981100
	5337	19676	53509	44585	1593499
	6411	16247	20639	37539	1405556
	7820	54052	28367	31882	1589018
MAERSK	827162	6291	52614	273	24918
	75322	4136	13099	568	26174
	82377	4937	14507	648	32447
	11977	5421	25850	866	18315
	16461	1425	24628	736	18186
	10913	1412	5518	2220	2972
	11408	1335	7501	1941	522
	15076	2437	7804	2745	219
	29108	680	5373	2266	398
	7455	721	4819	8577	458
	5868	758	3824	8747	407
B&H Oil	177210		41160	8419	138917
	209821		38162	11271	201782
	221385	221384	50000	11342	123288
	262330	262330	63121	9546	86481
	364085	130660	6341	98249	124385
	284531	63918	6882	93128	155360
	167074	55086	7633	120610	113488
	300305	82318	3778	76406	124709
	76384		62285	95931	110438
	108285	12937	405514	250685	89219
	1046231	13937	412060	246189	48997

APPENDIX 2
Descriptive Statistics for Annual changes in variables

	GINTX	GBND	GBNL	GDEBT	GLS
Mean	187.2256	97.75819	148.8101	147.5610	135.8741
Median	5.335527	3.088909	4.841008	1.483848	0.603738
Maximum	18097.20	3836.000	10149.52	14496.41	6965.979
Minimum	-99.39341	-99.28862	-98.72534	-96.60528	-96.77262
Std. Dev.	1298.323	435.2430	754.7956	1024.197	673.2539
Skewness	11.42353	6.484708	9.856344	11.66540	7.227640
Kurtosis	147.8311	49.51522	122.3812	154.5167	61.60949
Jarque-Bera Probability	232895.5 0.000000	25261.94 0.000000	158604.9 0.000000	254600.9 0.000000	39476.97 0.000000
Sum	48678.67	25417.13	38690.64	38365.86	35327.27
Sum Sq. Dev.	4.37E+08	49064034	1.48E+08	2.72E+08	1.17E+08
Observations	260	260	260	260	260

APPENDIX 3 Correlation Matrix

Covariance Analysis: Ordinary
Date: 10/16/21 Time: 10:16
Sample: 2011 2020
Included observations: 289
Balanced sample (listwise missing value deletion)

Correlation Probability	INTX	BND	BNL	DEBT	LES
INTX	1.000000 -----				
BND	0.072554 0.2188	1.000000 -----			
BNL	0.059285 0.3152	0.267331 0.0000	1.000000 -----		
DEBT	0.059409 0.3142	0.189002 0.0012	0.350299 0.0000	1.000000 -----	
LES	0.327039 0.0000	0.161647 0.0059	0.045077 0.4452	0.085095 0.1490	1.000000 -----

APPENDIX 4

Hausman Test

Dependent Variable: LINTX
Method: Panel Least Squares
Date: 10/16/21 Time: 10:24
Sample: 2011 2020
Periods included: 10
Cross-sections included: 29
Total panel (balanced) observations: 290

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.102438	0.630685	0.162423	0.8711
LBNL	0.274527	0.074136	3.702999	0.0003
LLES	0.485452	0.058907	8.241050	0.0000
LDEBT	0.421762	0.081704	5.162063	0.0000
LBND	-0.114099	0.065484	-1.742400	0.0825
R-squared	0.584734	Mean dependent var		10.85713
Adjusted R-squared	0.578906	S.D. dependent var		3.042971
S.E. of regression	1.974639	Akaike info criterion		4.215739
Sum squared resid	1111.271	Schwarz criterion		4.279013
Log likelihood	-606.2821	Hannan-Quinn criter.		4.241089
F-statistic	100.3267	Durbin-Watson stat		0.497552
Prob(F-statistic)	0.000000			

Dependent Variable: LINTX
 Method: Panel Least Squares
 Date: 10/16/21 Time: 10:25
 Sample: 2011 2020
 Periods included: 10
 Cross-sections included: 29
 Total panel (balanced) observations: 290

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.035884	0.639180	0.056141	0.9553
LBNL	0.280975	0.075000	3.746329	0.0002
LLES	0.480756	0.060011	8.011103	0.0000
LDEBT	0.422923	0.083336	5.074904	0.0000
LBND	-0.111458	0.066339	-1.680133	0.0941

Effects Specification

Period fixed (dummy variables)

R-squared	0.592112	Mean dependent var	10.85713
Adjusted R-squared	0.572900	S.D. dependent var	3.042971
S.E. of regression	1.988669	Akaike info criterion	4.259880
Sum squared resid	1091.526	Schwarz criterion	4.437047
Log likelihood	-603.6826	Hannan-Quinn criter.	4.330862
F-statistic	30.81975	Durbin-Watson stat	0.481329
Prob(F-statistic)	0.000000		

Dependent Variable: LINTX
 Method: Panel EGLS (Period random effects)
 Date: 10/16/21 Time: 10:25
 Sample: 2011 2020
 Periods included: 10
 Cross-sections included: 29
 Total panel (balanced) observations: 290
 Swamy and Arora estimator of component variances

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.102438	0.635166	0.161277	0.8720
LBNL	0.274527	0.074663	3.676873	0.0003
LLES	0.485452	0.059325	8.182907	0.0000
LDEBT	0.421762	0.082285	5.125643	0.0000
LBND	-0.114099	0.065949	-1.730107	0.0847

Effects Specification

	S.D.	Rho
Period random	0.000000	0.0000
Idiosyncratic random	1.988669	1.0000

Weighted Statistics

R-squared	0.584734	Mean dependent var	10.85713
Adjusted R-squared	0.578906	S.D. dependent var	3.042971
S.E. of regression	1.974639	Sum squared resid	1111.271
F-statistic	100.3267	Durbin-Watson stat	0.497552
Prob(F-statistic)	0.000000		

Unweighted Statistics

R-squared	0.584734	Mean dependent var	10.85713
Sum squared resid	1111.271	Durbin-Watson stat	0.497552

Correlated Random Effects - Hausman Test

Equation: Untitled

Test period random effects

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Period random	1.873182	4	0.7591

** WARNING: estimated period random effects variance is zero.

Period random effects test comparisons:

Variable	Fixed	Random	Var(Diff.)	Prob.
LBNL	0.280975	0.274527	0.000050	0.3639
LLES	0.480756	0.485452	0.000082	0.6038
LDEBT	0.422923	0.421762	0.000174	0.9299
LBND	-0.111458	-0.114099	0.000052	0.7131

APPENDIX 5

Residual Cross-Section Dependence Test

Null hypothesis: No cross-section dependence (correlation) in residuals

Equation: Untitled

Periods included: 10

Cross-sections included: 29

Total panel observations: 290

Note: non-zero cross-section means detected in data

Cross-section means were removed during computation of correlations

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	693.8955	406	0.0000
Pesaran scaled LM	10.10315		0.0000
Pesaran CD	0.975624		0.3293

Panel Cross-section Heteroskedasticity LR Test

Null hypothesis: Residuals are homoskedastic

Equation: UNTITLED

Specification: LINTX C LBNL LLES LDEBT LBND

	Value	Df	Probability
Likelihood ratio	162.9931	29	0.0000

LR test summary:

	Value	Df
Restricted LogL	-606.2821	285
Unrestricted LogL	-524.7856	285

Unrestricted Test Equation:
 Dependent Variable: LINTX
 Method: Panel EGLS (Cross-section weights)
 Date: 10/16/21 Time: 10:35
 Sample: 2011 2020
 Periods included: 10
 Cross-sections included: 29
 Total panel (balanced) observations: 290
 Iterate weights to convergence
 Convergence achieved after 12 weight iterations

Variable	Coefficien	t	Std. Error	t-Statistic	Prob.
C	-1.259791	0.364613	-3.455149	0.0006	
LBNL	0.256558	0.050937	5.036769	0.0000	
LLES	0.377010	0.034566	10.90707	0.0000	
LDEBT	0.446722	0.049758	8.977828	0.0000	
LBND	0.075032	0.036404	2.061078	0.0402	

Weighted Statistics

R-squared	0.839740	Mean dependent var	18.48051
Adjusted R-squared	0.837490	S.D. dependent var	15.74467
S.E. of regression	2.086964	Akaike info criterion	3.653694
Sum squared resid	1241.295	Schwarz criterion	3.716968
Log likelihood	-524.7856	Hannan-Quinn criter.	3.679044
F-statistic	373.3388	Durbin-Watson stat	0.782219
Prob(F-statistic)	0.000000		

Unweighted Statistics

R-squared	0.536144	Mean dependent var	10.85713
Sum squared resid	1241.299	Durbin-Watson stat	0.417316

APPENDIX 6

FGLS ESTIMATE

Dependent Variable: LINTX

Method: Panel EGLS (Period random effects)

Date: 10/23/21 Time: 17:14

Sample: 2011 2020

Periods included: 10

Cross-sections included: 29

Total panel (balanced) observations: 290

Swamy and Arora estimator of component variances

White cross-section standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.102438	0.373519	0.274250	0.7841
LBNL	0.274527	0.070262	3.907205	0.0001
LLES	-0.485452	0.075214	-6.454246	0.0000
LDEBT	0.421762	0.058567	7.201381	0.0000
LBND	-0.114099	0.049426	-2.308487	0.0217

Effects Specification		S.D.	Rho
Period random		0.000000	0.0000
Idiosyncratic random		1.988669	1.0000

Weighted Statistics			
R-squared	0.584734	Mean dependent var	10.85713
Adjusted R-squared	0.578906	S.D. dependent var	3.042971
S.E. of regression	1.974639	Sum squared resid	1111.271
F-statistic	100.3267	Durbin-Watson stat	0.497552
Prob(F-statistic)	0.000000		

Unweighted Statistics			
R-squared	0.584734	Mean dependent var	10.85713
Sum squared resid	1111.271	Durbin-Watson stat	0.497552

APPENDIX 7

Panel unit root test: Summary

Series: LINTX

Date: 10/16/21 Time: 10:37

Sample: 2011 2020

Exogenous variables: Individual effects

User-specified lags: 1

Newey-West automatic bandwidth selection and Bartlett kernel

Balanced observations for each test

Method	Statistic	Prob.**	Cross- sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-4.95248	0.0000	29	232
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-2.02065	0.0217	29	232
ADF - Fisher Chi-square	87.2824	0.0077	29	232
PP - Fisher Chi-square	109.375	0.0001	29	261

** Probabilities for Fisher tests are computed using an asymptotic Chi

-square distribution. All other tests assume asymptotic normality.

Panel unit root test: Summary

Series: LBNL

Date: 10/16/21 Time: 10:38

Sample: 2011 2020

Exogenous variables: Individual effects

User-specified lags: 1

Newey-West automatic bandwidth selection and Bartlett kernel

Balanced observations for each test

Method	Statistic	Prob.**	Cross- sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-24.1130	0.0000	29	232
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-4.90817	0.0000	29	232
ADF - Fisher Chi-square	109.068	0.0001	29	232
PP - Fisher Chi-square	120.273	0.0000	29	261

** Probabilities for Fisher tests are computed using an asymptotic Chi

-square distribution. All other tests assume asymptotic normality.

Panel unit root test: Summary

Series: LDEBT

Date: 10/16/21 Time: 10:38

Sample: 2011 2020

Exogenous variables: Individual effects

User-specified lags: 1

Newey-West automatic bandwidth selection and Bartlett kernel

Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-33.0148	0.0000	29	232
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-6.39489	0.0000	29	232
ADF - Fisher Chi-square	115.594	0.0000	29	232
PP - Fisher Chi-square	118.121	0.0000	29	261

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Panel unit root test: Summary

Series: LLES

Date: 10/16/21 Time: 10:38

Sample: 2011 2020

Exogenous variables: Individual effects

User-specified lags: 1

Newey-West automatic bandwidth selection and Bartlett kernel

Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-2.40775	0.0080	29	232
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-0.32493	0.3726	29	232
ADF - Fisher Chi-square	70.6542	0.1231	29	232
PP - Fisher Chi-square	79.2911	0.0331	29	261

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Panel unit root test: Summary

Series: LBND

Date: 10/16/21 Time: 10:39

Sample: 2011 2020

Exogenous variables: Individual effects

User-specified lags: 1

Newey-West automatic bandwidth selection and Bartlett kernel

Balanced observations for each test

Method	Statistic	Prob.**	Cross- sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-2.68201	0.0037	29	232
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-				
stat	-0.44488	0.3282	29	232
ADF - Fisher Chi-square	68.4479	0.1640	29	232
PP - Fisher Chi-square	127.971	0.0000	29	261

** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

APPENDIX 8

Residual Cointegration Test

Series: LINTX LBNL LDEBT LBND LLES

Date: 10/16/21 Time: 10:40

Sample: 2011 2020

Included observations: 290

Cross-sections included: 29

Null Hypothesis: No cointegration

Trend assumption: No deterministic trend

User-specified lag length: 1

Newey-West automatic bandwidth selection and Bartlett kernel

Alternative hypothesis: common AR coefs. (within-dimension)

	<u>Statistic</u>	<u>Prob.</u>	<u>Weighted Statistic</u>	<u>Prob.</u>
Panel v-Statistic	-2.187407	0.9856	-2.862789	0.9979
Panel rho-Statistic	4.443835	0.0381	4.482715	0.0363
Panel PP-Statistic	-2.802629	0.0025	-4.431974	0.0000
Panel ADF-Statistic	0.615434	0.7309	-2.034978	0.0209

Alternative hypothesis: individual AR coefs. (between-dimension)

	<u>Statistic</u>	<u>Prob.</u>
Group rho-Statistic	7.081002	0.0337
Group PP-Statistic	-7.698643	0.0000
Group ADF-Statistic	-3.577126	0.0002

APPENDIX 9

Kao Residual Cointegration Test

Series: LINTX LBNL LDEBT LBND LLES

Date: 10/16/21 Time: 10:42

Sample: 2011 2020

Included observations: 290

Null Hypothesis: No cointegration

Trend assumption: No deterministic trend

User-specified lag length: 1

Newey-West automatic bandwidth selection and Bartlett kernel

	t-Statistic	Prob.
ADF	-8.284273	0.0000
Residual variance	1.390706	
HAC variance	0.935267	

APPENDIX 10

Pairwise Granger Causality Tests

Date: 10/16/21 Time: 10:41

Sample: 2011 2020

Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
LBNL does not Granger Cause LINTX	232	2.06941	0.1286
LINTX does not Granger Cause LBNL		1.40593	0.2473
LDEBT does not Granger Cause LINTX	232	5.64499	0.0040
LINTX does not Granger Cause LDEBT		0.98850	0.3737
LBND does not Granger Cause LINTX	232	0.66549	0.5150
LINTX does not Granger Cause LBND		0.90379	0.4065
LLES does not Granger Cause LINTX	232	9.78101	8.E-05
LINTX does not Granger Cause LLES		3.61823	0.0284
LDEBT does not Granger Cause LBNL	232	2.70005	0.0694
LBNL does not Granger Cause LDEBT		8.63965	0.0002
LBND does not Granger Cause LBNL	232	0.52015	0.5951
LBNL does not Granger Cause LBND		3.39630	0.0352
LLES does not Granger Cause LBNL	232	1.73693	0.1784
LBNL does not Granger Cause LLES		3.68147	0.0267
LBND does not Granger Cause LDEBT	232	2.74477	0.0664
LDEBT does not Granger Cause LBND		4.43841	0.0129
LLES does not Granger Cause LDEBT	232	5.33992	0.0054
LDEBT does not Granger Cause LLES		3.68017	0.0267
LLES does not Granger Cause LBND	232	6.19074	0.0024
LBND does not Granger Cause LLES		2.85015	0.0599

```
. xtabond2 intx bnl debt les bnd, gmm(l1.intx) iv(bnl debt) small
```

Favoring speed over space. To switch, type or click on mata: mata set matafavor space, perm.

Warning: Number of instruments may be large relative to number of observations.

Dynamic panel-data estimation, one-step system GMM

```
-----
Group variable: companynum      Number of obs   =   290
Time variable : year           Number of groups =    29
Number of instruments = 47      Obs per group:  min =    10
F(4, 285)   =   240.30         avg =   10.00
Prob > F    =    0.000         max =    10
```

intx	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
bnl	.3882328	.0461455	8.41	0.000	.2974035	.479062
debt	.3237267	.0501114	6.46	0.000	.2250912	.4223622
les	-.3502625	.1041365	-3.36	0.001	-.5552367	-.1452883
bnd	-.4877062	.0904659	-5.39	0.000	-.3096401	-.6657723

Instruments for first differences equation

Standard

D.(bnl debt)

GMM-type (missing=0, separate instruments for each period unless collapsed)

L(1/9).L.intx

Instruments for levels equation

Standard

bnl debt

_cons

GMM-type (missing=0, separate instruments for each period unless collapsed)

D.L.intx

Arellano-Bond test for AR(1) in first differences: $z = -2.75$ $Pr > z = 0.006$

Arellano-Bond test for AR(2) in first differences: $z = -0.77$ $Pr > z = 0.440$

Sargan test of overid. restrictions: $\chi^2(42) = 26.35$ $Prob > \chi^2 = 0.135$

(Not robust, but not weakened by many instruments.)

Difference-in-Sargan tests of exogeneity of instrument subsets:

GMM instruments for levels

Sargan test excluding group: $\chi^2(34) = 63.55$ $Prob > \chi^2 = 0.002$

Difference (null H = exogenous): $\chi^2(8) = 202.80$ $Prob > \chi^2 = 0.000$

iv(bnl debt)

Sargan test excluding group: $\chi^2(40) = 216.20$ $Prob > \chi^2 = 0.000$

Difference (null H = exogenous): $\chi^2(2) = 50.15$ $Prob > \chi^2 = 0.000$

**KIDNAPPING FOR RANSOM AND NATIONAL SECURITY CHALLENGES IN
NIGERIA**

BY

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REG.NO. POS/Ph.D./17/007**

**A DOCTOR OF PHILOSOPHY DEGREE (Ph.D) DISSERTATION CARRIED
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SUBMITTED TO

**POST-GRADUATE SCHOOL,
UNIVERSITY OF CALABAR
CALABAR-NIGERIA**

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF
DOCTOR OF PHILOSOPHY DEGREE (Ph.D) IN POLITICAL SCIENCE
(INTERNATIONAL RELATIONS AND STRATEGIC STUDIES)**

SEPTEMBER, 2021

DECLARATION

I, Dada, Hassan Taiwo, with registration number POS/Ph.D/17/007, hereby declare that this Dissertation on “Kidnapping for Ransom and National Security Challenges in Nigeria” is original and was written by me. It is a record of my research and has not been presented before in any previous publication.

Dada, Hassan Taiwo

Signature.....

Date.....

CERTIFICATION

We certify that this thesis entitled **Kidnapping for Ransom and National Security Challenges in Africa: A Critical Appraisal in Nigeria, 1999-2020** by: **Dada, Hassan Taiwo (POS/Ph.D /17/007)**, carried out under our supervision, has been found to have met the regulations of the University of Calabar. We, therefore, recommend the work for the award of **Doctorate degree in Political Science (International Relations and Strategic Studies)**

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Date: 28/9/2021.....

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ABSTRACT

Kidnapping for ransom, hostage taking and other forms of organized crimes has become an issue of both global and regional concern; in Nigeria it has reached a level that it should be treated as a threat to Nigeria's national security. It is also common sense to note that, every sovereign nation on earth is facing one security challenge or the other that is typical to their prevailing socio-economic and political circumstances in their domains. However, the case with Nigeria is seemingly overwhelming as the crime of kidnapping for ransom gets sophisticated on a daily basis. Five research questions and five hypotheses guided the study in line with the objectives. Two theories provided the framework for this study, the Anomie theory and Social learning theory by Albert Bandura. The cross-sectional survey research design was employed in conducting the study. The researcher utilized observational techniques, secondary data in terms of document analysis from reliable sources. Primary data for the study were collected through in-depth and Key Informant Interviews (KII) during field work. The interviews were mostly conducted through telephone conversations and few were one-on-one with respondents in all twenty three respondents were reached. Both primary and secondary data were presented to answer the research questions and test the hypotheses posed for the study. From the analysis, the following findings were reached: it was found that socio-economic factors, failure of state security architecture, ungoverned spaces, failure of governance and value system/corruption significantly influences kidnapping for ransom and a threat to national security in Nigeria. Based on data and evidences presented, the study concluded that, the wave of kidnapping for ransom in Nigeria constitutes a serious threat to Nigeria national security. It was recommended among

others that: The government should as a matter of urgency address the ever widening gap between the rich and the poor in the country. That government should also, as a matter of urgency, reorganize the security architecture of the state to embrace the use of technology and reflect the modern security strategies. Furthermore, it was recommended that the federal government and the rural communities should collectively make efforts to secure ungoverned spaces so as to dislodge criminals from their strongholds to make the people around such areas more secure. Finally, the current legislations on kidnapping should be strengthened and the process of implementation be made to serve as a deterrent to kidnappers.

(Words Count: 393)

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The first two decades of the 21st century have been characterized by kidnapping for ransom, hostage taking and other forms of organized crimes in Nigeria which have called into question Nigeria's national security. It is pertinent to state that, every sovereign nation in the world is facing one security challenge or the other that is typical to their prevailing socio-economic and political circumstances in their domain. However, the case with Nigeria is seemingly overwhelming. Studies in the past on kidnapping and security challenges observed that, one of the most fundamental challenges facing contemporary states is how to ensure national sustainability in the face of manifold and ever burgeoning security challenges. Notable among these security challenges is the issue of organized crime, like terrorism, banditry and kidnapping (Okoli & Orinya, 2013).

Organized crimes carry with it some international coloration and are high profile crimes which are often perpetrated through transnational syndication and racketeering. Notable among such cases today in Nigeria are, Boko Haram led terrorist activities, banditry, the influx of herdsmen in parts of Nigeria. These crimes are traceable to Niger, Chad and as far as Mali which span beyond the Nigeria borders. Case in point include terrorism, piracy, human trafficking, drug trafficking, money laundry and ransom kidnapping. Globally, indications are rife to the effect that organized crimes such as ransom kidnapping are not only getting prevalent; indeed they are also getting more sophisticated and consolidated. In effect, they are becoming rather entrenched both locally and globally and constituting a major threat to the lives and security of citizens in

most countries today, including Nigeria. Kidnapping for ransom has become the major headlines in our Dailies and television programmes.

In time past, a good number of researches have been carried out by students of international relations and Conflict Resolution, experts and stakeholders in the security sector, such as Nigerian Military Intelligence (NMI), The National Intelligence Agency (NIA), Department of State Security (DSS) and a host of others on different courses and how to avert the threatening security challenges with particular reference to kidnapping dominating such literature. This has somehow helped to fill the gap in research and contribute to knowledge, but not with the view to advanced empirical literature in curbing the rate of ransom kidnapping and other security issues in Nigeria. The findings of such studies, to some extent have their attendant implications on the overall performance and rating of the security architecture of the country, concerning the nature of their investigation and intelligence gathering, in terms of the probable solutions and strategies offered as the way forward for the advancement of peace and ensuring economic stability and national security both internally and externally.

However, there are several forms and reasons for kidnapping, the current study properly focuses on the new trend, which is kidnapping for ransom. The researcher during his professional line of duty and interaction has observed a shift from other forms of kidnaping such as political and religious kidnaping to kidnaping for ransom. It has gotten to a level whereby those who were initially kidnapping for other reasons now ask for huge ransom from their victims for release. This development calls for detailed research into the growing trend and its threat to the national security of Nigeria. More worrisome is the level of successes recorded according to the available literature in terms

of ransom paid so far by victims. It seems to continue unabated in our national space. It is interesting to note that the major road for instance, the Abuja - Kaduna highway is gradually being abandoned for fear of being taken over by kidnapers. It has gotten worse and the only way to perceive this in terms of national security is to first treat the issue as a threat to Nigeria's national security.

According to global security best practice, nations whose value system is to engendered peace and national development, ensures that human lives and protection of citizens' property is a key priority of government and will treat the current trend of ransom kidnapping in Nigeria today as a threat to national security. The high state of insecurity and the inability of the federal government to deal with the orgy of killings by herdsmen for instance in the country, certainly challenge the very basis of Nigeria's existence as a sovereign nation. Some scholars attribute the rising spate of ransom kidnapping in Nigeria and some African countries to socio-economic factors, such as poverty, unemployment, poor government policies, security structure and the likes. It has also been associated with the phenomenon of 'failed or failing state' syndrome (Adibe, 2008). In effect, some have opined that, the prevalence of crime such as kidnapping in Africa demonstrates the dwindling capabilities of her states to ensure sustainable development and national security (Okoli, 2013). Bassey (2019) cited Daily Sun of August, 2018) also emphatically stressed that, "there is no doubt that there are subsisting issues with the ability of the police to effectively police the country and ensure the enforcement of law and order. That the present system which allows for deliberate obfuscation of lines of authority, cross abdication of responsibilities and abuse of power should be done away with."

Kidnapping as it concerns the researcher's interest in this study is to establish what such a menace implies to national security and economic development and to ascertain why the security architecture in Nigeria cannot curb the trend as it is done in other climes. This evaluation views kidnapping as veritable threat to national security in Nigeria in view of its negative impacts and implications vis-à-vis the country's corporate wellbeing and sustainability.

With the different security formations across the country to combat kidnapping and other crimes, fundings of different research and programmes notwithstanding, there is still less significant impact as the threat is having a progressive geometric increase and is today assuming a gigantic proportion. To demonstrate the humongous nature of the threat of kidnapping, Chad, Cameroon, and the United States have in the past, joined in the fight to curtail the excesses of kidnapping and other related crimes in Nigeria by signing some bi-lateral security partnership. In daily discussions with security experts, some hold the view that, Boko Haram and kidnappings may be motivated by both politics and religion, according to their own leaders as well as the Nigerian government. Kidnappings in Nigeria have severally been reported to be political, reasons being that corrupt politicians use it as a tool to either advance their political gains and aspirations or use it as tool to destroy the government of their political opponents, which date back to 1960.

A more recent example is the Chibok girls in 2014, which many alleged was targeted to bring down the Government of former President Goodluck Jonathan. Some had also argued that, kidnappings are also religious, for instance, in the case of the Dapchi school girls who were adopted by the Boko Haram sect in the present government

of President Muhammadu Buhari, the only adoptee not released was said to be a Christian and her refusal to denounce her faith was the reason she was kept back. The researcher is deeply considering kidnappings as one of the country's biggest threat to national security in contemporary Nigeria deserving the attention of government, organized groups, civil societies and other individuals. More so, now that Nigeria faces many problems, including unemployment, corruption and high rate of illiteracy.

In the context of this study, kidnapping means the taking away of persons against their will with the intent to holding them in illegal confinement in order to elicit a ransom, or in furtherance of another crime (Okoli, & Agada, 2014). In the light of this definition, three elements are needed to establish the act of kidnapping. These elements are:

- (i) taking a person away without his consent;
- (ii) holding a person in false imprisonment or illegal detention/confinement;
- (iii) extortion of the victim (the kidnapped victim) through ransoming or forced acquiescence.

History has shown that, before colonial Nigeria, kidnapping was a means of sourcing for slaves to be sold to foreigners. After the abolition of slave trade, kidnapping for ritual continued in some countries in West Africa. In the past, political kidnapping was introduced by the Niger delta militant, who targeted foreigners, especially the Americans and British, mainly to draw attention of their plight of environmental degradation, caused by oil and gas exploration and production. The hostages were usually kept for weeks and released after a press conference, which will be broadcast by big

media outlets, such as CNN and BBC. This trend continued and actually broadened the desired publicity to the Niger Delta issue.

The fact on the ground now shows that the rate of kidnapping for ransom is indeed very high and the researcher is worried at the dimension the crime is taking. But what exactly is the problem? Has the security structure failed like many alleged, in the protection of lives and properties, which is the primary responsibility of government? Do those charged with the responsibility to address national threats of this nature have the needed resources (men and equipment) to tackle the challenge? Thus, this study carried out a comprehensive evaluation of the rate of kidnapping for ransom as a threat to national security in Nigeria with a view to underscore its implications for national stability and economic development with conscious attention on the security structure and operational failure in the country.

1.2 Statement of the problem

Kidnapping for ransom has become a major national security threat in Nigeria during the period under review, which has transformed into organized crime, with immense political and economic consequences. There is no doubt saying that kidnapping for ransom is on the increase in Nigeria. Statistically, Nigeria records more than 1,000 kidnapping incidents a year, and there are undoubtedly many that are unreported (Catlin Group, 2012). However, some recent studies have confirmed that, the control of kidnapping has been hindered by prolonged and persistent unemployment, worsening political instability, internal grievances and get rich quick syndrome. Though these things are known and appreciable effort seems to have gone into ameliorating them, kidnapping for ransom has assumed a gigantic proportion and a real threat to national security.

This state of affairs has resulted in the feeling of insecurity, especially among the Very Important Persons (VIPs), and the well to do in the society, who are often targets for this kind of kidnapping. It has taken a rather dramatic twist in Nigeria recently with its spread from the Niger Delta, through the South East and presently dominating the Northern part of Nigeria. It has become unprecedented given its magnitude and rate of occurrences, so much so that, some major roads in Nigeria such as, the Abuja – Kaduna high way, the Abaji – Lokoja high way, Suleja – Minna and so on, are now dreaded for fear of being kidnapped even at broad day light for outrageous ransom.

The bulging concern of the researcher to embark on this study is, with all that is known about kidnaping already as mentioned above, what has sustained the progressive trend in kidnaping for ransom in Nigeria? With the level which the crime has reached why have the police and other security agencies responsible for combating such crimes not put a stop to it? Have they been overwhelmed, or what is particularly fueling kidnaping for ransom. Predicated on the foregoing, the researcher is speculating that, can socio-economic factors be a contributing factor, could there be a problem with the state security architecture, in terms of structure, will decentralizing the police system in the country help? Could there be a problem with ungoverned spaces, could it be failure of governance to address kidnaping for ransom and finally the researcher is thinking, has Nigeria's value system eroded over the years?

With these concern in mind, the research therefore, sets out to conduct an evaluation of kidnaping for ransom as a threat to national security from 1999 - 2020, with the aim of identifying the underlying factors responsible for this crime and advancing possible solutions to stop its threat to national security.

1.3 Objectives of the study

The purpose of this study is to evaluate and critically assess kidnapping for ransom as a threat to national security in Nigeria from 1999 - 2020. Specifically the study set out to determine whether:

1. Socio-economic factors have significant effects on kidnapping for ransom and national security in Nigeria.
2. Failure of state security architecture has significant influence on kidnapping for ransom and national security.
3. Ungoverned spaces influence kidnapping for ransom and national security.
4. Determine if failure of governance has significant effects on kidnapping for ransom and national security in Nigeria.
5. Value system/corruption have significant effects on kidnapping for ransom and national security in Nigeria.

1.4 Research questions

The following research questions guided the study

1. To what extent does socio-economic factors influence kidnapping for ransom and national security in Nigeria?
2. How does failure of state security architecture influence kidnapping for ransom and national security in Nigeria?
3. To what extent does ungoverned spaces influence kidnapping for ransom and national security in Nigeria?
4. How does failure of governance influence kidnapping for ransom and national security in Nigeria?

5. To what extent does value system/corruption influence kidnapping for ransom and national security in Nigeria?

1.5 Research hypotheses

Ho1 Socio-economic factors does not significantly influence kidnapping for ransom and national security in Nigeria.

Hi1 Socio-economic factors significantly influence kidnapping for ransom and national security in Nigeria.

Ho2 Failure of state security architecture does not significantly influence kidnapping for ransom and national security in Nigeria.

Hi2 Failure of state security architecture significantly influences kidnapping for ransom and national security in Nigeria.

Ho3 Ungoverned spaces does not significantly influence kidnapping for ransom and national security in Nigeria.

Hi3 Ungoverned spaces significantly influences kidnapping for ransom and national security in Nigeria.

Ho4 There is no significant influence of failure of governance on kidnapping for ransom and national security in Nigeria.

Hi4 There is a significant influence of failure of governance on kidnapping for ransom and national security in Nigeria.

Ho5 There is no significant influence of value system/corruption on kidnapping for ransom and national security in Nigeria.

Hi5 There is a significant influence of value system/corruption on kidnapping for ransom and national security in Nigeria.

1.6 Significance of the study

Findings from the study, when completed, will benefit, security personnel (The Nigerian Police Force, DSS, NSCDC, the military and the likes), government of Nigeria, researchers and students, particularly,

The study will contribute to the advancement of knowledge in how to tackle issues of ransom kidnapping and its implications for national security. Furthermore, it would help to stimulate further research on the menace of ransom kidnapping in Nigeria and how it has affected Nigeria's national security architecture. It is also hoped that the study would add to the existing literature and body of knowledge, in terms of kidnapping for ransom.

Secondly its findings would help the paramilitary and military on how best to address the problem of kidnapping for ransom. It is also believed that, the finding will help them interrogate the recruitment processes of all security outfit in Nigeria. It will reveal a more stringent strategy on how to tackle ransom kidnapping as threat to national security.

Also, the study will help government to change strategy on security funding and care for the welfare of security personnel. The study will also be of benefit to government in the area of national value reorientation of the citizenry towards patriotism and national development.

1.7 Scope of the study

Kidnapping is a very broad concept which would require considerable amount of time, effort, resources and literature to adequately address. However, this study would concentrate on ransom kidnappings as the more dominant and current security challenges

in Nigeria from 1999 – 2020. This is as a result of it being the most burning issue in the national security discourse in the state. The study would take a cursory look at major variable such as, socio-economic factors, failure of state security architecture, ungoverned spaces, value system/corruption and ransom kidnapping as a threat to national security.

1.8 Assumptions of the study

The study will be based on the following assumptions:

1. That, the respondent will give honest response to the interview to be granted.
2. The literature used here are products of sound research findings.
3. Records of kidnapping for ransom could be obtained and used as a guide for the study.

1.9 Limitations of the study

The major problem the researcher encountered which served as a major hindrance to this work was getting respondents for the interviews. The victims of kidnapping and their relatives were not willing to talk about it except for few because of security concern. The security personnel were also not willing to disclose some issues concerning security and strategies on ground to combat the problem. The researcher is feels that, the security personnel may not have shared completely the information available to them on kidnapping. The challenge with gathering data also delayed the study because respondents could only be reached through informant.

1.10 Definition of terms

For the purpose of this study, the following terms will be defined as follows:

1. Kidnapping: The act of taking someone by force against his/her will and kept in a confinement for various reasons.
2. Ransom: The money paid or the worth of what is paid for the release of a kidnapped victim. Payment made for the release of an adoptee or a kidnapped person.
3. Socio-economic: Relating to means of livelihood and survival of a people. How the society engages with each other to earn a living and their individual status in the society.
4. Value system: this is what the society treats as important and hold in high regards. It is also what drives the people or a society at a time.
5. Ungoverned spaces: An area of land or water without government presence or control.

CHAPTER TWO

LITERATURE REVIEW

This chapter presented the review of relevant literature for the study from both contextual and empirical reviews from reputable sources. The review was presented in line with the sub-theme for the study.

2.1 Conceptual literature

2.1.1 General context review

Kidnapping and abduction for ransom is one security challenge that has continued unrelenting in Nigeria. The act is described in Section 364, Chapter 77 of the Nigerian Criminal Code Act of 1990 as unlawfully imprisonment of any person in such a manner as to prevent him or her from applying to a court for his or her release or from disclosing to any other person the place where he or she is imprisoned, or in such a manner as to prevent any person entitled to have access to him or her from discovering the place where he or she is imprisoned. From whatever perspective one may see kidnapping, it involves the act of abducting and holding a person or group of people captive, and in the context of this study, to obtain ransom. Literarily, the word, which has become notorious, putrid and nauseating in the ears of virtually everyone is derived from "kid" meaning; child and "nab" which means; to snatch.

The kidnappers have been found to engage in the criminality for several complex motives ranging from unemployment, idleness, vengeance, rituals, monetary gains and political reasons (Ngwama, 2014). Kidnappers may keep their victims for few days or longer as it appeals to them and how it satisfies their reason for the kidnap and for ransom kidnapping, to request more ransom from relatives of the victims, a view which

was also held by Uzochukwu, (2018) when he noted that “Sometimes kidnappers hold their captives longer in order to demand more from the relatives of the victim”. Closely related and most of the times taken together is the issues of hostage taking.

As noted by Adewale (2009), kidnapping which now appears to be an emerging concern in Nigeria is not a new phenomenon. It is as old as the word itself. But the motive may vary from country to country, and time to time and that is why the current study is situated around kidnaping for ransom which seems to be the recent trend in Nigeria. Since 1673 the unfriendly world has been used to the practice of stealing of children for use as servants or labourers in the American colonies; in the Western part of Nigeria was the issue of “Gbomo-Gbomo” which was ritual kidnapping, political kidnapping and so on. But all these seem to have abated and giving way for ransom kidnaping. So it has come to mean any illegal capture or detention of a person or people against their will, regardless of age for wrong motives.

According to the United Nations (UN, 2013), hostage taking is the act of seizing or detaining and threatening to kill, to injure or maim or to continue to detain another person in order to compel a third party, such as, State, an international intergovernmental organization, a natural or juridical person, or a group of persons, to do or abstain from doing any act as an explicit or implicit condition for the release. The condition may include but not limited to ransom. The concept has been defined differently by various scholars to represent their perspective of the concept.

For instance, Inyang and Abraham (2013) defined kidnapping as “the forcible seizure, taking away and unlawful detention of a person against his/her will. It is a common law offence and the key part is that it is unwanted act on the part of the victim”.

Another definition is offered by Fage and Alabi (2017) who conceived kidnapping as “forceful or fraudulent abduction of an individual or a group of individuals for reasons ranging from economic, political, and religious to (struggle for) self-determination”. However, the authors later admitted that, the forcefully or fraudulently abducted individuals are carried off as hostages for ransom purposes. This implies that while political and economic factors can instigate kidnapping, the economic reason is the most common predisposing factor of the phenomenon.

In line with the context of the current study which situates around ransom kidnapping, Ngwama (2014) opined that, kidnapping can be seen as false imprisonment in the sense that it involves the illegal confinement of individuals against his or her own will by another individual in such a way as to violate the confined individual’s right to be free from the restraint of movement. This involves taking away of person against the person’s will, usually to hold the person in false imprisonment or confinement without legal authority. This is often done for ransom or in furtherance of another crime. It is important to stress here that, no one is insulated from being kidnapped. Kidnappers are everywhere, targeting both foreigners and non-foreigners alike with little or no resistance from our law enforcement agents. The security system seemed weakened in the face of this confrontation and it has indeed become a threat to our national security

In the same vein, Uzorma and Nwanegbo-Ben (2014), defined kidnapping as the “act of seizing and detaining or carrying away a person by unlawful force or by fraud, and often with a demand for ransom. It involves taking a person from their family forcefully without their consent with the motive of holding the person as a hostage and earning a profit from their family”. In the context of this study, ransom is the practice of

holding a prisoner or item to extort money or property to secure their release, or it may refer to the sum of money involved. The word *ransom means* "payment" made for the release of an adoptee or a kidnapped person. It is the money demanded for the release of a captive. That is where the phrase "held for ransom" emanated. That means someone has been captured and is being held prisoner until a sum of money is delivered to the captors.

In addition, this study identifies that ransom kidnapping is usually motivated by financial gain or political demand. Thus, opportunist or traditional criminals as well as political dissidents can resort to ransom kidnapping in order to illegally obtain economic gains or have their demands granted. Recent typologies of kidnapping, whether they originate in social science or business milieu, focus on criminal motivation. Some examples that belong to the sophisticated end of the analytical spectrum: criminologist and risk evaluator, such as Elio Zannoni proposes a distinction between criminal (with economic motivation) and political (with political motivation) of ransom kidnapping (Zannoni, 2003), suggesting that 'in many instances 'kidnapping is a "business" involving a demand for ransom which may vary considerably, depending on the type of criminals involved and the victim's personal status' (Tnazelli, 2006). Two claims are important here: (a) that in every kidnapping a form of economics is involved, and (b) that the status of the hostage is of significance in the payment of ransom.

2.1.2 General Context of Security

In national development and security studies, the concept of security is critical and often discussed with passion. It is an element that keeps a nation together and central to all facets of the nation's peace and development. Security is a fragile and significant issue which conveys different meanings to scholars, analysts, policy makers and

organizations across the globe. Basically, security has to do with the presence of peace, safety, gladness and the protection of human and physical resources or absence of crisis or threats to human dignity, all of which facilitate development and progress of any human society. The concept of security has become a preoccupation for the decades following the end of the Cold War which could also be referred to as landmark for diverse school of thought with security studies. Security, as a concept, has diverse dimensions. It is aptly used in psychology, finance, information access, public safety, defense and military matters (Muyiwa, 2018).

The concept of security is indefinite as its scope continues to expand every day. The flexible nature of the concept of security attracts different meanings and different views. Security is an important concept that every human person desires and it has one or two meanings though it defies precise definition. Buzan (2017) describes security as ambiguous and multidimensional concepts in which military factors have attracted inappropriate attention. That, it has to do with the process connected with assuaging any kind of threat to people and their values. He furthered that, security is about freedom from threat and ability of states to maintain independent identity and their functional integrity against forces of change, which they see as hostile while its bottom line is survival (Bodunde, Ola & Afolabi, 2014).

From the foregoing, security is generally agreed to be about feeling of being safe from harm, fear, anxiety, oppression, danger, poverty, defence, protection and preservation of core values and threat to those values. William (2008) similarly opined that security is most commonly associated with the alleviation of threats to cherish values, especially those threats which threaten the survival of a particular reference

object. To Ogaba (2010), it has to do with freedom from danger or threats to a nation's ability to protect and develop itself, promote its cherished values and legitimate interest and enhance the well-being of its people. Thus internal security could be seen as the freedom from or the absence of those tendencies, which could undermine internal cohesion, and the corporate existence of a country and its ability to maintain its vital institutions for the promotion of its core values and socio-political and economic objectives, as well as meet the legitimate aspirations of the people.

Hettne (2010) defined security "as a reasonable level of predictability at different levels of the social system, from local communities to the global level" The understanding here is that at the global level, there is a presence of an order which is predicated upon the predictability of the behavior of other members within the system. At local level, security thus includes the ability of the state to predict the likely implication of any particular condition on its citizens. The recognition lies squarely not on the state's ability to enforce law and order, though that may be important, but in creating the necessary socio-economic conditions that guarantee fair amount of predictability on the behavior of its citizens. Aliyu, (2012) stated that, security is a state of reduced or contained threats and tension in the stability of territories, states and institutions among others. In all places and countries, security has been considered as a "first order value" worth preserving.

But with the spate of ransom kidnapping in the country, can one truly say Nigeria has security of any form, given the criteria so expressed in the definition of the concept above. In security studies, two schools of thought easily come to mind; traditional and non – traditional school of thought. Traditional School defines security in terms of safety

from danger and from external attack or infiltration. The traditional security model is a pragmatist paradigm of security in which the referent object is the state (Abolurin, 2010). It equates security with peace and prevention of conflict through military means in terms of deterrence policies, non-offensive defence and the like. For this reason, Walt in Muiyiwa (2018) defines security as a study of threat, use, and control of military force. It explores the situations that make use of force more likely, the ways the use of force affects individuals, states, societies and the specific policies that states employ in order to prevent or engage in war. This may account for why Nigeria engages her military in almost every aspect of security. This school of thought is strongly tied to the military.

Nwolise, (2008) stated that the Cold War period gave the high level domination to the conventional security doctrine to the extent that security rest on the belief that only a military system can efficiently deter attack and threat of force. While this may not be completely true, many other scholars still hold that opinion strongly. This was stressed by Ken Booth in Nwolise (2008) when he asserts that, one of the themes of the new thinking is the idea that security policy should have political accommodation as a primary and persistent aim. The negative effect of identifying security almost exclusively with military was evident throughout the cold war. This approach can be described as strategic reductionism which is conceiving security in a technical and mechanistic military way as manifested in an obsession with military balance and the use of state-of-the-art technology.

Following the postulations of Muiyiwa (2018), the second school of thought on the conceptualization of security is non-traditional school. He stated that, the school attempts to widen and deepen the definition of security. It argues that other issues like

environment, political, economic and social threats endangers the lives and properties of individual rather than the concentration on the survival of the state. This is where vices such as kidnapping for ransom which is the focus of the current research comes in. He added that, it does imply that a predominantly military definition does not appreciate the fact that the greatest threat to state survival may not be military but environmental, health, political, social and economic.

This school, Ochoche (2007), noted is all-encompassing and stated Security is more than military security or security from external attacks. He emphasized that, for many inhabitants in the developing countries, security is conceived as the basic level of the struggle for survival. Consequently, he suggested that, in order to provide an integrated Security Assessment, the non – military dimension of security should be added. That, henceforth, security as a concept should be applied in its broader sense to include economic security, social security, environmental security, food security, equality of life security and technological security. Seeing security from this point of view would mean that people/citizens must be liberated from those challenges, difficulties and constraints that may prevent them from carrying out what freely they would choose to do which includes epidemics, poverty, oppression, poor education, crises and so on.

Paradoxically today in Nigeria, politics, ecological issues, economic and demographic issues and particularly ransom kidnapping which the study is looking at which are non-military tend to pose serious threats to people's security. Buzan (2017) provided a theoretical insight to the understanding of the concept of security and he identified three levels of analysis; individual level, national level and international level. Buzan is of the belief that, individual security which other scholars called personal

security involves those values people seek to secure which include life, health, status, freedom and wealth. Some of the threats which individuals endeavor to secure themselves from is what is referred to as social security. This includes physical threat, economic threat and human rights abuse. Examples of these are pain, injury, death, seizure and destruction of properties, inaccessibility to work or resources for human sustenance, injustice, unjust imprisonment and the denial of normal civil liberties as well as threats to human dignity.

2.1.3 National Security in Nigeria

The concept of national security is fundamental and central to the survival and corporate existence of any sovereign state; more so in Nigeria with multiple threats to her National security due to attendant underdevelopment. The importance of national security is so much that, the 1999 constitution of the Federal Republic of Nigeria Section 14(1) (b) as amended, states that, the security and welfare of the people shall be the primary purpose of government. That is, the primary responsibility of any government is the protection of lives and property of her citizens. This means, national security is the essence of government. As a matter of fact, the concept of national security cannot be isolated from national development. As rightly reflected by International Peace Academy (2004), the ability to provide security based on good governance are essential for sound conflict management, the effect of which provides a safe and secure environment in which to entrench other programming initiatives. Thus, national security is a prerequisite for national stability and development.

Then, what is national security? It is the protection and maintenance of national interest of a state or nation. The ability to preserve the nation's physical integrity and

territory; to maintain its economic relations with the rest of the world on reasonable terms; to preserve its nature, institutions and governance from disruption from outside and to control its borders (Abolurin, 2011, Adedoyin, 2013). It is the preservation of independence and sovereignty of a nation state. In reality, every country has a large number of interests to protect. These interest put together constitute the national interest which originates from values, good governance and protection of social and economic well-being of the entire citizenry (Muyiwa, 2018). The Grand Strategy a major security policy document developed in 2000 by President Obasanjo defines National Security as “the aggregation of the security interest of all individuals, communities, ethnic groups, political entities and institutions in the territory of Nigeria. These components are aggregated into elements of state power, including economic and social development, defense, foreign policy, law and order and information management.

Asad (2007) says “that national security cannot be narrowed down to exclusively military term. Socio economic and cultural aspects, problems of development and modernization, and national integration should be deemed important in considering”. Al-Marshat in Ebeh (2015) suggested that national security is more than territorial defence and should focus on the “Physical, social and psychological equality of life of a society and its members both in the domestic setting and within the large regional and global system”. Again Mathew in same Ebeh (2015), states that, global development now suggests the need for another analogous broadening definition of national security to include resources, environmental and demographic issues. He noted that, national security question involves a lot of issues. It practically touches on all spheres of human existence. The best way to approach it is from the systems theory perspective where a

dislocation in any particular area of the system is bound to have an overlapping effect on other areas. It ranges from food security to issues of environmental degradation. It touches on health matters. It encompasses psychological security as well as arms security

There may not be universality in the definitions, but it is important to note that, the concept of national security is also captured in the postulations of Muyiwa as reviewed in earlier literature which contended that, there are fundamentally, two schools of thought as already explained. The traditional and non-traditional concept of national security; the traditional school of thought conceives national security from the war mongering approach with emphasis on military response and management of threat. They are of the view that, a nation is secured when it does not have to resort to war or threat of war to preserve its legitimate interest. To them, it is the protection and preservation of the minimum core values of any nation's political independence and territorial integrity. It also comprises the protection of the national interest, including national values, political and economic ways of life against internal threat and challenges. Some of them see national security as the pursuit of psychological and physical safety which is largely the responsibility of the national governments, to prevent direct threats primarily from abroad endangering the survival of these regimes, their citizenry or their ways of life (Ngbale, 2011, Lippmann, Maniruzzaman, & Orwa, in Muiyiwa 2018).

On the other hand, the new school conceived national security beyond the military to include non-military factors. They believed that, the old/traditional school conception of security cannot capture contemporary security threats such as poverty, hunger, environmental humiliation, unemployment and the likes. The proponents of the new school of thought cautioned that; any society that seeks to attain adequate military

security against the background of acute paucity of food, population explosion, low level of production, low per capital income, low technological development, inadequate and insufficient public utilities and chronic problem of unemployment has a false sense of security (Nwolise, 2008: 350, Abolurin, 2011: 186). The researcher is pondering if this may be the case with Nigeria. To this end, Nwolise stated that, a country may have the best armed forces in terms of training and equipment, the most efficient police force, the most efficient custom men, the most active secret agents and best quality prisons, but yet be the most insecure nation in the world as a result of defence and security problems within bad governments, alienated and suffering masses, ignorance, hunger, unemployment or even activities foreign residents or companies (Abolurin, 2011; 184).

Given this premise, the Reviewed Draft National Defence Policy (RDNDP, 2002) sees national security as an all-encompassing condition in which citizens can live in freedom, peace and safety; participate fully in the process of governance, enjoy the protection of fundamental human rights; have access to resources and necessities of life and inhabit in environment which is conducive to their health and well-being. Other as Maier said, national security is the capacity to control those domestic and foreign conditions that the public opinion of a given society believe are necessary for it to enjoy its own self-determination or autonomy prosperity and well-being (Maier in Nwaogu, 2013). Thus, it may be safe for the researcher to conclude here that, national security is the primary essence of government.

Babangida (2011) views national security "as the physical protection and defence of our citizens and our territorial integrity and also the promotion of the economic well-being and prosperity of Nigerians in a safe and secure environment that promotes the

attainment of our national interests and those of our foreign partners.” Likewise, Otto and Ukpere (2012: 67) and Adebakin, (2012:9) asserts that “security means protection from hidden and hurtful disruptions in the patterns of daily life in homes, offices or communities. Security must be related to the presence of peace, safety, happiness and the protection of human and physical resources or the absence of crisis, threats to human, injury among others”. Security is considered as any mechanism deliberately fashioned to alleviate the most serious and immediate threats that prevent people from pursuing their cherished values (Chris, 2012).

Orji, (2012: 199) advances that pivotal to the survival of any society is its law and order which are predicated on national security. National security must be broadened to accommodate economic, environmental and demographic issues as they are important in understanding the new causes of intra-state conflicts. Other dangers that serve as threat to national security include pollution, poverty, crime, and underdevelopment all of which fuel conflicts (Onigbinde, 2008).

According to United Nations (2010), most often distinction are being made between internal and national security, however they are rarely clear cut distinctions. This raises the concern of discussing in particular about human security and its components. The discussion will further the understanding around ransom kidnapping as a threat to national security with direct implications for human security. Some scholars point to this when they described security as stability and continuity of livelihood, predictability of daily life, protection from crime, and freedom from psychological harm (King 2016). The sanctity of human life is paramount and should not be compromised as Nwagboso (2012) viewed security as the act of being safe from harm or danger, the defence, protection and

preservation of values, and the absence of threats to acquired values. This is being negated by the widening spate of ransom kidnapping in the country.

These definitions are constituent element of the concept of human security or internal security, with fundamental difference from what is often termed as national security, where the focus is on the survival of the state against military threats posted by other state (Buzan, 2003, Stephen, 2006). According to Mofolorunsho, Idah and Abu-Saeed (2019), considerably the preservation of the people, history, cultures, territory and all unifying factors and values becomes the core concern for nation security. Therefore, any factor whether internal or external capable of tarnishing the values or unifying factor(s) of a country is a threat to national security. This as one can see is aptly related to the Nigerian experiences in the various facets of insecurities, where values of tolerance, social justice, discipline, and dignity of labour have been lost and have contributed to series of internal security issues with great consequence for national security.

Mofolorunsho, et.al (2019) concluded in these words “we therefore conceptualize National security as the ability of the government to curtail any form of internal or external threat capable of undermining her primary responsibilities of protecting her citizenry and property. It includes all attempts to safeguard the unity, values and all legitimate and culturally prescribed norms of citizens to perform their societal obligation as well as meet basic needs for survival. The Federal Republic of Nigeria has a National Security Strategy (NSSN) developed and published by the Office of the National Security Adviser in 2014, guides the formulation of policies and conduct of operations. Nigeria’s over-arching strategic vision is to create a peaceful, self-reliant, prosperous, strong nation (NSSN, 2014). The brain behind it is to apply all elements of national power to ensure

physical security, build individual and collective prosperity, cause national development and promote Nigeria influence in regional, continental and global affairs. However, recent happenings in terms of ransom kidnapping are a pointer that, Nigeria's national security is greatly threatened. The NSSN (2014) focuses on two critical threat areas:

National Security Interests: The core national interests as defined in Nigeria's National Security Strategy are the security and welfare of its people; sovereignty and defense of its territorial integrity; peace; democracy; economic growth; and social justice. Sub-regional security and economic cooperation are classified as strategic interests. Promotion of peace, security, development, democracy and international cooperation in Africa and the world are peripheral to Nigeria national interests. The second is:

Threats to National Security: The most potent threats to Nigerian national security as enumerated includes but not limited to, global challenges; terrorism; transnational organized crimes; crude oil theft or illegal bunkering; Nigeria's borders; climate change; communal and ethno-religious conflicts; pastoralists and farmers conflicts; politics and federalism in Nigeria; governance; poverty; kidnapping, proliferations of small arms and light weapons; proliferation of weapons of mass destruction; illegal migration; economic challenges; financial crimes; information technology and cyber security; natural, man-made and medical related threats; environmental security. According to Bala and Ouédraogo (2018), they are nevertheless the most potent and are adjudged potential sources of disaffection, discontent and instability that could adversely affect the country quest for national stability, unity and development.

Ebeh (2015) noted that, a number of factors may expose a nation to danger. To that extent, national security may also be viewed as a multidimensional process whose

purpose is to safeguard national values. The most fundamental values of any nation is its survival, self-preservation, and self-perpetuation. According to Anyadike (2013), in order to possess national security, a nation needs to possess economic security, energy security, environmental security, and so on. Security threats involve not only conventional foes such as other nation-states but also non-state actors such as violent non-state actors, narcotic cartels, multinational corporations and non-governmental organizations; some authorities include natural disasters and events causing severe environmental damage in this category. Measures taken to ensure national security include: using diplomacy to rally allies and isolate threats; marshalling economic power to facilitate or compel cooperation; maintaining effective armed forces; implementing civil defense and emergency preparedness measures; ensuring their silence and redundancy of critical infrastructure; using intelligence services to detect and defeat or avoid threats and espionage, and to protect classified information; using counterintelligence services or secret police to protect the nation from internal threats.

In the context of security according to Williams, (2008:6), who sees security as an essential concept is commonly associated with the alleviation of threats to cherished values, especially the survival of individuals, groups or objects in the near future, one cannot discuss national security without a detailed discussion on human security. This is so because, the sum total of human security will give raise to national security and a threat to human security is a threat to national security also. Thus, the researcher makes out time to discuss briefly, the concept of human security and its elements. According to the United Nations Development Programme in Gubak and Bulus (2018), human security (an aspect of national security) refers to “freedom from fear and freedom from want” and

“safety from chronic threats such as hunger, disease, and repression as well as protection from sudden and harmful disruptions in the patterns of daily life, whether in homes, in jobs or in communities.”

2.1.3.1 Human Security

The notion of human security emanates from the conventional security studies which centers on the security of the state. Its focus is individuals and its ultimate end point is the protection of people from traditional and non-traditional threats. Centre to this concept is the belief that human security deprivations can undercut peace and stability within and among states (Muyiwa, 2018). The Commission on Human Security (CHS) in one of its work defines human security as: the ability to protect the vital core of all human lives in such a way that it enhances human freedoms and human fulfillment. Human security means protecting fundamental freedoms that are the essence of life. It means protecting people from serious and persistent threats and situations. It means using processes that build on people's strengths and aspirations. It means creating political, social, environmental, economic, military and cultural systems that together give people the building blocks of survival, livelihood and dignity (Adedoyin, 2013: 125).

Muyiwa noted that, that human security covers every area of human needs. This is why it serves as the basis of all forms and categories of security. Hubert gives the importance of the concept when he asserts that: In essence, human security means safety of people from violent and non - violent threat. It is a condition of being characterized by freedom from pervasive threat to people's rights, their ability or even their lives. It is an alternative way of seeing the world taking people as its point of reference rather than focusing exclusively on the security of the territory or government. Like other security

concept - national security, economic security, and food security - it is all about protection (Hubert in Muyiwa, 2018). Since, human security gives primacy to human beings and their complex social and economic interactions, it derives its convincing quality from the fact that is based on the global concern and threats to human security are no longer secluded issues. It is pertinent to state that threat to human security are very easy to manage if preventive measures are taken at appropriate time before it advances to devastating state.

2.1.3.2 Components of Human Security

There are basically seven component of human security:

Economic Security: This type of security requires an assured basic income for individuals mostly from productive and remunerative work or from a publicly financed safety net. In this sense, only about a quarter of the world's people are presently economically secure and the economic security problem may be more serious in third world countries. Major threats of economic security are poverty, unemployment, indebtedness, lack of income. It germane to state that aforementioned threats constitute pertinent factors causing political tensions and other forms of violence in the developing countries.

Food Security: Food security demands that all people at all times have both physical and economic access to basic food. Major threats to this include hunger, famines and the lack of physical and economic access to basic food. Though United Nations maintain that the overall availability of food is not a problem; rather the problem often is the poor distribution of food and lack of money/purchasing power. In the past, food security problems have been dealt with at both national and global levels. However, their

impacts are limited. According to UN, the key is to tackle the problems relating to access to assets, work and assured income (related to economic security).

Health Security: This tends to guarantee a minimum protection from diseases and unhealthy daily life. In less - developed countries, the major causes of death traditionally were infectious and diseases, Inadequate health care, new and recurrent diseases including epidemics and pandemics, poor nutrition and unsafe environment and unsafe lifestyles; whereas in developed countries, the major killers are diseases of the circulatory system. However, lifestyle related chronic diseases are leading killers globally with 80 percent of deaths from chronic diseases occurring in low- and middle-income countries. In both developing and industrial countries, threats to health security are usually greater for poor people in local areas, particularly children. This is as a result of poor or bad nutrition and inadequate access to health services, clean water and other basic necessities.

Environmental Security: The primary goal of this is to protect people from the short and long-term ravages of nature, man-made threats in nature, and deterioration of the natural environment. In the third world countries, lack of access to clean water resources is one of the greatest environmental threats while the major threats in industrial countries are air pollution and global warming which are caused by the emission of greenhouse gases. Again, environmental degradation, natural disasters and resource depletion are general all over the world.

Personal Security: This is all about the protection of individuals and people from physical violence either from the state or outside the state. It could be from violent individuals, sub-state actors and from domestic abuse. Hence, the greater and the common threat to personal security are from the state (torture), other states (war), groups

of people (ethnic tension), individuals or gangs (crime), industrial, workplace or traffic accidents. The security threats and risks on persons and often families are many and vary from place to place and also from time to time. These include: theft, armed robbery, burglary, food poisoning, electrocution, fire outbreak, home accident and host of others.

Community Security: Community security aims to protect people from the loss of traditional relationships, values and from sectarian and ethnic violence. Traditional communities, particularly minority ethnic groups are often threatened. About half of the world's states have experienced some inter-ethnic rivalry. Threats to community security are usually from the group (oppressive practices), between groups (ethnic violence), from dominant groups (e.g. indigenous people's vulnerability). In Africa, many nation-states have witnessed ethnic clashes, land and boundary clashes, and intra - religious and inter - religious conflict all of which constitute threats.

Political Security: This embraces guarantee and protection of fundamental human rights of citizenry. It is concerned with whether people live in a society that honours their basic freedoms. Some of threats attached to these are political or state repression, including torture, disappearance, human rights violations, detention and imprisonment. The assessment of the Amnesty International reveals that, political repression, systematic torture, ill treatment, hostage taken and kidnapping are still being practice in about One Hundred and ten (110) countries. Human rights violations are frequent during periods of political unrest and by security agencies in the third world countries (UNDP, 1994).

2.1.4 Relationship between Kidnapping and National Security in Nigeria

From a professional security analysis, the researcher wants to note that, Nigeria is almost under a siege, if not under it already. Analysts had repeatedly in recent time

acknowledged that, Nigeria is under the siege of crises that threaten state and human security, and consequently jeopardizes peaceful co-existence and secured livelihood. The wailing and lamentations are in the lips of everyone, young or old, rich or poor, strong and weak ones alike because everyone is affected by the security situation, particularly kidnapping. Individuals are being held at random and unfathomable ransoms are requested from relatives. Day-in-day-out, things are growing worse than they first appeared. Several factors threaten Nigeria's national security, they include but not limited to persistent poverty, ethno-religious crisis, ethnic conflicts, the Niger-Delta crisis, sea pirate, arms smuggling, bunkering, kidnaping, political and electoral violence, murder and assassination and so on.

According to Jega, (2007:197), it is worrisome that despite the country's expansive resources base, and manner by which successive regimes under prolonged military rule have committed substantial public resources to military and national security expenditures in the past three decades, there seems to be neither the military capability, nor stable patterns of economic and political growth requisite to guarantee national security. Instead, there are daily emerging additional sources of insecurity and mounting threats to national cohesion and integration. Therefore it can be said that the opportunities offered by political liberalization under the on-going democratization have not been utilized by Nigerian leaders in enhancing national security in the country. While politicians use the expanded democratic spaces to push political brinkmanship to the precipice and exhibit a profound lack of capacity to learn lessons from past experiences, angry and hungry mostly unemployed or under employed youths have used the

opportunities to exhibit their disaffection and discontent with the failure of the state to address their needs and aspirations.

Sometimes to show dissatisfaction, they have engaged in open, often violent, contestation of the legitimacy of the elected federal, state and local government in many parts of the country. Ransom kidnapping on a steady rise, targeting the rich in order to have their own share and the concern is growing progressively. The research makes bold to say here that, any nation with the amount of insecurity as Nigeria, particularly ransom kidnapping and still feels safe is having a false idea of what security means. From every facet of the country's dealings, the national security today is being threatened by kidnapping because people no longer feel safe in their houses, streets as well as high ways, for fear of being kidnapped for ransom.

Idowu in Nweke (2018) highlighted conditions that threaten national security to include bad and weak government, human rights violation, unjust and inequitable distribution of national resources including political posts, industries, investments, funds, and so, disunited and un-integrated ethnic groups, ethnic and religious antagonisms and cleavages, weak and poor economy marked by corruption, weak currency, and the likes, social-economic hardship, unemployment, hunger, starvation, weak military might, coups and military rule, communal clashes, unhealthy competition among the ethnic groups for national resources, political domination, misappropriation of national revenue, abuse and misuse of power by some defence and security agents. He added that, on the merit of these conditions, there is need to seek ways of addressing the threats to secure stable polity. From literature, all these are known, however, the most threatening in recent time may be the issue of ransom kidnapping with the level it has reached.

Thus, one can find that, kidnapping for ransom or any form of kidnapping negates national security and contributes a great deal to making the nation unsafe for the citizenry. The concepts of kidnapping and national security are closely related. Related in the sense that, one cannot claim to be secured as a nation and then have high incidence of kidnapping. Thus, by every standard, kidnapping is related to national security. According to Elesin (2012), showcase terrorism, Armed Robbery, Kidnapping and other criminalities are quick survey of the security challenges in Nigeria. He argued that Militants in the southeastern parts of the country also contribute, in no small measure, to the security challenges facing the country. These problems either individually or collectively constitute threats to the peace, security and development of the country (Nweke & Nwachukwu, 2014). However, it will be important also to look at some factors that fuel kidnapping for ransom, which has assumed a big threat to our national security. Some of them will be showcased in sub-headings to broaden the readers' understanding of how all these things are connected and interrelated.

2.1.4.1 Unemployment

According to Nseabasi (2009), and Umoh, (2010) in their study they revealed another theory, which views ransom kidnapping from the angle of unemployment which pervade the countries labour market. This is blamed on the inability of the government to create adequate employment for the youth. They posited that the political consequence of kidnapping activity has had a spill-over influence on the jobless youths and criminals who take it as a new substitute or complement to robbery and pick pocketing. Such a group of kidnappers target not only prominent and well-off individuals but also ordinary citizens who possess little wealth. The common target includes every perceived person

with prospects of high and lucrative ransom including teenagers, children and adults alike.

The youth unemployment has been implicated as one of the strongest impediments for the solution of kidnapping behavior (Inyang, 2009 & Dode, 2007). In a study conducted by Adegoke (2015), unemployment was by a wide margin of 88% identified as the contributory factor for the youths engaging in kidnapping operation. To solve this problem, job creation must be in the frontline as some of the unemployed youths are university graduates and able-bodied individuals who are virtually frustrated with lack of employment opportunities. Inyang (2009) on unemployment and its impact on national security reported that a graduate, who is unable to secure employment, is bereft of possible means of economic survival. The aftermath of such deprivation is psychological developmental stage of negative behavior against the status-quo and socio-system.

The negative developmental behavior emerges as resistant tool against the social norms that may demand individual social compliance of the normative rules of the society. Curing this social ill would close down the social destructiveness that kidnapers are trapped (Inyang & Abraham, 2013). The perpetrators of kidnapping choose their victims based on their ability to cough out the money (Tzanelli, 2006). The problem of unemployment has become a national 'thorn in the flesh' in Nigeria. Ejimabo (2013) argues that "Nigeria needs problem-solving skills of leaders to help fight fraud and corruption in the country", otherwise, issues such as job creation and worsening political crisis would continue to be impediments to the control of kidnapping in the country. Job creation, along with other economic incentives would magnetize the youths' interest to

abandon the illegal commercialization of human commodity called kidnapping (Persson, 2014; Dode, 2007). Kidnapping has been commercialized, whereby, even the most revered clerics and clergies of religious bodies have fallen victims to the crime.

Adesina, (2013) reported that the occurrence of unemployment in Nigeria in this 21st century is geometrically increased and all proactive measure forwarded by the federal government to hold back its menace was failed woefully to the extent that the numbers of unemployed youths continue to increase every day. Hence, it is unbearable to pronounce how Nigeria graduates losing their lives searching for job in spite their professional achievement. Contemptibly, many of them were prancing as a sex hawker to the politicians in order to procure job, many others were taken into service as political propaganda to instigate havoc in their various society and the lucky ones are serving as political bloggers on social medial to disseminate bogus and counterfeit information in favor of political henchmen Adesina, (2013). As a result of this detrimental recruitment, these youths develop into monsters which result in the occurrence of incessant robbery and kidnapping.

It is imperative to be mentioned that, unemployment is one of the most serious problems facing Nigeria like many other countries in the world because it is a global phenomenon as simply put by Adesina, (2013) who concludes that eligible workforce of a nation is disengaged in the service of the nation. Meanwhile, the state of unemployment among youths has become a critical and alarming issue in the whole world and Nigeria in particular in Egwu, Omeje and Nwokenna (2014). To this effect, Kilishi, Mobolaji, Yakubu and Yaru (2014) believes that the rising trend of crime in Nigeria is usually blamed on the high rate of unemployment. That is why Suleiman (2017) concludes that

the problem of unemployment in Nigeria is one of the major syndromes that upturned youths to become atrocious actors. He pointed to the famous saying of the elders as known to us that 'devil works in idle hands' but Nigeria government underrate the negative impact of unemployed people.

However, the result of this research shows that most of the convicted kidnappers confessed that they were unemployed graduates looking for a way to survive and if there is no good way to stay alive then evil is the only option. This study further discovers that many youths have erred in joining criminal group because of unemployed ache. In the light of this, the paper recommends that, with immediate effect, Nigeria government should provide employment for the youth not only to discourage them from hostile habit but also to encourage them as good citizens. Despite the fact that thousands of unemployed youth are looking for white collar jobs under federal or state government yet, the researcher agrees that, federal government cannot cater for the existing unemployed youth let alone the new graduates that is joining the labour force every day. In essence, well to do people in the society should assist government in entrepreneurial advancement and creation of high-quality job for the youths.

2.1.4.2 Poor Political Ideology

The 'Political theory' of Kidnapping sees the act as a Political Tool which is motivated by attempt to suppress, outsmart, intimidate and subjugate political opponents, like the case in Anambra state when the former Central Bank governor who then was PDP gubernatorial candidate had his father kidnapped by the aggrieved opponents of the same party who felt marginalized by the PDP political process. Turner (1998) as cited by Nseabsi (2009) established relationship between "money and politics" accordingly, where

there are political motivations for kidnapping and where ransoms are also demanded. Such ransoms are often used to further the political objectives of the kidnapping organization or simply to facilitate the survival of the organization.

Nseabasi (2009) in his treatise stated that the most top kidnapping operations are masterminded by government officials, opposition groups, unrewarded or uncompensated members of election rigging militant groups, among others. Kidnapping is then seen as instrument for political vendetta and settling of political scores. The operation is organized and targeted mainly at key serving politicians or foreign workers or contractors working directly for government they affirmed. Once the victim is kidnapped, a high level negotiation is expected which will ultimately lead to a very heavy ransom. Such a ransom is used to further political goals, self -settling of aggrieved groups or a way of financially crippling a serving politician.

Kidnapping in Nigeria, before the oil exploration, has its origin within the village clans and village rivalries. The indigenous hate-rivalry was enough to capture human and carry the person away for humiliation and elimination. With the advent of civilian democracy, political undertone adopts the indigenous hate-system of 'capture and carry away'. During the political season, it is easy for an opponent to vanish without a trace. In this method of kidnapping, politicians are linked to this behavior as unemployed youths are deployed as political thugs against their political opponents, and sometimes, they are empowered to kill their opponent (Effiong, 2009). According to, Abati, (2009) kidnapping is no longer focused on the oil companies alone, it has taken a broader tone as business enterprising, spreading from political opponents, rivalry revenges, hatred,

business ventures, to ethnic disagreements in all corners of the country. Relatives of politicians are usually abducted for political motives (Abati, 2009).

According to study carried out by the following, (Ikpong, 2009; Badiora, 2015; Effiong, 2009), found out that sometimes, politicians under-mind the criminal law, indulge in 'do or die' political games in their local politics, provide arms and ammunitions to their political thugs, and eventually kidnap and destroy their political opponents in the process. In the report carried out by Uzorma & Nwanegbo-Ben, (2014), political kidnapping involves political concessions or demands that require government's attention. In fact; they mobilize political thugs with weaponry. The mobilization of political thugs with weapons during election process makes weapons available for further commission of other types of crime after the election.

Ikpong (2009), also carried out a study on worsening political instability and kidnapping reported that weapons given to thugs during elections are usually not withdrawn from their political thugs after the election, creating more impediments, for the control of kidnapping behavior. When criminals are armed with sophisticated assault weapons in society, removing them from their hands are obstructed. The Nigerian communities are blessed with the abundance of mineral resources and crude oil reserves, especially in the Niger Delta Regions. The contemporary crime of kidnapping the expatriates and the staff of the oil companies slowly began with the communities' grievances against the Federal government and the oil companies for usurping their mineral resources without compensations. The oil companies such as the Exxon Mobile, Shell Exploration Company, Agip, and others, have tapped their resources, polluted their

environments, and generally neglected the communities where those mineral reserves are located.

The environmental degradation was quite obvious and offensive to the communities. This negligent behavior ignited aggression against the oil companies and expatriates. The unemployed youths in the communities formed internal militant organizations as a means of drawing national and international attention to their demands for compensations. As a result, ethnic militias such as MEND was formed by the Ijaw Youth Council (IYC), Niger Delta Vigilante (NDV), the Bush Boys, the Dodan Barrack Group, the Ogoni Movement (MOSOP), and the Titanians sprang up soliciting for their rights and kidnapped the expatriates working at the oil wells. These organizations were made up of youths who were virtually unemployed, poor and frustrated with the system of government that exploits their resources, pollute their environment and leave their areas underdeveloped.

The indigenes expected adequate compensations with infrastructural developments such as good roads, hospitals, good schools, modern commercial trading centers, good drinking water, and even award scholarships to the indigenous sons and daughters for further studies as remuneration for the minerals extracted from their communities. The failures to reward those communities plus the stench from unemployment ignited and heightened the internal grievances against the Federal Government and the oil companies. The crime of kidnapping cannot be halted easily without meeting the demands of the kidnappers. The inability of the government and oil companies to meet the demands of the kidnappers has become a frustrating impediment to the solution of the crime of kidnapping in the nation. Because kidnappers owned the

means of assessing their potential victim, they are also able to exert almost total control over social domain of the crime, the limitation of their victim and criminal justice system (Akanni, 2014; Ezeibe & Eze, 2012).

Nigeria's national security policy since 1960 has been tied to the challenges of external aggression and addressing the problem of internal upheavals. The Nigerian Constitution rightly provides that the security and welfare of the people shall be the primary purpose of government (Constitution of the Federal republic of Nigeria, 1999, Section (14) 2). The role of the public policy process in matters of national security cannot be overemphasized because of the crucial role it plays in identifying problems, deciding on what measures to take in addressing those problems, assessing effectiveness, or otherwise, of the measures, as well as in monitoring and implementing these measures (Bello, 2014). At the beginning of the Fourth Republic in 1999, the government of Former President Olusegun Obasanjo (1999 – 2007) focused its national security policy on ensuring the safety of Nigerians, domestically and internationally as well as ensuring the protection of the sovereignty of the country (Teniola, 2016). President Obasanjo's security policy focused on bringing together the security interests of individuals, communities, ethnic nationalities, political groups and institutions in the country (Teniola, 2016).

In 2007, during the administration of Former President Umaru Musa Yar'adua (2007-2010), there was an attempt to bring foreign policy and domestic affairs together in a way that made the citizen the focus of foreign policy (Dickson, 2010). According to Mbachu (2007) the main force of this new foreign policy initiative was the concern for the basic needs, human rights and socio-economic welfare of Nigerians in bilateral and

multilateral engagements. In 2015, the government of Former President Goodluck Jonathan (2010-2015), having observed the absence of a Comprehensive National Security Policy and Strategy document for the country (Nigeria Stability and Reconciliation Programme (NSRP, 2015), launched a framework for a holistic and more coordinated approach and response to security concerns in the country called the National Security Strategy (NSS) (Jatau, 2017).

The NSS identified major security issues and assigned roles and responsibilities to the government, civil society, private agencies and individuals in addressing these issues, including counterterrorism and cyber-security strategies (Jatau, 2017). The Jonathan administration acknowledged that the strategy demanded multi-sectoral, domestic and international approaches, efforts and cooperation for its success (Usman, 2015). However, the strategy was aimed primarily at combating terrorism, and is contained in three separate documents National Security Strategy, Counter Terrorism Strategy and Cyber Security Plan and Strategy (Usman, 2015). The implication of this state-centric focus on terrorism was that the underlying factors that created the environment for terrorism itself were not given the relevant attention. In May 2015, the government of President Muhammadu Buhari (2015-till date) came on board, having inherited all the security challenges of previous administrations. In November 2017, the Buhari administration launched its own policy framework and national action plan to prevent and counter terrorism (Ogunmade and Olugbode, 2017). With the challenges of Boko Haram, Herdsmen/Farmers, Niger Delta militants and the secession calls for the state of Biafra, the Buhari administration has been neck deep and sometimes appears overwhelmed with looking for solutions to these challenges.

The response of these administrations to security challenges reveals a state-centric view, overdependence on military force and lack of interest in tackling human security challenges. The Niger Delta crisis has been one of the critical fault lines of Nigerian politics and the shedding of blood has been a recurrent part of the government's domestic policy towards issues in the Niger Delta (Aghalino, 2009:57). In 1999, during the Obasanjo administration, over 2000 people were killed, many more wounded and properties damaged, in a vengeful action of the government in the Odi massacre (Aghalino, 2009). The actions of the Movement for the Emancipation of the Niger Delta (MEND) were perceived, by the government as acts of terrorism and subversion and called for „decisive military action“ (Bassey, 2012).

Also, the escalation of the Boko Haram threat is often traced to the brutal killing of members of the sect along with their leader, Mohammed Yusuf in 2002. The creation of the Joint Task Force (JTF) in 2004, to combat the threat of the group, further revealed the government's view of the situation (Williams, 2016:182). These cases are an indication of the brutality and heavy handedness with which Nigerian leaders perceive and deal with legitimate political dissention (Aghalino, 2009). The government has a narrow view of security and has focused more on state security at the expense of human security as seen in the rise in defense spending over the years in tackling security issues. An exception to this state-centric behaviour was the „citizen diplomacy“ of the Yaradua administration which was people oriented and could have been a stride in ensuring that national and international actions would be driven largely by the need to promote citizens welfare and security (Eze, 2009).

However, this shift has not been sustained largely because it was not consistent with the strategic culture of the Nigerian state, as placing the citizen at the center of national policy, in practice, is alien to the Nigerian state (Dickson, 2010:6). In a recent statistics posted by NationMaster.com, according to Adewale (2009) showed that out of the 13,973 reported cases of kidnapping, United Kingdom had 3,261; South Africa was 3,071, while Iceland had two cases among the countries documented. Aster Van Kregfen, Amnesty International Representative Researcher in Nigeria, stresses that Nigerian police needs to be strengthened to the challenge of kidnapping.

The way to be tough on violent crimes like kidnapping is to strengthen police ability to detect potential crime before they occur and prevent them. The Federal Government needs to strengthen the police training resources to increase police investigation capacity and effectiveness. According to the Inyang & Abraham,(2013) they reported that the Post-2000 patterns of kidnapping in Nigeria was primarily credited as starting with the February 2006 kidnapping oil workers by Nigerian militants. It is widely accepted that this particular kidnapping was conducted to draw international media attention to the disparity of wealth in the Niger Delta From then, a total of 24 incidents, involving 118 hostages, were documented in the Niger Delta (Ibaba, 2009). At the same time, kidnapping began to spread to other parts of the country, particularly to the southeastern states (Osumah & Aghedo, 2011). Overall, a major reason for this initial increase of kidnapping in Nigeria is because of its utility in gaining international press and media attention.

However, kidnapping in Nigeria has evolved substantially from those initial occurrences and now encompasses more motivations and drivers. In Nigeria today, some

Another common factor ultimately feeding into the rise of kidnapping in Nigeria is the recruitment of youth to help elect local and national politicians. These youth comprise a significant share of the personnel for these election campaigns, and it should be noted that most of these youths work very hard to support the causes they have chosen. During the election process, this work gives the youth a sense of inclusion while perceiving that they are working to improve society and bring about positive changes for Nigeria. However, many of the youth supporters are promptly abandoned by the politicians after elections. The youth often work on these campaigns with an expectation of long-term employment with the politicians. As might be envisioned, many of the youth then develop a strong negative opinion towards these politicians because of their abandonment by these politicians. Some of these youths then turn to alternative methods, such as kidnapping, to retaliate (Inyang & Abraham, 2013).

Current Statistics and Incidents of Kidnapping in Nigeria

2.1.4.3 Socio-Economic Factors

Leadership Failure

Accordingly, the 'Economic Theory' views kidnapping from economic concept of making ends to meet, Nseabasi (2009) citing (Tzanelli 2006) has raised the idea that kidnapping is regulated by the laws of demand and supply and is a type of social action that involves the calculation on the most efficient means to the desired ends. Kidnapping is a social enterprise and according to The Nation (May 10, 2002), "kidnappers are businessmen, they just happen to be on the illegal side of it...if you deprive them of the demand then there is not going to be any supply. This is the reason why perpetrators of

this crime choose their victims based on their ability to cough out good money (Tzanelli 2006).

The current state of anomie on our political history could be blamed on poor leadership elite who are unresponsive to this state of insecurity as they over concentrate on how to acquire political power. They place and give little or no value to matters concerning greater nation aspiration and the dignity of lives of the people. Increasing rate of kidnapping and other criminal activities is a direct consequence of failure of leadership. Our political leadership is too engrossed with issue of power acquisition because of what they personally get out of it and negates the responsibilities expected of them. The character of our political leadership at all levels contradicts the logic and philosophy of governance which essentially is the promotion of human dignity and the protection of core values of society.

Poor Security System

While there is need to condemn these acts of criminality, there is need also to condemn the security agencies for incompetence and complicity on their part. There is the need to restate that the Federal Government which has the exclusive power over security matters immediately put in place a mechanism for ending the booming kidnapping or hostage-taking racket particularly in some parts of the country, anything short of ending the prevailing tension, regime of fear and general insecurity is unacceptable to the Nigerians who have waited in vain for the realization of the promises of democratic governance since 1999. The negative impact of the worrying trend on the economic well-being of the country was also lost on government. Wogu (2010) described the incident as a violent assault on the dignity and right of Nigeria workers.

Value System

In Nigeria society, some people just emerge rich anyhow without anybody asking question how such individuals got their money. In this contemporary society, everybody is a businessman; nobody questions the nature of the business or how some people acquire their wealth (Inyang, 2009). It is easy in Nigeria to see a poor young college dropout today build a 'Ten Storey-Building' without the government or private citizens questioning how such a youth made that kind of money. Therefore, the kidnappers are not afraid of demanding excessive ransom payment, knowing that nobody would direct question its sources. In a comparative analysis, nations such as United States and United Kingdom would maintain registration of every building structure, and use internal revenue service's (IRS) to police, track down individual incomes and investments to ensure accountability. If a poor college dropout buys an expensive vehicle in cash of \$10,000 and above in United States, such an individual would be interrogated by the internal revenue service to account for such cash payment. In fact, the inconsistency between economic transparency and accountability in normal government affairs and the desire to amass wealth among the general public contribute to the leverage among the kidnappers (Inyang, 2009). Therefore, lack of effective systematic model of checks and balances is a major impediment to the control of kidnapping behavior in the country.

Gaibulloev and Sandler (2009), refer to kidnappers and hostage-takers as terrorists, identified two types of success for kidnapping operations: logistical success and negotiation success. Logistical success indicates that the kidnappers completed their mission as planned. Negotiation success indicates that the kidnappers received some of their initial demands as a result of the operation.

Yun (2007) asserts that the relationship between the majority of kidnapping cases in Nigeria and efforts to obtain material gain from kidnapping has a low casualty rate, when compared to other types of kidnapping. Additionally, Yun (2007) suggests that further understanding of the kidnapping problem in Nigeria can lead to determinations of when the probability of hostage execution is high, which would signal the need for the involvement of hostage negotiators. The focus of the negotiator could be to negotiate the release of the victim(s), or even just to buy time to enable a rescue attempt. Additional studies about the outcomes of kidnapping events in Nigeria may be able to identify and develop tailored responses to these events, in order to increase the success of responses to hostage situations.

Poverty is one of the causative spectrums that lead many people to turn out to be notorious criminal in Nigeria. Poverty is a financial incapacity or state of lacking basic requirement to live rational life. Basic requirement such as money, food, water and shelter among many others are the scourge of poverty which demoralized the less privilege to be inflicted with the wrath of anomaly (Suleiman, 2016). Meanwhile, this study discovers that poverty has twisted many youths to have become disreputable kidnapers due to the implacable famine and deficient means to survive economic downturn. Adesina (2013) confirms that Nigeria is currently facing serious job challenge and widespread decent work deficits, a development that is capable of increasing the spread of poverty. Therefore, the outcome of this research discovers that, the high the price of goods and service in Nigeria, the greater the number of poor people living under unrestricted famine and the higher the increase of poverty in a given society the greater the number of crime and detrimental vices predominant in that society.

In this respect, many people out of option concluded to kidnap well to do people in the society because, the widespread of poverty in Nigeria has incurred outrageous predicament to the life of many Nigerian that is why(Suleiman ,2017) concludes that poverty has triggered perilous spectrum to the life of people in Nigeria ever than before this current administration and thus, more than 60 percent were living in despicable famine, 20 percent were on the breadline, 10 percent were neither rich nor poor which as a result of this assessment only 10 percent can boast of their three time meals. Contrary to the level of poverty bedeviling Nigerian, this country is one of the nations blessed with natural resources such as oil, gas and other valuable raw-materials yet, while mysterious hunger are killing people in thousands every day, the politician are burying money in a sock away pit while some of them are procuring expensive property that is not functional to their daily needs. As vengeance, some youths ganged up in order to kidnap and demanding huge ransom from well to do people who are not ready to assist their immediate circumstances. This paper therefore recommends that, federal government should look in to the negative impact of poverty and it consequential shortcoming on the national security.

Pertinently, the kidnapping of all manner of persons has gained ascendancy in Nigeria. A malady previously unknown to the people has rapidly become domesticated. In the last ten years, the volatile oil rich regions of the Niger Delta witnessed this phenomenon on a large scale with the target being mostly expatriates and Nigerians in the oil business. It has spread throughout the country extending to places as far as Kano and Kaduna in the far Northern part of Nigeria. South- East and South-South Nigeria have become known as the kidnapers' playgrounds of Nigeria (Ngwema, 2014). In the view

of Emanemua and Akintolu (2016), kidnapping has recently become profitable venture among youths in Nigeria. According to him this criminal practice was first instigated in form of hostage taking in the Niger-Delta region of the country in calling the attention of the government to the marginalization of the region has seemingly become a variant of armed robbery with high level of expertise in abducting people for ransom illegally.

Otu (2013) confirms that the high rate of kidnapping in Nigeria is the byproduct of world publicity of advance fee fraud (419). For the last two decades, 419 were very lucrative and there was no need for kidnapping for ransom. Nnamani (, 2015) pointed out that, it appears that the use of cheque-books and the introduction of cashless society have made the armed bandits to change from armed robbery to another “lucrative” alternative (kidnapping). Furthermore, Emanemua and Akinlosotu, (2016) authenticate the Constitution of the Federal Republic of Nigeria to have states that, the security and welfare of the people shall be the primary purpose of the government. Unfortunately, this primary purpose has become more and more challenging with the ascendancy of several insecurity threats such as: militancy, armed robbery, ritual killing, insurgency, hostage taking and kidnapping among others.

It is pertinent to recall that the current situation in Nigeria could be likened to an inferno drawing the old and the young, the rich and the poor, the local and the international community to itself. Hardly a day passes in Nigeria without kidnapping incidents making the headlines (Odoh, 2010). Therefore, the aims of this research is not only to examine the link and available materials on the causes and consequence of Kidnapping as a crime of unlawful, forceful seizure and detention of a person against their wish in anticipation of payment of ransom or to settle some scores of disagreement

but also to scrutinize the range at which the menace of kidnapping affect Nigeria as a nation with scholastic philosophy. If kidnapping were adequately deterred by legal and security measure, or even deterred by a lack of operational success in Nigeria, it would likely not be at the levels of activity that are seen today. Gaibullov and Sandler (2009), who refer to kidnappers and hostage-takers as terrorists, identified two types of success for kidnapping operations: logistical success and negotiation success. Logistical success indicates that the kidnappers completed their mission as planned. Negotiation success indicates that the kidnappers received some of their initial demands as a result of the operation. Gaibullov and Sandler (2009) stated that kidnappers "are drawn to such events provided that the expected payoffs accounting for risks equal or exceed expected costs. A high expected payoff may result owing to publicity, recruitment benefits, concessions, or induced society-wide anxiety." They identify money as a strong positive indicator of negotiation success in kidnappings. Osumah and Aghedo (2011) stated that kidnapping is now a multi-million naira business in Nigeria. The lucrative aspects of kidnapping have now led to collusion with bank employees and state security agencies participating in the kidnapping in order to earn money Osumah and Aghedo (2011).

Yun (2007) asserts that the relationship between the majority of kidnapping cases in Nigeria and efforts to obtain material gain from kidnapping has a low casualty rate, when compared to other types of kidnapping. Additionally, Yun (2007) suggests that further understanding of the kidnapping problem in Nigeria can lead to determinations of when the probability of hostage execution is high, which would signal the need for the involvement of hostage negotiators. The focus of the negotiator could be to negotiate the release of the victim(s), or even just to buy time to enable a rescue attempt. Additional

studies about the outcomes of kidnapping events in Nigeria may be able to identify and develop tailored responses to these events, in order to increase the success of responses to hostage situations.

Looking at Nigeria today we have mortgaged our culture of respect, love for human lives, hard work, friendliness and receptiveness to strangers in exchange of the Western culture and ostentatious orientation. These have given birth to the modern crime and social evil destroying the core value of our society. Onovo (2009) attributed the rising crime in the different regions to the celebration of fraudsters by leaders. He frowned at the appointment of individuals indicted of corruption as head of parastatals and various ministries of government. As noted by Oyefusi (2008), "greed and grievance are symbiotic." For kidnapping to occur, there must first be a grievance, some of which have already been identified and discussed. Furthermore, "rebellion needs grievance to mobilize and overcome the severe constraints on entry" (Oyefusi, 2008). Despite the personal or societal grievances, there are also logistical necessities to conduct kidnapping, the most prominent being cash flow. Criminal groups or kidnapping rings need revenue to finance their operations. It is possible, Oyefusi (2008) asserts, that this need for money may make greed desirable and sometimes required.

In most countries, increased education results in a reduced risk of political violence and higher incomes. This converse relationship between the two variables is believed to mostly occur because higher levels of education translate to citizens more interested in solving problems through "institutional pathways" (Oyefusi, 2008). However, this is not the case in Nigeria. Nigeria has a surplus of educated youth when compared to the availability of jobs. Those who join criminal groups or rebel

organizations must perceive a benefit in doing so. Oyefusi (2008) identifies these benefits as pecuniary and non-pecuniary. Pecuniary awards are identified as wages and other tangible items, which result from the revenue of the group. Non-pecuniary awards are identified as satisfaction and identifying with a cause. Some recruits may also want to satisfy a desire to fight “for the cause of their people” (Oyefusi, 2008). He states that the discussed benefits will often increase with personal grievance, and can be affected by a lack of gainful occupation, lack of economic and social access, environmental damage by oil companies, and the costs of past experiences of violent conflicts.

Oyefusi (2008) concluded in his study that civil peace is tied to the amount of oil wealth in a region. More specifically, the sample indicated that the greater the availability of oil, the more likely the region is to experience unrest. It is stated “thus, oil availability appears to have a corrupting influence on the disposition to civil peace among youths an influence that grows with the size of endowment. It was determined, in this study that a unit increase in oil size, defined by Oyefusi as the discovery of a new oil well, increased the odds of willingness to join a rebel group by a factor of 1.18 (18%). However, a unit increase in income level will decrease the odds of joining a rebel group by 37%. The study showed that a unit increase in education would also reduce those same odds by 36%. However, to be a true deterrent, education level would need to be tied to gainful employment.

The same study analyzed the effect of grievances against the government as a contributing factor to joining a rebel group, but this was then found to be statistically insignificant. Personal grievances such as income and basic needs were actually more strongly linked to the decision to join rebel groups because of the opportunities presented

by the groups, not because of the grievances themselves. Unemployment did not represent a statistically significant grievance level and did not help explain the probability of joining a rebel group. Oyefusi concludes, "Asset immobility, rather than asset possession, appears to matter more for rebel participation." A key argument is, "while further studies using alternative datasets would be required to get a clearer understanding of how grievance and its determining factors may influence rebel participation in the Niger Delta, the findings from this article suggest that strategies to achieve long-lasting civil peace must go beyond grievance, to address individual-level factors that determine the opportunity cost of participation in violence and community-level factors that create an opportunity to profit from extreme forms of civil disobedience.

2.1.5 Some Empirical Review on the Threat of Kidnapping

One of the prominent methods of locating abducted victims is through tower communication device. Idachaba (2011) carryout a study on kidnapping and its impact on communication network in Nigeria, the findings revealed that "kidnapping in Nigeria is fueled by the inability of security agencies to quickly identify the location of the kidnapped persons". The inability of the law enforcement authorities to comprehend the complexity of the Global Positioning System (GPS) is a serious impediment to the control of kidnapping activities. According to Idachaba (2011), the GPS Module is configured as a data pusher in that it sends the position data of the tracked object through a GSM Network. This transmission is facilitated by the use of a GSM Modem and microcontroller. The module stores the location data and sends it at predetermined intervals. The complexity of the communication device in Nigeria is an impediment to the control of kidnapping in the nation.

Campbell, (2019) in his study on Nigeria's solution to expanding wave of kidnappings, reported that Nigeria is experiencing a wave of kidnappings. In the past, kidnapping has often had a political dimension. In the oil patch, for example, militants have long kidnapped oil company employees to advance a political agenda. Boko Haram in the northeast is notorious for kidnapping young girls, the most famous episode being the 2014 kidnapping of the Chibok schoolgirls. The current wave is different. It is nation-wide, rather than confined to a specific region. It appears to be purely mercenary; the goal is to extract the maximum ransom possible rather than advancing a political agenda. Kidnapping victims now include the entire social spectrum, rather than being confined to those with some money or property. Nobody is exempt. An inlaw of President Muhammadu Buhari was kidnapped in the northern city of Kano in early May; the police rescued him in a shoot-out only this week. Kidnapping is a violent, terrible, sensational crime and poses national security challenge for the country.

Osumah and Aghedo (2011) in their study reported that kidnapping gained momentum in Nigeria as a response to joblessness, moral decadence, hopelessness and frustration among the youths. The politicians and disgruntled individuals seized the opportunity to perpetuate criminality. The miscreants use this criminal model as the easiest method for intimidating human beings for easy access to cash. Osumah and Aghedo (2011) argue that kidnapping is "an engagement for economic survival, securing political and business advantage over rivals and co-competitors.

Emewu and Anyanwu (2009) attest that the former Governor of Anambra State was kidnapped in July 10, 2003 by members of his political party who opposed his

visionary scheme. The politicians are not the only victims, the nation in general is victimized and this has depicted the country into senseless insecurity. Kidnapping and terrorism are twin demons eating up the nation's sense of identity and security, as it affects virtually everybody. The crime of kidnapping has created serious security challenges for the nation as it affects foreign expatriates, oil industries, and create negative image for the country. The security of the nation is at stake with series of incidence of kidnapping activities in many parts of the country.

The exact definition of kidnapping varies across the international community, though most definitions point to the same overall concepts. Nwadiaro and Nkwocha (2011) define kidnapping as the “means to seize and detain unlawfully a person by force and fraud and to remove a person to an undisclosed location against their will and usually for use as a hostage or to extract ransom”. Another definition, provided by Inyang and Abraham (2013) focuses more on the basis of the crime. Kidnapping is identified as the “forcible seizure, taking away and unlawful detention of a person against his/her will”. For the purposes of this thesis, it is accepted that the action of forcibly seizing an individual is an unwanted action by that same individual. Inyang and Abraham (2013) incorporated the end objective of kidnapping by expanding their definition as “an act of seizing, taking away and keeping a person in custody either by force or fraud it includes snatching and seizing of a person in order to collect a ransom in return or settle some scores of disagreement among people.” Similarly, Nwadiaro and Nkwocha (2011) highlight a definition of kidnapping as the “illegal abduction and detention of a person for the purpose of using his/her captivity to demand for ransom or make other demands”.

Academic definitions also periodically tie kidnapping to terrorism, because kidnapping uses acts or threats of violence to achieve an objective.

Osumah and Aghedo (2011) outline three types of kidnapping, which will be used in the data analysis portion of this thesis. First, there is ritual kidnapping. This is identified as the “oldest form of kidnap.” The targets of ritual kidnapping are often children, the developmentally disabled, and the physically disabled. The victims of this form of kidnapping are most often killed, as the desire of the kidnappers is usually to harvest organs or other body parts for sacrifice or money-making rituals. This form of kidnapping is the least reported in the press. The second form of kidnapping is identified as political. Political actors in Nigeria place a high premium on power and employ any means to acquire power for self-regarding gains. Political kidnapping is reported to be the highest in areas with large amounts of disenfranchised youth. The youth provide the politicians with a pool of available individuals ready to be dispatched for kidnapping missions by desperate politicians. The third type of kidnapping is business-oriented, or economic. Originally, this form of kidnapping was done to threaten rivals or curb competition, but today it has morphed into more of the money-making and ransom motivated kidnapping events.

Worldwide, kidnapping has occurred as long as societies have existed. Yun (2007) attributes the global increase in kidnapping during the last twenty years to the end of the Cold War. He further adds that kidnapping is one of the “unintended” consequences of globalization (Yun, 2007). As the world continues to globalize at a swift pace, kidnapping trends are expected to correspond, becoming an increasing concern to people worldwide. In Nigeria, specifically, the crime of kidnapping has increased

significantly during the last 40-50 years, but it is an issue that has long-plagued the country. Rivalries between slave traders in the nineteenth century resulted in raids, kidnapping, and piracy (Osumah & Aghedo, 2011). However, the Cold War is still implicated as a root cause of the modern issues of kidnapping in Nigeria. According to Yun (2007), as many experts correctly point out, transnational organized crime, international terrorism, illegal immigration, drug trafficking, human trafficking for sexual purposes, arms trafficking, and money laundering are all matters closely related to the end of the Cold War and the advancement of globalization.

He then explains that as the world becomes more globalized, more people travel for pleasure and work, and more people live abroad. As a result, there is a growing target population for kidnapers. Additionally, it is pointed out that “globally integrated capitalism has produced more numbers of people who are alienated and disenfranchised from the prosperity of a globalized economy” (Yun, 2007). Some academics identify the Nigerian Civil War of the 1970s as a catalyst for the increase in kidnappings in Nigeria. During this civil war, many Nigerian youths gained military experience, in conjunction with interactions or engagement in criminal activity for their first time. It is also noted in the same study that the breakdown of traditional Nigerian communities, as the country became increasingly urbanized, also contributed to the kidnapping culture in Nigeria. In this hypothesis, it is believed that the breakdown of the traditional way of life led to a breakdown in the social controls that are often associated with tight-knit rural villages. With little or no social controls, crime was allowed to take root throughout the country with little interference (Nwadiaro & Nkwocha, 2011).

A poor person today can show up with an expensive car tomorrow and nobody dare to question the sudden wealth. Also, people who have donated money to develop their communities are rewarded with chieftaincy titles thereby creating a wrong impression in the minds of Nigerian youths who thereafter take to kidnapping. The inconsistency between economic transparency and accountability in the running of normal government affairs and the desire to amass wealth among public office holders at different levels of government often also contribute to the leverage by kidnapers. This inconsistency between economic transparency and accountability, compounded with the issue of “moral decadence” and the “quest to get rich quick”, is believed to exacerbate the kidnap for ransom crimes in Nigeria (Inyang & Abraham, 2013).

As a result of the prevalence of this crime throughout the country, kidnapping has created a state of panic in much of Nigeria. The culture has swiftly changed to one of distrust and fear. Osumah and Aghedo (2011) describe this as a “palpable apprehension among the people who are unsure of whom [sic] the next victim will be.” Even something as simple as night travel has become a very dangerous activity. Inyang and Abraham (2013), reported that some Nigerians have been indirectly forced out of their homes by kidnapers. Some residents now go to extreme measures to make themselves appear less wealthy, to lessen the probability of becoming a kidnapping target. When it comes to personal cars, many Nigerians are no longer interested in purchasing new vehicles, because they could attract the attention of kidnapers. In Rivers State, it has been reported that the wealthy are now riding in taxis and taxi motorcycles, because those methods of transportation do not attract attention from would-be kidnapers and hostage-takers (Inyang & Abraham, 2013). Despite the lavish possessions the wealthy can afford,

few in Nigeria want to portray that image anymore. The rich are targeted by kidnappers because of the immediate payoff of kidnapping them, causing them to rethink the appearance of their lifestyle to remove the societal label of “rich” from themselves (Inyang and Abraham, 2013).

It is also important to discuss kidnappings conducted by radical Islamist groups, a growing issue in Nigeria. For these groups, kidnapping is purposefully used as a weapon. Due to Nigerian military efforts to combat the Islamist groups, Yun (2007) asserts that radical Islamist terrorist groups “have adopted alternative ways to continue their fight and exact revenge based on the understanding that their conventional fighting capabilities are no match for the combined coalition forces.” As a result, Yun (2007) states that hostage-taking and kidnapping have “become two of the most valued weapons in the modern terrorist’s arsenal.” It is both the success of the terrorist groups in conducting kidnappings, as well as the recent increase of radical Islamic groups operating in Nigeria, that gives cause for concern about the future of this crime in certain parts of Nigeria. Of particular interest is the April 2014 kidnapping of over 250 school girls in Nigeria by the Islamist group Boko Haram (Economist, 2014). Since the mass kidnapping, the group has continued to kidnap additional women and girls in northeastern Nigeria.

Compounding the issue in Nigeria, according to Essien and Ben (2013) is that the government of Nigeria seems to have not taken this issue seriously enough. The government’s “attitude of using the military option to suppress the people’s demand,” has led to the people’s choice of hostage taking, hijacking, and kidnapping of oil workers as their response. As a result, the “crime of kidnapping, in particular, degenerated from

targeting oil workers and multinationals to targeting politicians, clergy, entrepreneurs, and business owners” (Essien & Ben, 2013).

The growing incidence of hostage-taking and kidnapping

2.1.6 Laws and Law Enforcement

Little in the way of law enforcement or the penal code has impacted the kidnapping trend in Nigeria. According to current Nigerian law, kidnapping is a crime that can be punishable up to ten years in prison. Some Nigerian states have even passed a law titled the “Prohibition of Hostage Taking and Related Offences Law,” which stipulates the death penalty as punishment for kidnapers. Despite those legal measures, the safety of people in Nigeria and their property cannot be guaranteed. Nigerian bills with capital punishment for kidnapping are currently under review by the National Assembly, though the outcome is unlikely to affect the kidnapping rate (Inyang & Abraham, 2013).

The country also suffers from a lack of resources and training for its police forces to successfully combat kidnapping. Worsening the issue, there is rampant corruption within Nigerian law enforcement entities, which disables police units from operating efficiently to address the growing kidnapping issue in the country (Inyang & Abraham, 2013). Between legal inefficiency and underequipped and corrupt police forces, Nigeria has failed to either slow or stop kidnapping within its borders. Osumah & Aghedo (2011), on the other hand, reported a more robust security posture in Nigeria. They noted that security is increasing in kidnapping-prone regions of the country. Checkpoints have been established in many cities, police surveillance has increased, and some states now have anti-terrorist units. Yet, these efforts do not address the root causes of kidnapping and are

likely to have only a marginal impact until those root causes are addressed. Ikelegbe (2005) stated that the presence of military units in some parts of the North East has resulted in actions of recklessness and indiscriminate brutality. These responses further disenfranchise the population.

Okechukwu and Anyadike (2013) asserted that in the face of government expenditure on the security of the nation, the security forces appear helpless to curb the insecurity trends. The internal security mechanism appears to have broken down completely as the state no longer has the monopoly of the means of violence. In addition, the involvement of very powerful individuals has escalated the problem, bringing an unprecedented sophistication to the vice, as their automatic weapons such as the AK94 and mode of operation have beaten the low ranging arms of the police hollow in the crime war. At least, ten to thirty lives are lost either through violent robbery, political assassinations, murders and religious killings in the north eastern parts of Nigeria on a daily basis. Other manifestations of threats to national security include drug trafficking, human trafficking, hostage-taking human sacrifice, ritual killings, sectarian and political violence, communal strife and natural disasters (Darmer, 2004). Indeed, the realities on ground are very worrisome. Even when government officials are targets of the violent attacks and some of them are kidnapped by hungry and angry youths, the federal and state governments have been unable to surmount the challenges.

The situation lend credence to the fact that the insecurity situation calls for a reform in the security sector, because of the sole responsibility of government to protect the lives and properties of citizens. A government that cannot guarantee this, to say the least, has lost its essence. Apart from militancy, economic corruption gives impetus to the

threats to national security. National security is a big-time business, as bureaucrats and military officials are said to divert security votes and expenditure on defence to personal coffers. They tactically fuel the insecurity in different parts of the country to get more funding from all levels of government (Eboh and Obodoechina 2012). Albert (2005) described the incidences of bombing and attendant threats to national security in Nigeria, as a political intrigue unleashed on the nation by the ruling elites to cover up corruption. These justify the clamour for an effective and preventive state policing in Nigeria (Tunde-Awe, 2005). Antagonists against the establishment of State Police argue that the country is not ripe for it and that the state governors might turn them into a personal army to fight political oppositions in their states (Ehinder, 2012).

2.1.7 Decentralization of the police force and community policing

Structurally, the Nigerian Police force is under the general administration and operational of an Inspector General of Police appointed by the president and ratified by the senate. Police primary responsibility is maintenance of law and order. The Inspector General of police is supported by deputy Inspector general of police (DIG) and by police Commissioner assigned to each state. Nigerian constitution provided for establishment of

burgeoning security challenges. One of such is the call on the Presidency to cause the Ministry of Police Affairs and Inspector General of Police (IGP) to facilitate a functional decentralisation of the NPF, with budgetary powers vested in the 11 zonal commands under Assistant Inspectors General (AIGs). Just as well, it also proposed the amendment of extant laws governing all components of the country's security agencies from the military to the paramilitary outfits to reflect the new dispensation (Daily Trust, May 11, 2020). There is a nagging state of dissatisfaction across the country over lapses in the security of the nation, with fingers pointed mainly at the NPF, being the main frame of the country's security architecture. In the same vein the trending conversation has also focused on the weaknesses associated with the centralisation of the command structure of the NPF, in a multi-cultural society as Nigeria. This is the beam where whatever arguments for its decentralisation is anchored.

According to Cambell (2020), advocates have long argued that police forces under the control of the states would be congruent with Nigeria's federal system and that the states could impose greater accountability on the police than the federal government. Some see the NPF as evolving into something akin to the U.S. Federal Bureau of Investigation, with state-based police dealing with most criminal activity as in the case of India and other countries which state policing is working effectively. Small community policing initiatives, some supported by the United States and United Kingdom, have been met with success in the past. The issue has always been institutionalizing such initiatives and scaling them up. Most observers will welcome the decentralization of policing, but the organization of police is only part of the problem; the police remain underfunded, undertrained, and likely number

too few for a country of some 200 million people. Further, the police are widely hated, not least because of their corruption, which, in turn reflects their low and inconsistently-paid salaries. Those issues would not appear to be addressed by the devolution of local policing authority from the federal government.

Meanwhile, the arguments for the decentralisation of the NPF run along two main directions. In one vein is the clamour for state police which generations of protagonists including past and serving state governors, have always favoured. In the other vein is the advocacy for community policing which the federal government seems to be comfortable with as it is believed to run with contemporary political realities of an emerging democracy as Nigeria. As at the current policing structure in Nigeria, section 214 and 215

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A significant feature of the recommendations is a marked emphasis on improved synergy when all security components and assets in the country's security establishment participate fully at every tier of governance. By this emphasis on inclusiveness of all stakeholders in matters pertaining to security, the Senate committee's report seems to have taken to a new level, the imperative for closer collaboration between the various components of the security architecture. Presently this is not happening as every component simply acted in isolation from the rest, thereby providing for the serial slips in the country's security management regime. Given the far outcry and acceptability of the

perceived reform of the Nigeria police force, the bill proposed by Senator Surajudeen Ajibola Basiru titled “The Nigeria Police Act 2020 (Amendment) Bill, 2021” has since been signed with the following provisions:

The amendment seeks to insert a new Section ‘6(7)’ which provides for the structure of the Nigeria Police Force (NPF) as follows:

(a) Force Headquarters; (b) Zonal Headquarters; (c) State Commands; (d) Training Institutes; (e) Area Commands; (f) Divisional Police Headquarters and (g) Police Stations.

The new section makes provision for an organic structure for the police force so that its operations would be streamlined easily and better coordinated in line with global best practices.

The new Section 6(9) (a) of the bill establishes the zonal structure of the NPF to be headed by an Assistant Inspector-General of Police, who is given the power of budgetary control over the respective zones.

The provision makes for an even spread to all the geopolitical zones in the country and also obviates the unnecessary administrative bottleneck of having to report to the Inspector General of Police (IGP) in Abuja before key decisions are made, especially urgent decisions on funds.

Section 6(9)(a) Zonal Structure of the Nigerian Police Force provides thus:

(i) The zonal offices of the Nigeria Police Force shall consist as follows:

Zone 1: Kano/Jigawa/Katsina; Zone 2: Lagos/Ogun; Zone 3: Adamawa/Taraba/Gombe;
Zone 4: Benue/Plateau/Nasarawa; Zone 5: Edo/Delta/Bayelsa; Zone 6: Rivers/Akwa-
Ibom/Cross River; Zone 7: Kaduna/Niger/FCT; Zone 8: Ekiti/Kwara/Kogi; Zone 9:

Imo/Abia; Zone 10: Sokoto/Zamfara/Kebbi; Zone 11: Oyo/Osun/Ondo; Zone 12: Bauchi/Yobe/Borno and Zone 13: Anambra/Enugu/Ebonyi.

(ii) Each zonal office shall be headed by an AIG of police who shall report to the IGP.

(iii) The zonal offices shall have an operation and budgetary control over the police formations in the zone and shall prepare and submit to the Force Headquarters their budget.

Sections 6(9) and (10) of the bill made provisions for the establishment of zonal and state security advisory councils, respectively.

These advisory councils are designed to be headed by the governors, on a rotational basis for the zones, and by each state governor in the states.

The bill said the advisory councils have the membership of the senators from the zones, speakers of the Houses of Assembly from the zone, all the security agencies, civil societies, traditional councils, business communities, local government chairmen, leaders of faith-based organisations, and representatives of the zones in the House of Assembly etc.

According to the sponsor, "The amendments being sought to be implemented in the Police Act also align with the clamour for state police as the bill has made way for the participation of state actors in the affairs of the police force as it affects their zones and or states respectively.

"These amendments, if favourably considered and implemented, would improve our security apparatus and address the security challenges facing the nation," he said.

2.1.7.1 Differences with existing police structure

The new bill is a clear departure from the existing police structure.

The command structure, also referred to as the authority structure of the police force, is predicated on the regimental nature of the force and conducted along the force badges of ranks.

Thus, in accordance with Section 215(2) of the 1999 Constitution, Section 6 of the Police Act, 1990 Laws provide that, "The Force shall be commanded by the Inspector-General of Police".

This simply means that orders, directives and instructions to perform or carry out the duties with which the police are charged, flows from the IGP, through the chain of command, to any officer positioned to implement such order.

The Nigeria police is further structured in line with the geopolitical structure of the country, with provisions for supervisory formations. The structure formation enables police operational of the internal territory of Nigeria in the following order: Force headquarters; zonal headquarters; state command headquarters; divisional police headquarters; police station; police post; and village police post. (Daily Trust, Thursday March 23, 2021).

Despite known benefits of the planned decentralization or introduction of state and community policing, many still are antagonizing the policy reform. Forgetting that currently, there are community security groups in the states, even though they have not been officially designated as state police (James, 2014). In Kano State, it is called the Hisbah and was used by the state government to enforce the sharia legal system. There were once the Bakassi boys, which operated in Anambra and Abia States. In Borno State under Ali Modu Sheriff, there was the ECOMOG group, which many people believe has transformed into the Boko Haram sect, which is presently terrorising the country (James,

2014). The opponents of state police use some of the human rights abuses perpetrated by these groups as basis for their argument, saying that the groups operated contrary to the provisions of the Nigerian constitution. This school of thought also argues that the state police will be abused by the state governors. They opine that it will produce the same result as the immunity clause which has entrenched corruption at various levels of government. The introduction of state police they argue will worsen the bad security situation in most states of the federation.

For instance, Information Nigeria (2014) reported that the Inspector-General of Police (IGP), had reiterated his objection to the establishment of state police in Nigeria, arguing thus: "We are not yet ripe for the state police. I'm not saying there shouldn't be state police; we are not yet ripe for it. I'll cite several examples. Check countries of the world which are operating the state police, how many years from their independence? Take Britain, take United States, and take any European country that you can call as an instance, we are talking of 200 years in the United States. How old are we? Do they have the challenges we have?" This is apart from the fear of governors using state police against political opponents. The opponents of state police further base their position on politicians who already use all manner of funny-looking guys as personal guards to terrorise the common man. In addition, they argue that state funds will be used to influence a handful of members of the security agencies to intimidate, harass, maim and in extreme cases, kill innocent citizens who perform their statutory duties (Egboosiuba, 2013).

However, Fashola (2014) stated that the call for state police is a subject of the wider clamour for "true federalism". Prominent lawyers in Nigeria have decried the over-centralization of the police, drawing out implications for public order and safety.

Governors are the Chief Security Officers of their states with 'security votes', yet they have no control over the police. Rather, it is the Inspector General of Police (IGP) in Abuja through his Commissioners of Police (COPs) in each state that has the sole power over this monolith command structure (Eboh, 2014). The first republic had local, regional and central police institutions in accordance with the tenets of true federalism. Unfortunately, this arrangement was eroded by the military and replaced with the unitary system which the country's democratic order has adopted over the years. Ochei (2014) held that a veritable way out of the current security quagmire would be the establishment of state police formations. He views pundits' fear of abuse of the force by state governors as untenable in the light of the damning allegations of abuse of the Nigerian Police Force (NPF) by those who currently run and control it. Moreover, Eboh, (2014) insisted that the governors will never abuse the state police because the State Houses of Assembly will always be there to monitor their activities and ensure compliance

2.2 Summary of Literature Review

Nigeria as a nation has of late been adjudged one of the topmost notorious nations in terrorism, kidnapping and poverty capital of the World. To say that the peace of the entire country is threatened by various forms of organized crime is to state the obvious. The advancement in information and communication technology (ICT) is so epochal and has speeded the compression of time and space to the extent that the world is today seen by many as a global village. The expected global advantage in the synergy and interaction of nations in trade and commerce is gradually becoming a mirage as organized crime is to a great extent creating fear in the minds of investors and nations seeking to evolve as a solid global village. The reviewed literature show that there are

various environmental factors which influence the total eradication of organized crime such as kidnapping in Nigeria. Previous studies reviewed found that security personnel's attitudes, adequacy of funding security programmes and citizens lack of security cautiousness are all reported to in one way or the other contributed to the increase in organized crime in Nigeria.

Although efforts are being made in different studies to explore other security threat, no much is being done in the area of kidnapping for ransom as a threat to national security. Researchers are yet to completely consider in particular, ransom kidnapping as a security threat. In several studies, the researcher observed this generic use of kidnapping without distinction even though we have many reasons and motives for kidnapping. Therefore, this study is a attempt to cover that huge gap in literature and provide some empirical support to advance knowledge on the subject area of ransom kidnapping.

2.3 Theoretical framework

Two theories provided the framework for this study, there are: the Anomie theory by Robert Merton 1938 and Social learning theory by Albert Bandura 1977.

2.3.1 The anomie theory by Robert Merton (1938)

The anomie theory of Robert Merton seems best to explain the crime of ransom kidnapping as a security threat in contemporary Nigeria. The word "anomie" is of the French origin, which denotes normlessness (lawlessness). It was anglicized and conceptualized in the 20th Century by a Sociologist, Emile Durkheim (1858–1917), in his groundbreaking Thesis to mean generally, the absence or violation of norms (laws) and core values guiding human actions in society. Nevertheless, the anomie-strain theory of Emile Durkheim was modified to means-end paradigm by Robert K Merton in 1938. The

anomie theory argues that society creates its own brand of crime and criminals by defining its goals, standards and values without providing corresponding legal opportunities for achieving them. All societies, according to Merton (1938), have a cultural system which embodies the socially approved values and goals and the institutionalized means for achieving them.

Regrettably, the prescribed goals and means do not permit all members of the society to pursue only the success in legitimate ways. This exerts undue pressure on some segments of the society in a non-conforming (criminal) way as they struggle to achieve the success goals and values. This happens when the goal of success is over-emphasized more than the acceptable ways of achieving it. Conversely, Merton acknowledges that not all the people are deviants or criminals; this he did by identifying five adaptive ways people tend to respond when under structural strains. Merton's typology of individual adaptations to structural pressures is referred to as the „plus-minus paradigm“, namely, Conformity: (+ +), Innovation: (+ -), Ritualism: (- +), Retreatism: (- -), and Rebellion: ($\pm \pm$). The plus (+) sign stands for acceptance, the minus sign (-) represents rejection, and plus and minus ($\pm \pm$) signs signify rejection of both the institutionalized goals and means and substitution of new goals and means (Merton, 1938).

Innovation, the thrust of this study, explains a situation whereby individuals accept the culturally defined goals of the society (+) but reject the legitimate means of achieving them (-).

The innovator rather assumes criminal roles by adopting illegitimate means to achieve material success. Merton suggests that innovation in particular is a characteristic of the lower class, the location in the class structure of American society (as applicable to

contemporary Nigerian society) where access to legitimate means is limited and the „strain towards anomie“ is most severe. Encumbered by structural blockages, the researcher observes, individuals in the base of the social ladder then employ unlawful means in an attempt to achieve the culturally over-emphasized goal (success) of the society. This class of people is believed to have been inveigled into kidnapping by environmental pressures and economic deprivations that are commonplace in Nigeria. The relevance of anomie theory to the study lies in its far-reaching impact and analytical dissection of kidnapping and kidnappers in relation to „innovation“ as progressively demonstrated. Igbo and Anugwom (2002) applaud this theory when they say that social problems (such as kidnapping) are often associated with changes induced by the adoption of innovations in society.

The anomie theory is relevant to this study owing to the fact that wealth acquisition is a common feature in contemporary Nigerian society. The meteoric rise in kidnapping incidence in the country is, to say the least, a concomitant effect of certain socio-political and economic backlogs in the nation's social structure and political economy, which limit and frustrate citizens of Nigeria from effectively competing for the overstressed success. Akinyemi (2002) explains that when people are asked to pursue economic success and at the same time denied means of achieving it, there is a goal blockage; the aspiration is frustrated and may lead individuals to choose illegitimate means (such as ransom kidnapping) to achieve their goals. No wonder many interviewees in our study averred that people take to ransom kidnapping in order to make a living.

The focus of this study agrees with Igbo (2007) that Merton's postulation aptly describes the situation in our country Nigeria today, particularly in Northern Nigeria

where material wealth has become the major yardstick for measuring success and where people have little or no regard whatsoever for the rules of the game. Nigerians have come to glorify and even worship wealth, regardless of how it was acquired, whether by fair means or foul. This study adds that this type of society coupled with weak formal and informal social control is usually a breeding ground for kidnapping and kidnappers. I little wonder that our Western-borrowed crass materialistic culture and anti-egalitarianism tendencies have inescapably resulted in emerging forms of organized crime and criminals, particularly ransom kidnapping.

2.3.2 Social Learning Theory by Albert Bandura in 1977

Social learning theory was propounded by Albert Bandura in 1977. The basic tenet of the theory is that behavior is learned from environment through the process of observational learning (McLeod, 2016). The theory explains that, children acquire their behavior through observing people around them; hence behavior is learned. Social learning theory also stipulates that behavior is acquired through observation and imitating others (Bandura, 1971). In same vein, David (2015) added that social learning theory indicates that behavior is learned through modeling; meaning that, “following the footsteps of others”.

This theory is based on the idea that we learn from our interactions with others in a social context. Separately, by observing the behaviors of others, people develop similar behaviors. After observing the behavior of others, people assimilate and imitate that behavior, especially if their observational experiences are positive ones or include rewards related to the observed behavior. According to Bandura, imitation involves the actual reproduction of observed motor activities (Bandura 1977). The principles of social

learning are assumed to operate in the same way throughout life. Observational learning may take place at any age. Insofar as exposure to new influential, powerful models who control resources may occur at life stage, new learning through the modeling process is always possible. (Newman B.M. & P.R, 2007). The theory points that people learn from one another through observation, modelling and imitation.

The probability that persons will engage in criminal and deviant behavior is increased and the probability of their conforming to the norm is decreased when they differentially associate with others who commit criminal behavior and espouse definitions favorable to it, are relatively more exposed in-person or symbolically to salient criminal/deviant models, define it as desirable or justified in a situation discriminative for the behavior, and have received in the past and anticipate in the current or future situation relatively greater reward than punishment for the behavior. (1998: 50) Whether individuals will refrain from or initiate, continue committing, or desist from criminal and deviant acts depends on the relative frequency, amount, and probability of past, present, and anticipated rewards and punishments perceived to be attached to the behavior. Thus, the ability of the security architecture of state to deter people from crime is key to ending the current situation. There seem to be gross failure in fighting crime and so there is almost no punishment for criminal behaviour and this is reinforcement crime in the society.

The implication of this theory to the current study is that, social learning theory explains the rationale for the persistent incidence of kidnapping and hostage taking in Nigeria. Kidnapping for ransom have proven to be a lucrative endeavor as a result of the large amount of money victims pay to their abductors. As a result of this, many young

people have gone into kidnapping because by their observation to those who go into it are making it financially, likewise they too can make it through same means; hence the persistence incidence of kidnapping. No one is born a criminal, it is the society that impart on the individual through what he/she learns from his/her immediate environment that make them become criminals and turn into criminals and indulge in all kinds of rimes.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Research design

A cross-sectional study design was used for the study; to measure the effect of kidnapping for ransom and security challenges in Nigeria. Cross-sectional study design is a type of observational study design; and in an observational study, the investigator does not alter the exposure status. The investigator measures the outcome and the exposure(s) in the population, and may study their association. The participants in a cross-sectional study are just selected based on the inclusion and exclusion criteria set for the study. Once the participants have been selected for the study, the investigator follows the study to assess the exposure and the outcomes. The investigator can study the association between these variables. It is also possible that the investigator will recruit the study participants and examine the outcomes in this population. The investigator may also estimate the prevalence of the outcome in those surveyed.

Kidnapping for ransom and security challenges in Nigeria have raised serious concerns more in Nigeria. A cross-sectional study was considered suitable for this study because it is less time consuming and always suitable for covering a large spectrum of research participants for investigation. The study cut across all the states in Nigeria with focus on the South East, South-South, North West and North East geo-political zones which currently serve as a major flash point of kidnapping for ransom in the country and are seriously under attack by bandits, herdsmen and kidnapping dominating the security challenges faced by citizens in the study area.

3.2 Population of the study

The population of the study comprised of all recorded kidnap cases that have occurred in Nigeria. The total population for the study comprised all recorded kidnap cases between the periods, 1999 to 2020. Since the study is first a document analysis, the researcher used reliable records from agencies responsible for fighting this crime and others in similar services to effectively cover the population within the period under review. The police report and review of kidnap cases in Nigeria formed the source of information on this.

3.3 Sampling technique

For the purpose of data triangulation in meta-analysis, interviews are often given to strengthen existing literature and secondary sources available to the researcher. For this study, the researcher conducted in-depth interviews with victims or relatives of kidnap persons and key informant interviews with top security personnel involved in fighting kidnapping in these flash points. Purposive sampling was used through snowballing technique to access interview participants. This method is applied when it is difficult to access subjects with the target characteristics. In this method, the existing study subjects recruit future subjects among their acquaintances (Abedsaeidi & Amiraliakbari (2015).

Sampling continues until data saturation this method, which is also called the “chain method,” is efficient and cost effective to access people who would otherwise be very difficult to find. In this method, the researcher asks the first few samples, who are usually selected via convenience sampling, if they know anyone with similar views or situations to take part in the research. The snowball method not only takes little time but also provides the researcher with the opportunity to communicate better with the samples,

as they are acquaintances of the first sample, and the first sample is linked to the researcher (Polit-O'Hara & Beck, 2006). This type of networking is particularly useful for finding people who are not willing to reveal their identities. The in-depth and key informant interviews were used to strengthen the meta-analysis from secondary sources.

3.4 Sample of the study

Although the researcher targeted a sample size of Thirty-six (36) senior police officers and other security agencies of equivalent rank as respondents for the study, and victims or relatives of kidnap cases across the study areas. Not all were reached due to the nature of the subject under consideration; however, Twenty three (23) respondents reached and their responses formed the basis for the results so arrived at. Not many of the persons contacted through the snowballing method were willing to share their experiences, because of the traumatic times they had in the hands of their captors and for security reasons, the personnel were reluctant to share several information. Some revealed that, it is against their job ethics to share some critical security details with the general public. However, it is believed that, in studies of this nature smaller but focused samples rather than large samples are often most appropriate (Cassel & Symon, 1994; Denzin and Lincon, 2005; Patton, 1990). Thus the number of sample reached was enough to triangulate the document analysis.

3.5 Instrument for data collection

The study used both primary and secondary sources of data collection. The study is first a document analytical study, thus utilized secondary literature for analysis. However, interviews were used to complement the meta-analysis to give credence to the findings. For the interview, the researcher used a validated self-administered interview

guide. The information elicited were in line with the research variables which guided the study. For the secondary data, the researcher conducted a systematic and vigorous search for relevant and reliable literature from credible sources. Research articles from reputable journals, official web site of security agencies in the country, international and organizational database, technical reports from non-governmental organizations, secondary interviews by other researchers, experts opinions and other empirical sources were obtained through the google search engine and offline contact with some organizational documents.

3.5.1 Validation of the instrument

The face and content validity of the interview guide was done by comparing its items with previous studies and by matching them with the stated objectives. In addition, copies of the research proposal and the interview guide went through series of expert reviews in the Department of political science, and other lecturers in the Faculty of Social Sciences University of Calabar, Cross River State, Nigeria. After thorough scrutiny the researcher submitted the guide to his supervisor for more input and final approval. The final copy was used for the in-depth and key informant interviews.

3.6 Procedure for data collection

The main data source for the study was secondary sources, being relevant literature and statistics from reliable government agencies in charge of security. The interviewees and the key informants were purposively drawn across the study area. The IDIs were conducted with few victims of kidnapping in these areas or their relatives who can talk from personal experience, the KII data were generated from security personnel who were directly involved in combating kidnapping in those zones. To reduce physical

contact and strictly adhering to the Covid-19 protocol in data collection, most of the interviews were done via phone calls and only in very necessary situation that the researcher resolved to one-on-one with respondents. This procedure was crucial to protect both the researcher and respondents. For each participant, the researcher introduced himself and the topic and purpose of the study to get informed consent before engaging respondents for the interviews.

3.7 Procedures for data analysis

The content analysis of documents was organized in line with the research objectives. Also the interviews were transcribed and used to support findings from the secondary sources identified for each of the research variable. The analysis of the interview was in themes as revealed from the responses obtained.

CHAPTER FOUR

KIDNAPPING FOR RANSOM AND NATIONAL SECURITY IN NIGERIA

Chapter four covers the historical background of kidnapping for ransom in Nigerian. This is done in line with the emergence of the threat of kidnapping in the country and the various natures it has taken over time. The usual victims were foreign nationals working in the oil companies and the culprits were the oil militants demanding control of the natural resources in the oil rich region. It has since become pervasive and commercialised. It has spread from the Niger Delta to virtually all parts of the country, with some states of course being the epicenter. In same vein, their victims have changed from being predominantly foreign oil workers to Nigerians, including parents, grandparents, kids and about anyone who has a relative that could be blackmailed into coughing out a ransom. Recently, school children are now targets to blackmail government and state structures into paying ransom. Those behind the recent wave of the despicable act have also changed from being exclusively Niger Delta militants to dodgy elements from different walks of life - armed robbers, unemployed, professionals and in some cases, security personnel as collaborators.

Just like SB Morgen (2020) report reflected “insecurity in Nigeria has risen sharply in the last few years. In every region of the country, there are at least two major security crises, and we have reached a point where the Nigerian military was, as of December 2019, deployed on policing duties in every state of the country bar Kebbi and the FCT. The Boko Haram insurgency marked a decade in 2019 and has coloured much of the security atmosphere in the last decade. In the North West and North Central, pastoral conflict between farmers and herders has led to increasing hostilities. Youth gang

violence is rife in the three geopolitical zones of the south, as well as armed robbery and sea piracy in the South West and South East. In all of these, the spate of kidnapping is a feature in all parts of the country. Kidnap for ransom is a lucrative business in Nigeria”.

From the above report, while other crimes are confined to regional sphere, kidnapping for ransom is said to be a future in all parts of the country. The situation is already a threat to national security and calls for urgent state of emergency in the security sector if things must not degenerate beyond the current state we are in right now. No part of the country seems safe at a moment and this should bother all well-meaning Nigerians and particularly stakeholders in the security of life and properties of citizenry in the country.

4.1 General overview and historical perspective of kidnapping for ransom

Kidnapping can be defined as the taking away of a person against the person's will, usually for ransom or in furtherance of another crime. This has become everyone's nightmare in our Nigeria. Every day, we read frightening stories of people being abducted as they go about their daily business especially now the raising wave of school kidnapping for ransom. The phenomenon of kidnapping in Nigeria has taken an alarming and disconcerting dimension which tends to threaten the substratum of our national security. At various regions, perceived economic marginalization, militant agitations gave has given rise to kidnapping in Nigeria. At a time when militants in the Niger Delta embraced the federal government's amnesty, political thugs who appear to have been used and dumped by do or die politicians picked up the vice and continuously, it appears the army of unemployed youths are adding to the vice.

Tzanelli (2006) noted that the modern usage of the term 'kidnapping' dates back to 17th-century Britain where infants ('kid') of rich families have been 'napped' (caught in

the sleep) for ransom. This is still well with us as the trend is on the increase all over the world as reported by the Global Slavery Index (2014), throughout 2014, men, women and children continue to be kidnapped in village raids and held as slaves by militias in different regions of Africa. At the earlier stage, kidnappings was a major contributor to a climate of insecurity in the South East, the Niger Delta and the South-western region, but today, kidnapping is a major security threat to all parts of the country and by extension a threat to the national security of Nigeria. Some reports had it that, between 2008 and 2010, the Nigeria Police Force recorded 887 cases across the country (Action on Armed Violence, 2013).

However, the incidence of kidnapping is thriving more in the moment of terrorism, insurgency and other forms of political violence (Dodo, 2010). For instance, the kidnapping of 250 girls in a girls' secondary school in Chibok, Borno State in 2014, the Daptchi Girls, the Kankara boys in Katsina state, the Kagara boys in Niger state and the Jengebe girls in Zamfara and many more by Boko Haram is a proof of the above ascertainment by Dido and represent the growing incidence of the kidnapping in Nigeria. This is clearly a threat to our corporate existence as a people and the national security of Nigeria.

Egbegi, Onyejegbu and Chinweze stated that, in couple of years, Nigeria has witnessed an unprecedented level of kidnapping for ransom. Also Chukwuma (2019) observed that kidnapping for ransom has remained the most virulent form of banditry in Nigeria. It has become the most pervasive and intractable violent crime in the country. Adeola (2012) again disclosed that Nigeria accounted for a quarter of kidnap for ransom cases reported worldwide in the year 2011 for instance, and that the country had been

designated as the global capital for kidnap for ransom due to the huge record of kidnap cases reported in the country yearly. The researcher observed that the narrative is yet to change in 2021. The situation is threatening to note that Nigeria remains country with the highest number of kidnaping in the world. Nigeria is now the kidnap for ransom capital of the world, accounting for a quarter of globally reported cases.

Regrettably, before the 1990s, kidnapping for ransom was not a major issue in Nigeria, though it may not be entirely true to say it did not exist (Egbegi, Onyejebu and Chinweze, 2019), but it was not a major issue in the country or a threat to national security. People had been kidnapped and sold into slavery during the 18th and 19th centuries, others were kidnapped from their homes and assassinated as a result of quarrels over farmlands, people also kidnap children and used them for money-making rituals (Sanyaolu, 2009). But to say the least, that before the 1990s, incidences of kidnapping for ransom in Nigeria were at minimal level and so never considered a threat to national security.

In giving the sense of history, Odoh (2010) confirmed that the current wave of kidnapping began with the abduction of expatriate oil workers by the Movement for the Emancipation of the Niger-Delta (MEND, a youth group) in late 2005 as a means of alerting the world of the many years of injustice, exploitation, marginalization and underdevelopment of Niger-Delta region. This position is also held by many as it run through in most of the literature drawn from scholars for this study. Aligning thus, Nnamani (2015) asserts that the early incidence of kidnapping may have been copied from the Niger Delta region when the militants abducted some oil workers in February, 2006 to draw global attention to the sorry situation in the oil rich Niger Delta region and

the victims were mostly foreigners. But in recent times, there are indications that the trend has since changed.

Inyang and Abraham (2013) agreed that the gravity of kidnapping is so intense that it has virtually affected most people in our society. Since the MEND experience, the social problem of kidnapping has spread like wild-fire in most parts of the country, especially in the south-eastern region. The targets were no longer foreigners alone practically every Nigerian became a target. As the Niger Delta militancy degenerated, kidnapping became rather entrenched as one of the awkward legacies of the struggle. Expatriate oil workers were then targeted and kidnapped for ransom. It got worse as observed by Raheem (2008) that, "the huge ransom paid to secure the release of the expatriates soon became bait. It became an energizer to the militants to go for more. Soon, it became a huge racket and money-making venture for both the abductors, and the negotiators.

A rough estimate of incidences of kidnapping as early as 2009 by the then Inspector General of Police in Nigeria said that between 2008 and 2009 about 130 people were kidnapped in Nigeria and about N15billion have been paid as ransom to the kidnappers (Inyang, 2009). That goes to show the intensity of the problem at a time and that has long changed as the situation is now worst. The same trajectory was reported by Abugu (2009), that as at July 2009, more than 200 people had been kidnapped in the Southeast geopolitical zone alone and released at the payment of ransoms by their families or friends/associates. Considering the current situation, that figure is nothing to compare with. Ajah, Nwokeoma and Okpan, (2017), reported that, "city residents from Aba say that an average of two people were abducted by militants daily between July and September 2010, there were also regular incidents of kidnapping in Rivers, Abia, Imo,

Enugu, Anambra, and Bayelsa States within that period”. This can only be seen as a state of the nation and a serious threat to the national security.

According to SB Morgen (2020) report, “in terms of the absolute number of reported kidnap incidents, four of the top 10 states with a high number of kidnap incidents over the last decade are in the South-South geopolitical zone, with three of them, Bayelsa, Delta and Rivers being a part of the Niger Delta. These three are also the states with the strongest history of Niger Delta militancy. Kaduna, the state with the second-highest number of incidents also has a significant history of violence, especially along its connecting road to Abuja. While it is not in the top 10, Abuja has the 11th highest number of kidnap incidents over the last decade and there is anecdotal evidence that some of the perpetrators responsible for Kaduna’s high rate of kidnap attempts have extended their operations into the federal capital territory. Overall, Nigeria is becoming less safe each year. Kidnapping has increased in almost all states, but the sharpest rises have been in Kaduna, Rivers, Katsina, Zamfara and Taraba, while only Bayelsa in the entire country, and saw a fall in the number of incidents compared to the period of 2011 to 2015”. If the nation’s capital is under threat of kidnapping for ransom, then the national security is under threat definitely. Thus, historically speaking, what in the past seems like common crime in the 1990s had exponentially and astronomically grown into a monster that may consume the nation soon if proper steps are not taken to address the already worse situation.

Fundamental catalysts of kidnapping for ransom in Nigeria

4.2 Economic/poverty as a catalyst

There are several factors that have predicated the current monster called kidnapping in Nigeria and particularly, kidnapping for ransom. People have different reasons for engaging in this crime and there are some factors that have aided the seemingly endless crime in Nigeria. Just like some pessimistic policy analyst would conclude, that the crime of kidnapping for ransom will soon consume Nigeria if nothing serious is done now and urgent too. Considering how it all started, Hazen and Horner (2007) reported that some groups in the Niger Delta have in the past used the kidnapping of international oil workers to raise international attention regarding the plight of those living in the Niger Delta, the environmental damage caused by oil spills and the oil industry, and the demand for more local ownership of the extraction of natural resources.

They noted that, the use of this tactic has not been entirely political in nature, as there are reports of significant ransom payments, which have then been used to fund the activities of these groups further. Thus, not only economic deprivations and environmental issues were the reasons for kidnapping, but payment of ransom to further their course was fully part of the reason why they were kidnapping. In fact, the tactic has proven so lucrative that a number of criminal groups appear to have taken on the task in order to simply make money (Bello & Jamilu, 2017). From evidence, it would appear that in the south, while kidnapping may be frequent, the selection of victims is more targeted and the kidnapers see it more as a business transaction, trying hard to extract money from their criminal activities (SB Morgen, 2020). Thus, the economic benefit of the proceeds of kidnapping seems to be the major catalyst because it looks like experts

consensus. This targeted approach makes their victims less expendable as they are usually fewer in number at a time. In the North, the modus operandi is more likely that a larger number of people are simply rounded up and then ransoms demanded enmasse. Because of this approach, victims that are unable to pay up as quickly as expected are more likely to be killed by the kidnappers.

According to Hino (2005), in Nigeria most indicators of social and economic progress, including real per capital consumption, literacy, access to clean water and income distribution, show that poverty has worsened since 1960. Despite its human and natural resources, Nigeria has become one of the poorest nations of the world. Per capital income was lower in 2002 than in 1975. Poverty in Nigeria is generally believed to be the prime cause of kidnapping and abduction in the country as perpetrators demand ransoms before the release of their victims he concluded. Because people are falling into poverty by the day, young men are easily recruited into almost anything that can pay them something to end a living not minding the dangers involved. Poverty has been responsible for the desperation to do anything to survive which is taking many into crimes generally.

Many other researchers such as Thom-Otuya, (2010); Inyang (2009) and Ogbuehi, (2018) attribute the upsurge of kidnappings in Nigeria to endemic poverty in the country. For instance, the World Poverty Clock as at June 2018 revealed Nigeria as the headquarters of poverty with half of its population, around 87 million people, living in extreme poverty on less than 1.90 US dollar a day; and that in every sixty seconds six Nigerians slither into poverty (Onu, Bax, Adamu and Ibukun, 2019). Again the ever-widening gap between the rich and the poor combined with poor governance characterized by corrupt practices tend to breed strain and desperate tendencies in the

youths due to their real or perceived sense of economic deprivation (Catlin Group, 2012). The seeming nature of the kidnap for ransom venture as a money spinning industry has a potential of luring teeming hungry youths who desire to 'live like the rich' whose lifestyles they aspire to emulate, hence the growing desperation and desire for quick money particularly among the young Nigerian population. This may explain why most researchers found positive correlation between poverty and the increase in kidnapping and crime in general.

Justifying economic reason for why kidnaping for ransom is thriving, another report by Voice of America (2020) and Morgen reiterated that, "one reason why kidnap for ransom has come to stay is the economics surrounding it. ... in US dollar terms, between the \$545,000 paid to secure the freedom of Ernest Ohunyon in Edo state in November 2011, and the \$6868 paid to free Ojo Ekundayo and Benjamin Iluyomade in Ondo state at the end of March 2020, at least \$18,343,067 changed hands between victims and kidnapers. It is important to point out that in the earlier years, there were fewer incidents, and larger amounts changed hands. Now there are a lot more incidents for smaller amounts, but the sheer number of incidents, speaking to the democratisation of the kidnap industry, means that the kidnap economy now makes more money. Morgen report said, they reported an investigation by the Voice of America in September 2019 which revealed that, kidnapers demand between \$1,000 to \$150,000 as ransom, depending on the financial resources of the victims. Crime, in this case kidnapping, does appear to pay" the report added. Thus, kidnapping for ransom though negative is becoming a big industry in Nigeria.

For instance:

“Wadume was said to have made millions from ransom. His gang carried out a kidnapping in Takum on 16 February 2019 of a petrol dealer Usman Garba. The Wadume gang demanded N200 million ransom. Despite that relations of the victim were able to hand over N106.3 million, he was killed. In late April 2019, the chairman of Universal Basic Education commission, Dr Muhammad Mohmoud Abubakar and his daughter were abducted by armed gangs in military uniform along Kaduna-Abuja highway. Their driver was also shot and killed during the incident which occurred at Kurmi Kari village. They were both released a few days later with ransom paid. On 29 January 2019, 16 villagers were abducted by armed bandits in Zurmi local government area of Zamfara. Their abductors demanded N8.5 million. They were released after the community rallied around to raise N3 million. When gunmen abducted four staff of the National Emergency Management Agency (NEMA) in Abua Odual LGA of Rivers state on 24 April 2019, at least N6 million was paid for their release. These examples show there’s a whole thriving economy built around the abduction of persons. Insecurity is increasingly becoming a profitable venture for its merchants who look set to rival the illegal arms running businesses” (Morgen, 2020).

Presenting a similar narrative, Emanemua and Akinlosotu (2016) opined that, “Kidnapping has recently become a profitable venture among youths in Nigeria. This criminal practice that started in the form of hostage taking in the Niger-Delta, region of the country in calling the attention of the government to the marginalization of the region, has seemingly become a variant of armed robbery with high level of expertise in abducting people for ransom illegally. The ascendancy of this insecurity threat is now becoming perplexing to several citizens, business people, foreign investors, law enforcement agencies and the government”, they concluded. They obviously associate kidnapping to the ransom paid which is the economics of the crime. Like Turner (1998) listed four key rationales for kidnapping, money was central to all four in any way it is presented, (kidnapping for money but no politics; kidnapping without any political or

monetary motive; kidnapping for money and politics and kidnapping for politics but no money). The author was deliberate in including money in all the factors responsible for the rise in kidnapping in the country.

4.3 Unemployment as a catalyst for kidnapping

Everyone with no exception is worried about the state of unemployment in the country. One does not need to be an expert in Nigeria to describe the rate of poverty or its index because it could be felt unarguably. According to Morgen (2020), "rising levels of youth unemployment is a major factor responsible for the growth of kidnap cases. The group noted that, Nigeria's unemployment rate rose from 18.8 percent in the third quarter of 2017 to 23.1 percent in the third quarter of 2018. UN estimates for youth unemployment in 2019 were above 20%. In the South, the persistent problems of unemployment meet with political patronage by politicians and thus they are used for indescribable deals. Earlier research by same group showed that the crime rate soars during election periods and politicians key into the mass idleness of young people by using them for political violence and when elections are over, these idle hands turn to crimes and particularly kidnapping for ransom for survival.

Ohakhire, (2010); Ogbuehi, (2018) and Ibrahim and Mukhtar, (2017) identified lack of employment opportunities as drivers of kidnap for ransom incidents in Nigeria. In the same vein, A study conducted by Adegoke (2015) found unemployment by a margin of 88 % as the main driver of kidnap for ransom which is mostly perpetrated by the youths. The argument remains that, year-in, year-out able-bodied graduates are being produced in large number without corresponding job opportunities to absorb them. Thus, the unscrupulous and frustrated jobless youths often resort to criminal activities as a

means of survival (Inyang, 2009). Similarly, Ejimabo (2013) described the phenomenon of pervasive unemployment among the youths as an impediment to the control and prevention of crimes and delinquencies in the country.

Still the issue of unemployment as a catalyst, Inyang and Ubong (2013) also attributed the rise in kidnap for ransom incidents to the frustration occasioned by the joblessness of the youths whose personal responsibilities grow without any financial means to offset them. This position was corroborated by Thom-Otuya (2010) who argued that the rate of unemployment in Nigeria is responsible for the widespread kidnapping incidents across the country. It is too high that it poses serious implications for national development, the study concluded. From the psychological effects of unemployment on crime Inyang (2009) again stressed that graduates who could not secure jobs after graduation develop negative attitudes towards the society and the system and attribute their failure to secure the job to the society. Consequently, they develop the tendency of indulging in acts that negate the overall wellbeing of the society of which they are part; and at best they never provide any useful support needed to secure the society.

In support of what most scholars opined, Danesy (2011) argues that, the parental neglect, lack of proper counseling, poor skill acquisition and drop-out of school syndrome by youths have led many youths to migrate from rural areas to cities to meander around major roads where they have been seduced with cash benefit and conscripted into various types of gangs or secret cults where they have been trained as ethnic militia to unleash terror on other innocent people of their sponsors in the society. Many others believed that, the “man must survive” mentality and “quick money syndrome”, has brought many of these misfits, into group of kidnapers; targeting not

only prominent political leaders but also well-meaning Nigerians who they perceive to be persons of high financial prospect in the society.

According to a study conducted by Abdulkabir (2017), the result of this research shows that most of the convicted kidnappers confessed that they were unemployed graduate looking for a way to survive and if there is no good way to stay alive then evil is the only option. Abdulkabir further ascertained that many youths have erred in joining criminal group because of unemployed ache. He then recommended that, with immediate effect, Nigeria government should provide employment for the youth not only to discourage them from hostile habit but also to encourage them as a good citizen. Looking at his suggestions, have the youths been provided with jobs? If no, then this may have accounted for the unending of the wave of kidnapping in the country.

4.4 Failure of governance and corruption as a catalyst

Every indices of good governance today is in the negative, they seem to be gross failure of governance and the citizens have lost hope on what the government can do for them. Corruption is at its peak and everyone seems to do it as it suits them at a particular time. The frustration is real and could be heard in conversations and interactions in public spaces and between private individuals. Because of the pervasive corruption in the system, some people are of the opinion that, the crime fighters have also become part of the criminals. In a secondary interview as reported in one of the research, a respondent said that, while calling out the role of security agencies, he noted that the police “are accomplices, perpetrators, and victims. The ones involved in kidnap are there; those who are fighting kidnappers too are there”. That is the level of rot and corruption that is fueling the ugly trend of kidnapping for ransom. Because of corruption, people betray

others and become informant to the criminals, making their jobs easier because they can trace their target through reliable details about the person's whereabouts.

“... Kidnappers “break into the victim’s house or stop the victim on the road then take the victim to their camp. They have informants, people who tell them the whereabouts of the victims.” Another respondent said, another thing here is that most times, they use an insider from a community who gives out information to the kidnappers that enables them to track their victims.” The third respondent has this to say, but my own belief is that before a person is kidnapped, there must be an insider, there must be someone who knows you, so there is nothing the police can do about putting an end to it” (SB Morgen Report, 2020)

Talking about the failure of governance, the political importance of thugs and hooligans to party aspirants during campaign periods, seem to have had a trickle down and spill over influence on several innocent citizens. It has energized several crimes in the society. Jobless youths who were recruited by political god fathers to cause chaos, steal ballot boxes, and even kidnap viable political members from opposing parties and later abandoned after elections take into crime as a full time business. To this end, Arewa (2013) pointed out that consequently upon the collapse of the parliamentary system in Nigeria in 1966 through degeneration and revolutionary ouster, the state, its laws and institutions became dedicated instruments of despots and political forces and allowed to slip deeper and deeper in the mire of corruption and malfeasance far beyond the transformation.

The state of the Nigerian economy is very worrisome. There is social infrastructural decay and inability of governments to provide the needed dividends of democracy. State funds and resources are embezzled by individuals in highly placed

positions of political authority. Funds meant for state projects are often misappropriated. This often has a far reaching effect on the citizens. Greed, moral decadence and the quest to get rich quick syndrome have been identified as factors motivating kidnapping (Ogbuehi, 2018; Inyang and Ubong, 2013; Inyang, 2009; Nnamani, 2015). Talking about the youth quest to get rich syndrome, Nnamani (2015) stated that the display of affluence by the wealthy individuals coupled with the societal emphasis on material wealth, and the roles played by particularly the traditional rulers in conferring traditional titles to any rich individual without questioning the source of their wealth makes some youths venture into criminality so as to make wealth overnight. This is more worrisome considering the fact that the society seems to be quiet when an individual that is known to be poor today, suddenly shows up with material wealth yet nobody dare question the source of their sudden wealth.

The foregoing encourages moral decadence as so many desperate youth wanting to be like them would not hesitate to mortgage their integrity to acquire wealth regardless of the means (Inyang 2009). This seems to be swelling the number of youths sliding into the crime of kidnapping for ransom every day. Agreeing to this, Inyang and Ubong (2013) opined that greed is a major factor predisposing kidnappers to brutalizing and dehumanizing their fellow humans in the quest for quick riches. This was also the submission of Ogabido (2009), Nworah (2009), Arewa (2013), Thom-Otuya (2010), Nnamani (2015) who in their different studies shared the opinion that, poor and corrupt governance are the factors responsible for the rise in kidnapping incidents in Nigeria. And Ogbuehi (2018), concluded that some people use kidnapping as a means of taking revenge or political vendetta. Everything speaks about the colossal failure in governance

and pervasive corruption in the society where citizens are ready to do just anything to survive.

4.5 The problem of ungoverned space

As the problem of ungoverned spaces in Nigeria become more pronounced even in urban centres, non-state actors will continue to take advantage of these gaps to entrench themselves deeper in society. According to Okoli and Lenshie (2018), Nigeria is a territorially challenged and fragile state. It is characterized by what they termed “virtual territorial ungovernability”. They stated that, this existential syndrome is evident in the near absence of governmental presence and control within critical domains of the country’s wider territorial sphere. They again stressed that, Nigeria’s territorial ungovernability is thus instantiated by the huge governance deficits in the country’s physical and maritime boundaries, cyberspace, forest areas, as well as mainland, airways and waterways. Nigeria’s ungoverned spaces syndrome is most saliently and vividly demonstrated by the vast and porous borderlines of the country Okoli and Lenshie concluded.

In a publication by The Nigeria World Today (2017), they are of the opinion that, “Nigeria borders are vast with hundreds of footpath, overlapping to the adjoining countries of Chad, Cameroon and Niger, with links to Sudan, Mali and Libya”. They added that: ... there are more than 250 walkways from Maiduguri, Damaturu axis to Niger, Chad or Cameroon. Most of these paths are unknown to the security agencies and are neither manned nor guarded and they are being used frequently by criminals to sneak in instrument of death into the country”. Kidnappers and other criminals have their abodes within the country and can keep their victims until ransom are negotiated and paid

without the security agencies coming near them. As a matter of fact, many victims are still held hostage till today within the country. About 112 girls adopted from Chibok are yet to be released seven years after their kidnap. The case of Leah Shibu is still well with us and many other unaccounted victims all still held within a country with legitimate government.

There are vast expanses of rangelands and forests that are physically and functionally separated from the sphere of effective state control. These ungoverned spaces have often been occupied and utilized by criminals, insurgents and terrorists as operational strangleholds (Okoli & Ochim, 2016). Ungoverned territories can be failed or failing states; poorly controlled land or maritime borders or airspace; or areas within otherwise viable states where the central government's authority does not extend. It will be pertinent to note that, since the government has no control over these spaces, the criminals dwell there in peace to carry out all kinds of crimes including kidnapping almost unhindered. According to the US Department of Defense, an ungoverned space as an environment not effectively governed, under-governed or ill-governed by the state or central government as a result of conflict or violence or inadequate governance capacity. This clearly describes the situation in Nigeria and also explains why kidnappers have havens to keep their victims.

Rightly so, the lack of state presence also manifests in low adherence to the state laws. In such an environment, illegal activities such as unlawful exploration of natural resources and smuggling could attract little or no attention by the state security agency to apprehend the perpetrators. This again explains why many criminal activities go unnoticed by the state. Thus, it will be right to say that Nigeria is inundated with

ungoverned spaces across the country because these criminals thrive in almost every part of the country in recent times. Ungoverned spaces are mainly the remotest peripheral areas bordered by different countries with little or no state presence. It is believed that the more secluded they are the more they are vulnerable to extremism, radicalization, kidnapping and other crimes (Ali, 2017).

Hence, declaring a space ungoverned is actually a normative judgment on the type of governance, or the way in which a space is governed. Again, it is clear that, in Nigeria, there is a strong connection between ungoverned spaces and insecurity. It was rightly stated that ungoverned spaces are areas where the state institutions cannot exercise their full authority (Olaniyan & Akinyele, 2016). A classic case of ungoverned space is the Sambisa Forest that served as a sanctuary for the Boko Haram terrorist group and their kidnapping activities for ransom. The size of the forest report said can be compared to the geographical landscape of Lagos state in South Western Nigeria or the geographical size of Belgium (Okoli, 2017). The forest gained its global recognition when the Boko Haram abducted the Chibok Schoolgirls, who were later taken to the forest. Sambisa forest provides a safe haven for the Boko Haram for their operational, logistical, technical and organizational base and destination for the insurgents' prisoners of war who are sometimes kept for negotiation with the state for ransom.

Within the Niger Delta also, criminal elements have capitalised on this problem by attacking communities. Classic example of such incidents was reported in November 2019 when sea pirates raided Opurudiegbene community in Burutu, carting away generators, household appliances and an unspecified amount of cash. Three children were kidnapped following the attack, and there is no record of them being rescued. Kidnap

syndicates who operate out of the North also rely on big forests as their staging areas. Again Rigasa and Birnin Gwari are areas in Kaduna with large forests that have been used as hideouts of kidnappers. Recently, the Ondo state governor asked the Fulani herdsmen out of their forest due to increased cases of kidnapping and banditry. Such spaces are littered across the country and government needs to be more deliberate in their attempt to govern the ungoverned spaces in the country again.

4.6 Failure of state security architecture

Several times, on the floor of the Nigeria senate, the senate committee chairman on army, Senator Ali Ndume had lamented how the Nigeria army and other security agencies are ill equipped to deal with the wave of crime in the country. They have made several comments to suggest that the security architecture of the Nigerian state have failed. How poorly funded the army is and how insurgents for instance are better armed. This paints a picture of a failed security system. A situation where bandits now walk into a school and carry over 300 students from their hustles in Katsina State unchallenged and many other similar incidents suggest that the security architecture of the nation have failed. The Nigerian Police, the Military and other paramilitary organizations are not given equipment that would help them fight crime totally.

As argued by Thom-Otuya (2010), that in most of the kidnaps carried out by the militant, their victims are always ferried to the creek for custody. The author added that the Nigerian Navy does not have enough functional equipment to monitor and secure the porous water ways. Others also suggested easy access to hard drugs, proliferation of arms and military gadgets to be the major drivers of kidnapping for ransom in Nigeria (Nnamani, 2015; Chidi, Rose & Uche, 2015) which is a clear sign of security failure.

where agencies responsible for checking those crimes have failed and the crime go on without control. The National Drug Law Enforcement Agency (NDLEA) have in the past failed to stop the youth free access to hard and prohibited drugs and substances, so young people abuse these drugs and substance and at the end take to crime. To the end, Nnamani stated that there is strong connection between easy access to hard drugs and prevalence of kidnap for ransom. The claim is based on the fact that, the way the kidnapers operate is so brutal that it can only be committed by those under the influence of hard drugs and substance. The crimes have no human face.

So many arms including specialized weapons meant for the security agencies have found their way to the hands of unemployed Nigerians which alone is a motivation to go into criminality. Even herders now go about with AK47 freely which cannot happen in a country where her security architecture is still working. Similarly, Inyang (2009) on his part attributed the prevalence of kidnapping to the proliferation of arms in the country coming from failure to secure the country's borders. Nigeria is said to account for about 70% of illegal small arms in West Africa (Eribake, 2016), most of which come into the country through its porous borders. While other researchers are of the opinion that the fall of the former Libyan leader, Muammar Gaddafi contributed to the illicit movement of arms from that country to Nigeria which are in turn used by unscrupulous youth to extort ransom from the well placed individuals and their relatives in the country, if we have well equipped functional security system and the immigration mount our borders, those arms would have been stopped.

Categorically, Arinze (2013) said Nigerians believe that the state institutions and agencies are failing in their roles. The reason for this is that of selfish purposes. It is sad

that after 52 years and more of independence, the Nigerian State cannot protect the lives and property of the citizens of the country. Nigerians are asking themselves the question of how long it will take the different levels of government to put into place corrective actions to eradicate the problems associated with lawlessness. They have no confidence in the government anymore. One has observed the proliferation of AK47 rifles, submachine guns and other sophisticated weapons in the country due to the people's readiness for self defence is the reason for the surge in kidnapping for ransom in the country. Therefore, Nigerians can only wait for the security agencies to raise to the challenges and perform their statutory responsibilities in order to secure the nation going forward.

4.7 Kidnapping for ransom as a threat to Nigeria national security.

There is no gain saying that what Nigeria is going through currently in regards to kidnaping for ransom is a clear threat to our national security. According to a blog post by John Campbell on May 29, 2020 from Africa in Transition, Africa Program, and Nigeria on the Brink: "Kidnapping in Nigeria: A Growth Industry" Campbell reported that "When talking to Nigerians about insecurity, especially those that live in the Lagos-Ibadan corridor, Abuja, and Port Harcourt, some of the most developed parts of the country, the first thing they often raise is their fear of kidnapping specifically and crime more generally. For them, kidnapping is far more immediate than the carnage of Boko Haram, far away in the northeast, or the carnage in the middle belt over land and water use between "farmers" and "herders". He also stated that, in the past, kidnapping victims tended to be the wealthy and the prominent, and so kidnapers had every interest in keeping their victims alive to

extract the maximum ransom possible. If the above situation should not be described as a threat to national security, then what could the situation be?

Ayuba (2020) in a study noted that, in Nigeria, kidnapping was seen as a unique strategy adopted by the militants in the Niger Delta to vent their grievances against foreign nationals on the infrastructural decay in the region. However, today kidnapping has become ubiquitous in the country. This is evident in the series of kidnapping incidents that involved both high-net-worth and even the downtrodden personalities across various divides in the country. The magnitude of its occurrence is such that, hardly a day passes without a reported kidnapping incident, yet, the unreported cases are likely higher. More terrifying is the frequency of its occurrence in northern Nigeria, a region that is already suffering from numerous social ills and economic quandary. In another report from SB Morgen in 2020, a Nigerian consulting firm, using data gathered from a variety of open sources, including the Council on Foreign Relations' Nigeria Security Tracker, shows that, over time, the pool of potential victims has greatly expanded.

Their report added that, now victims are often poor villagers, sometimes kidnapped indiscriminately, a departure from the targeted kidnapping of wealthy people. They struggle to pay ransoms quickly because of their relative poverty, and victims are much more likely to be killed. The report also presents a valuable attempt to quantify the costs of kidnapping and to map its spread. Between 2011 and 2020, it concludes that over \$18 million had been paid in ransom. The amount of ransom accelerated in the latter portion of that period: between 2016 and 2020, around \$11 million was paid out. It shows that kidnapping has spread from the oil patch to the

entire country and that the army is now stationed in almost every Nigerian state, essentially to keep order. This is even a more serious reason for it to be described as a threat to national security. Today in many parts of the country, kidnapping appears to have become a business, especially for otherwise unemployed youth. SB Morgen expresses concern that kidnapping will increase as Nigeria falls into recession driven by the coronavirus and the fall in oil prices, putting more people out of work.

Painting the new narrative of kidnapping for ransom as at 2020, Ayuba presented a frightening account thus:

“the recent upsurge in kidnappings in northern Nigeria tends to change the narrative as it has taken a horrendous dimension thus attracting attentions of both local and international communities. Since 2009 when the activities of Boko Haram began to intensify in the north eastern Nigeria, unprecedented and hitherto unknown criminal activities in the region such as the kidnappings and abduction of minors began to rear their ugly heads. Thus, by 2014 large scale kidnappings ensued, particularly the abduction of secondary school girls in Chibok, Borno State, Nigeria which attracted global attention. This incident marked the beginning of notorious kidnappings in northern Nigeria, and since then several other kidnapping cases such as the abductions of the former Comptroller-General of the Nigeria Customs Service and the current District head of Daura, Katsina state, the president’s home town, Alhaji Musa Uba, and the father of the Nigerian national team’s captain, John Obi Mikel in 2018 to mention but a few, have been making the headlines” (Ayuba, 2020).

Similarly, a report by the United Nations Children Education Fund (UNICEF, 2018) from 2013 to 2018 more than 1,000 children had been abducted by the armed terrorists in the north east Nigeria including the widely publicised abductions of 276 Chibok girls and 113 from Dapchi Borno and Yobe states respectively. Yet, this figure represents only a fraction of the incidents of kidnappings in the region as many cases go unreported due to the volatility of the crisis in the region and the poor media coverage.

Today, the north western Nigeria has particularly overtaken other regions of the country in terms of the scourge of kidnap for ransom. However, the account of Ayuba in 2020 cannot in anyway be compared to what had happened in the first quarter of 2021. A lot more had happened recently and is still happening that calls for questioning of our national security architecture and seeming threat to national security.

During the first quarter of 2020, the then Acting Inspector General of Police revealed that, 79.8% of the national total of kidnappings was recorded in the three northern geopolitical zones, with the North West being the hotspot, where 365 people were kidnapped in the first quarter of the year (Toromade, 2019). Just like their counterparts in the Niger Delta who attacked expatriates and locals working in the multinational corporations in the region, the kidnapers in the north western Nigeria have made it habitual to abduct not only minors and high-net-worth personalities but also the poor citizens, an act that has plunged the entire region into a state of fear and uncertainty for both the rich and poor residents in the region, Toromade added. Admitting the current situation as a threat to national security, Okoli and Agada, (2014); Imhonopi and Urim, (2016); Ihe, (2018); Samuel, (2019); Ibrahim and Ahmad, (2020) all agreed that, the incessant incidences of kidnapping have incurred immense threat to the government, the security agencies, and all related stakeholders in the country.

The national economy is challenged; investors are scared, foreigners fear for their lives, citizen take their investment to safer places and the country is sliding gradually into the hands of criminals running a lawless situation. The country needs to negotiate her way back to normalcy and address this threat to our collective existence as a people. To

TABLE 1
Diary of kidnapping for ransom in Nigerian between 2011 to 2020 with date, victim, state, and amount paid as ransom in Naira and Dollar value

DATE	VICTIM	STATE	AMOUNT (N)	DOLLAR VALUE (\$)
November 2011	Ernest Ohunyon	Edo	85,000,000	545,088.43
2012	Tom	Edo	100,000,000	635,001.27
June 2012	Mbarikatta William Uboma	Lagos	20,000,000	122,642.58
August 2012	Leo Abraham	Lagos	15,000,000	94,848.46
August 2012	Paul Cole	Lagos	20,000,000	126,464.62
August 2012	Mohammed Jammal	Lagos	17,000,000	107,494.93
September 2012	Kingsley Nwokenta	Lagos	15,000,000	95,010.37
October 2012	Anthony Ozoanidobi	Lagos	15,000,000	95,298.00
November 2012	Uyi Oloton	Edo	100,000,000	633,224.00
December 2012	Nkiru Sylvanus	Imo	8,000,000	51,232.79
2013	Dan Odiete	Edo	100,000,000	624,348.34
April 2014	Rapheal and Michael	Lagos	2,000,000	12,414.65
July 2014	Edith Chinedu	Kogi	5,000,000	11,500.00
December 2014	Popoola Morenikeji	Lagos		27,322.40
2015	Raymond Okoye	Lagos		1,000,000.00
2015	Uche Okoroafor	Lagos		1,000,000.00
May 2015	Mrs Adebisi Orekoya	Lagos	2,500,000	12,553.79
June 2015	Hawwau Amarea	Kebbi	10,000,000	50,222.99
July 2015	Martha Nestor Binabo	Bayelsa	8,200,000	41,165.49
July 2015	Friday Ozogo	Rivers	50,0000	2,510.09
August 2015	3 DPR Staff	Bayelsa	10,000,000	50,188.21
November 2015	Elias Ukachukwu	Lagos		2,000,000.00
December 2015	Macquain Obi	Delta	2,000,000	10,022.05
2016	James Uduji	Lagos		1,200,000.00
January 2016	Cosmas Ojukwu	Lagos		1,000,000.00
February 2016	Victor Ogadinma	Imo	1,000,000	5,044.98
March 2016	Prince Onovirighose	Delta	1,000,000	5,022.60
April 2016	Frank Umeh	Lagos	190,000,000	954,194.16
April 2016	Cosmas Ojukwu Anayo	Lagos		1,000,000.00
May 2016	Rufus Uzoma Allwell	Delta	2,000,000	10,152.18
May 2016	Sani Rebo	Oyo	3,000,000	15,228.27
July 2016	Francis Umeh			1,000,000.00

August 2016	Luis Ubah and Chika Ezenwa	Rivers	2,800,000	8,979.31
August 2016	Onyeka Ani and Pastor Okezie Akara	Rivers	750,000	2,405.17
September 2016	Margaret Emefiele	Edo	80,000,000	254,129.61
September 2016	Chief Tsegba	Benue	5,000,000	15,883.10
October 2016	Alhaji Oyebanji Wasiu and Alhaji Isiaka Owolabi	Lagos	22,000,000	70,422.76
November 2016	Goriola Oseni	Lagos	151,000,000	319,915.25
November 2016	Ekezie	Rivers	1,000,000	2,118.64
November 2016	Tabolayefa Ozagu	Rivers	840,000	1,779.66
December 2016	5 expatriate staff of Dangote	Ogun	5,600,000	18,619.68
December 2016	Hon. Adoyi Omale	Kogi	2,000,000	6,649.89
February 2017	Ejiofor	Enugu	2,000,000	6,597.68
February 2017	Mike Ejiofor	Kogi	15,000,000	49,482.58
February 2017	Donatus Dunu	Lagos	150,000,000	494825.77
March 2017	Unknown	Rivers	110,000,000	258,823.53
March 2017	Uchenna Emeblu	Enugu	400,000	941.18
April 2017	Olu Falae	Oyo	5,000,000	16,077.43
May 2017	Taiwo ahmed	Osun	10,000,000	32,268.06
May 2017	Mrs Odebala	Delta	5,000,000	16,134.03
May 2017	Donatus Duru	Lagos	150,000,000	484,020.86
June 2017	Garba Umar-Durbunde	Kaduna	10,000,000	320,58.37
July 2017	Dr. Udom	Akwa Ibom	5,000,000	15,860.43
July 2017	6 pupils	Lagos	31,000,000	98,334.66
July 2017	Esther Okwe	Niger	500,000	1,586.04
August 2017	Jamie Larcar and Mario Maglundo	Lagos	400,0000	10,921.20
October 2017	Andy Ehanire	Edo	61,000,000	168,044.08
November 2017	Usman Muhammadu	Ekiti	500,000	1,406.31
December 2017	Unknown	Abia	250,000	694.56
December 2017	Unknown	Abia	1,000,000	2,778.24
December 2017	Unknown	Abia	5,500,000	15,280.32

2017				
December 2017	Ubani Onyema	Rivers	10,000,000	27,782.41
December 2017	Alex Atama-Pepple	Rivers	9,500,000	26,393.29
February 2018	Nemi Adoki	Rivers	9,000,000	24,725.27
April 2018	Twins belonging to Dr. Lekan Balogun	Oyo	10,000,000	27,774.69
April 2018	Goodluck Umetor	Rivers	1,000,000	2,777.47
April 2018	Martin Onah	Niger	1,500,000	4,166.20
May 2018	Mr Onoakpoma Onose	Delta	500,000	1,389.46
June 2018	John Iheanacho	Rivers	6,000,000	16,598.89
July 2018	Michael Obi	Enugu	10,000,000	27,590.77
July 2018	John Adeyi	Benue	2,000,000	5,518.15
July 2018	Afdal Hadi	Niger	150,000	413.86
July 2018	Amos Akano	Imo	2,000,000	5,518.15
September 2018	Theo Mbakwe	Imo	600,000	1,655.05
October 2018	Maiwada Galadima	Kaduna	10,000,000	27,472.83
October 2018	Omosaye	Ondo	150,000	412.09
November 2018	Suleiman	Lagos	500000	1,373.62
November 2018	DSP Patrick Ewuru	Lagos	500,000	1,373.62
November 2018	Victor Adigboluja; Anthony Otegbola; Joseph Ediae; and Emmanuel Obadjere	Delta	10,000,000	27,472.41
December 2018	Taiwo Akinyemi	Ondo	500,000	1,375.52
December 2018	Bunmi Falodun	Ondo	10,000,000	27,510.32
December 2018	Justina Tanko	Rivers	5,000,000	13,755.16
January 2019	Hassana Bala and Hussau-na Bala	Zamfara	15,000,000	41,331.08
January 2019	Tochukwu Okeke	Enugu		2,000,000.00
January 2019	Abdullahi Biffo	Katsina	15,000,000	41,331.08
April 2019	Rasaki Musibau	Lagos	5,000,000	13,909.37
April 2019	3 Police officers	Abuja	1,400,000	3,894.62
April 2019	Rasaki Musibau and six others	Lagos	6,000,000	16,691.24
April 2019	Kyliuk Morris	Ogun	2,500,000	6,954.68

April 2019	Usman Mayo	Taraba	100,000,000	278,187.33
May 2019	Chizoba	Abia	500,000	1,400.56
May 2019	Alhaji Maijama	Taraba	8,000,000	22,408.96
May 2019	Abubakar Sani	Zamfara	2,500,000	7,002.80
May 2019	Hajiya Hauwa Yusu	Katsina	30,000,000	84,033.61
May 2019	Benedict Audu and 2 others	Abuja	7,000,000	19,607.84
May 2019	Rufus Oladele	Ekiti	5,000,000	14,005.60
May 2019	Olayinka Adegbehingbe	Osun	5,045,000	14,131.65
June 2019	Folake Hosanna	Oyo	2,000,000	6,521.03
June 2019	Felix Akinde	Ondo	500,000	1,630.26
July 2019	Chinese expatriate	Kebbi	9,000,000	25,352.11
July 2019	Ogere Siasia	Bayelsa	600,000	1,690.14
July 2019	Mohammad Mahmood Abubakar	Kaduna	5,000,000	14,084.51
August 2019	Maryam Bello, Fatima Jalingo and Umar Sagir	Delta	5,500,000	15,363.13
August 2019	Okoro	Oyo	3,000,000	8,379.89
September 2019	Jide Opadijo	Abuja	4,000,000	11,173.18
September 2019	Aishat Ardo	Oyo	1,000,000	15,000.00
September 2019	Shakiru Weti	Kaduna	250,000	2,793.30
September 2019	Esther Katung	Edo	7,500,000	698.32
September 2019	Chike Onyemenam	Adamawa	4,000,000	20,949.72
October 2019	Amina Umar	Adamawa	2,000,000	11,142.06
October 2019	Unnamed professor at Modibbo Adama University of Technology		20,000,000	5,571.03
October 2019	Eke	Bayelsa	4,400,000	55,710.31
October 2019	6 cattle herders	Adamawa	13,600,000	12,256.27
October 2019	6 pupils	Kaduna	10,000,000	37,883.01
October 2019	Patrick Kogbodi	Delta	20,000,000	27,855.15
November 2019	Abubakar Bashir	Adamawa	500,000	55,244.04
November 2019	Hamza Abubakar Mahuta	Kaduna	2,000,000	1,381.10
November 2019	Adamu Chinoko	Kaduna	5,000,000	5,524.40
November	Abdullahi Kabiru and	Kaduna	2,100,000	5,800.62

2019	Sanusi Dabai			
November 2019	Osondu Nwachukwu	Nasarawa	40,000	110.49
December 2019	Abdulmalik Musa	Ogun	300,000	819.40
December 2019	HRH Mohammed Ibrahim Pada	Abuja	6,500,000	17,753.74
December 2019	Abubakar Mohammed	Gombe	9,000,000	24,582.10
December 2019	Abdulmalik Musa	Ogun	300,000	819.40
December 2019	Aminu Jika	Taraba	20,000,000	54,626.90
January 2020	Bola Ataga	Kaduna	8,000,000	22,253.13
January 2020	Michael Nnadi	Kaduna	10,000,000	27,816.41
January 2020	Abdurrahman Muhammad Kawuyo	Adamawa	1,450,000	4,033.38
January 2020	5 persons	Taraba	1,600,000	4,450.63
January 2020	Taiwo Soniyi	Ogun	1,700,000	4,728.79
February 2020	Hassan Mohammed	Zamfara	5,000,000	13,812.15
February 2020	Motunrayo Rafiu	Ogun	1,000,000	2,762.43
March 2020	Okun Dada	Delta	1,700,000	4,670.33
March 2020	Ekundayo Ojo and Benja-min Iluyomade	Ondo	2,500,000	6,868.13

(Source: SB Report 2020)

give us a sense of history and the seriousness of the subject matter of this study, the researcher is presenting a chronicle of all reported kidnapping for ransom cases between 2011 to 2020 and the amount paid as ransom for each victim. The idea is to give us a view of how overwhelming the situation has become.

The researcher wishes to state that, there are several unreported cases of kidnapping for ransom that did not make it to this list or other forms of kidnapping for purposes other than ransom. The current study is focused on kidnapping for ransom and the research is selective in gathering sources relevant to the research focus.

CHAPTER FIVE

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

Chapter Five presents the analysis of data collected from the field. Both primary and secondary sources of data were used in this study. The primary data were elicited through In-depth interviews (IDI) and Key Informant Interviews (KII). The interviewees and the informants who were purposively drawn across the South East, South-South, North West and North East geo-political zones which currently serve as a major flash point of kidnapping for ransom in the country. The IDIs were conducted with few victims of kidnapping in these areas or their relatives who can talk from personal experience, the KII data were generated from security personnel who were directly involved in combating kidnapping in those zones. Due to the nature of the problem under study, only few victims were willing to grant interview on their ordeals due to their traumatic conditions and other security concerns, which inform the number of and sample ample size as adjusted. To reduce physical contact and strictly adhering to the Covid-19 protocol in data collection, most of the interviews were done via phone calls and only in very necessary situation that the research resolve to one-on-one with respondents. This procedure is crucial to protect both the researcher and respondents.

5.1 Data Presentation and analysis

Apart from secondary data, the primary data were elicited through twenty (20) In-depth interviews (IDI) and fifteen (15) Key Informant Interviews (KII) across the South East, South-South, North West and North East geo-political zones. The responses are presented in line with the study objectives alongside the foundations of findings from other studies. Although the nature of analysis is meta-data or content analysis which

answers directly research questions, it will be done in form of hypothesis-by-hypothesis analysis to give a proper understanding of the extent of the problem in each variable.

5.1.1 Hypothesis One

Ho1 Socio-economic factors does not significantly influence kidnapping for ransom and national security in Nigeria.

Hi1 Socio-economic factors significantly influences kidnapping for ransom and national security in Nigeria.

To test this hypothesis, the data on this objective and relevant statistics from reliable sources were gathered. Data on this variable suggests that, socio-economic factors have many dimensions but economic is central to them all. Data revealed that, particularly, kidnapping for ransom is perpetuated for the economic benefit of the crime. Many have taken to the crime as a means of earning a living for themselves. The general empirical study as presented below revealed that, kidnapping for ransom from experts opinion is for economic gains and other reason may be minor and in very few cases. Similar earlier studies such as Bello and Jamilu (2017) reported a significance influence of socio-economic factors on the raise in kidnapping for ransom when they noted that, “the tactic has proven so lucrative that a number of criminal groups appear to have taken on the task in order to simply make money”.

SB Morgen, (2020) reported same in agreement that, the selection of victims is targeted and the kidnappers see it more as a business transaction, trying hard to extract money from their criminal activities. This means that the socio-economic factors have significantly influenced the unending kidnap cases across the country. More specifically, Hino (2005) agreed that, in Nigeria most indicators of social and economic progress,

including real per capital consumption, literacy, access to clean water and income distribution, show that poverty has worsened since 1960, and in quest for the people to end a living, they have taken to all forms of crime and the reason why kidnapping for ransom is high. Thom-Otuya, (2010); Inyang (2009) and Ogbuehi, (2018) all attribute the upsurge of kidnappings in Nigeria to endemic poverty in the country which is central in discussing socio-economic factors.

A Voice of America report in 2020 again reiterated that, “one reason why kidnap for ransom has come to stay is the economics surrounding it. Kidnappers demand between \$1 000 to \$150 000 as ransom depending on the financial status of the victims. That is kidnapping for ransom has become a big industry in Nigeria. Exploring the significance of socio-economic factors on kidnapping for ransom and national security, Emanemua and Akinlosotu (2016) reported that, “Kidnapping has recently become a profitable venture among youths in Nigeria. Confirming the socio-economic significance on the rate of kidnapping and national security, one of the interviewee who was a kidnap victim and a clergy in Owerri Imo state have this to say:

With the rate of poverty in the land, what do you expect, throughout my stay in that push with them, all they were after was, call this, call that, do this or do that for them to bring the money. Each time they approach you, is to remind you of the urgency of why you should make effort and contacts that will bring the ransom quickly. They threaten to kill you if the said amount is delayed or not paid. I was in perpetual fear of what is next, but all they were after was the money. People in Owerri here believe in living big, young men show off their big cars and live as if they own the world and even parents dare not ask. So the reason why the crime of kidnapping is still going up is because more and more young people want the quick money. The easier way now is catch one person, keep him/her and call the family and friends to

bring ransom. This is a terrible situation and for me who has gone through it, I do not wish it for anyone (IDI_IMO_VICTIM_2021).

The respondent completely agreed that, the reason why people kidnap is the ransom involved. Another respondent, this time a security personnel said:

While we may consider other factors surrounding kidnapping for ransom which has since become the most coordinated crime in recent time, what is central in all the cases we have encountered is the large economy the crime has created. The successes of the criminals in the past in collecting huge ransoms from their victims have reinforced the crime. Many went into it for the money and it can be seen in the confessions obtained from some of the culprits we have apprehended. They are ready to keep their victims as long as possible if the ransom is not forthcoming.

Some had confessed going into the crime because they are unemployed and wants to end a living. That is to tell you how young people are now frustrated. They now see kidnapping as an alternative source of living. This may sound unbelievable but that is what we hear every single day from culprits. Even among case here in the north where the crime is clothed in religion, victims are used to negotiate for huge sum of money.

The activities of kidnapping and that of Boko Haram is gradually blending here in the north so much so that one now hardly distinguish the two. Boko Haram fighters will kidnap not just for their original course, but this time around for ransom. So it has become one big industry that is booming. This is actually making the fight difficult for us (KII_KADUNA_PERSONNEL_2021).

That again is in agreement with what the first respondent stated. Confirming the same trajectory of kidnapping for socio-economic reason, a relative of a kidnap victim in Akwa-Ibom State said:

Hmmmmm, the trauma was too much for us, there are so many things I will not personally want to remember in my life time. When you see your loved one being taken away in a commando style with gun shots in the air as in a war situation. We were not communicated after three days, the first call that came was to me, I heard the voice of someone I never knew, and the instruction was, "pay the sum of 30, million naira as soon as you can or forget about him, in case you want to confirm if he is here, they told my son to speak to me, he greeted me in faint voice and said mommy please try".

So the reason why all this crimes are happening is for money, they want to live like their counterparts who have made, not minding the cost, they want a good life by all means. I cannot forget, my wife and I do not have sleep, every call you receive is a reminder of what the state of things are. No matter the amount of plea and begging and cries from my wife each time they called, their demand move gradually to about 10, million, there was nothing my family could do, security agencies couldn't rescue him, friends and well-wishers rallied around and raised that money to pay.

The economic benefit from this crime is really what is encouraging others to go into it. The other people doing it are succeeding and so more will want to join. We agree that there is poverty in the land but greed and lust is pushing the young ones into kidnapping more (IDI_AKWA_IBOM_RELATIVE_2021).

This again is corroborating the other respondents' positions. To add to the narrative, a relative of one of the victims of kidnapping has this to say:

The problem with what is happening here is that, you cannot clearly understand the intentions anymore, when Boko Haram started, it was not for money making, they were not kidnapping but the recruit young people to join them sometimes using force. But as at now, their strategies now include kidnapping and collection of ransom. It may

not have been their intentions initially, but seeing the potential of money they can make from it, it was adopted as additional strategy. It began with Chibok, but now the list is endless. They have demanded huge ransom at each case and so you can see clearly that, their change of tactics to kidnapping is majorly for making money. The socio-economic gains are what they are after particularly with kidnapping and not their religious agenda.

You can imagine that, they now kill their victims if ransom is not paid on time. See what is happening, demanding for 800, million as ransom is unimaginable for me, where does the school get that kind of money? So one cannot help but conclude that, socio-economic factor is now the major driver or motivation behind kidnapping if you ask me. I don't want to tell my own story of what happened but it was a terrible experience (IDI_BORNO_RELATIVE_2010).

Thus, from literature and the major in-depth and key informant interviews capture here, the researcher concludes that, socio-economic factors significantly influenced kidnapping for ransom and threat to national security in Nigeria.

5.1.2 Hypothesis two

Ho2 Failure of state security architecture does not significantly influences kidnapping for ransom and national security in Nigeria.

Hi2 Failure of state security architecture significantly influences kidnapping for ransom and national security in Nigeria.

This hypothesis was tested using the already existing data on this variable and the primary sources gathered during the field work using in-depth and key informant interviews. Both the secondary and primary data will be presented alongside each other.

Opening discussion on this variable, a security personnel had this to say:

Events in recent times would have suggested exactly what you are saying. In fact that is what everyone is saying, that we have failed as security agencies. But have we actually failed? If you are talking to me as a private citizen, I will say yes, the security architecture of the state has grossly failed the people. Because how better can you explain the failure in security architecture? We have consistently failed to secure the lives and properties of the ordinary man on the street which is our primary role. Sleeping with your eyes close have become a luxury for people around Maiduguri where we are here, talk more of those in the far parts next door to Sambisa which is their stronghold.

So it is easier for an ordinary man on the street to conclude that the security has failed. That is what is making it possible for kidnappers and insurgents to take and adopt people in their numbers. Because if we were to be doing everything right, this won't happen or at worst, there will be great resistance. So talking like any other Nigerian, the security architecture has failed.

But as a personnel in the frontline, with what we are going through on daily bases, that we are not able to withstand these people most of the time is because our political leaders have paid lip service to security for too long. The things we are doing as personnel here in this place, if our leaders were to be serious with security, this problems would have ended. You have seen and heard how many times we have to leave our line of duty to protest for our own welfare as officers here. Then talk of equipment and what we need to prosecute these criminals. How many are we here compare to the criminals? This kind of attitude will only worsen the security situation because they criminal become bold and bold by the day because they are better armed and equipped for their crimes than you are to fight them. So the security architecture did not just failed, our political leaders are not serious about security. But I agree that this failure however has significantly influenced the rate of kidnapping and

*other crimes particularly in parts of the Northern region.
(KII_BORNO_PERSONEL_2021)*

Thus, following the narrative of the officer given above, whether it is because our leaders have failed in their role to do what they are supposed to do concerning security or not, like he mentioned, “they have paid lip service to security for too long” what could be deduced is that, he admitted that the security architecture have grossly failed in his own words. Not minding who the blame is on, what is established here by the researcher from the interview is the fact that, the country’s security architecture is no longer up to its responsibilities. This is a terrible situation and Nigerians can only continue to pray that things changes. People are now kidnapped under the broad day light without challenge from the security agencies. Insurgents move into a school, carry children in their numbers, drive kilometers to their hiding places without any exchange of gunfire by the security. A victim of kidnap in Kaduna has this to say:

....when they stopped our vehicle, we thought they were security personnel, they ordered us to come down, not in haste, we came down one after the other until the last person and they ordered us to march into the bush with one of them leading us in front with others carrying their guns and following us behind. We walked miles into forest and no chase from any security agent. We learned the police came later on but no one followed or chased after them into the forest. We were camped at a trek able distance from the road, though a little far for the first two days before being moved when they observed air surveillance, but we remained hostage until the ransom they demanded was paid. Tell me, do we have security? Is there still security in this country? Anyone who is relying on what the security can do for him at this time concerning kidnapping and other crimes is taking a great risk. Just live as if there is no one to protect you and all you have is you and your God. They made claims of recuing

*us, but I tell you, our families paid ransom to free us. You can understand what I mean now? What can be worse than failure, call it that. Each time it happen, they will go on the media to condemn and tell the people how soon it will end, but does it look to you like it is ending soon? We are in for this and I can tell you for free, the entire security architecture has failed, no intelligence gathering of any form, the agencies lack coordination and so their collaboration for this fight remains a struggle. Mennn..... we have failed as a nation including the security. Nothing is working, it's not just the security architecture.
(IDI_KADUNA_VICTIM_2021)*

Given the experience shared by this victim, it is clear that the security architecture has failed and there is no doubt about it. Thus, failure in the security architecture of the state has significantly influence the trend of kidnapping for ransom in the country. If the agencies were alive to their responsibilities, things would have been better.

In another interview, a relative in Rivers State said:

Do we say they have failed or they are overwhelmed? See how many crimes they have to fight today as compared to the past. Even our military are no longer in the barracks; they are seen now securing the high ways and even streets now. So to say out rightly that the security architecture have failed, I will prefer to say they are stretched and overwhelmed by the multitude of crimes they have to contend with which is making them ineffective in the discharge of their duties. However, this ineffectiveness could be termed failure on their part and so I will agree the security architecture has failed.

You know why I say so? Because when it happened here, there were security check points not too far from here but on the day it happened, they were not there and no one saw the kidnappers until they took our brother away and kept him for days until the required ransom paid. We had expected that they will rescue him, but we waited in hope for

as long as it could be. He was never rescued but instead we paid the ransom. So this is the ineffectiveness I'm talking about which also could mean failure.(IDI_RIVERS_RELATIVE_2021).

From the above interview also, the researcher can deduce an obvious admittance of failure of the security architecture in protecting lives and property as significantly influencing kidnaping for ransom and national security.

5.1.3 Hypothesis three

Ho3 Ungoverned spaces does not significantly influence kidnaping for ransom and national security in Nigeria.

Hi3 Ungoverned spaces does not significantly influence kidnaping for ransom and national security in Nigeria.

Both primary and secondary data are presented alongside to analyze this variable and test the hypothesis. Available data suggest that, because of large expanse of land in the north, the government seems to have a lot of ungoverned spaces which are being used by criminals for various activities. For instance, the popular Sambisa which has become so known for the bad reason, Olaniyan (2018) states that, "the terrorists then set up various camps in the forest and made Camp Zairo (Zero) their headquarters. It was from the various camps that deadly plans of attack were made. These include: launching deadly raids on towns and villages for the purpose of killing and pillaging; abduction of women and children for rape, forced marriage, sex slavery, and suicide bombing missions; keeping kidnap victims for ransom or execution; building a factory to make materials for suicide attacks, as well as armories for looted weapons". It is obvious from here that, the government has no control over such areas. It was left ungoverned and criminals took it as a breeding ground. It is one factor aiding the crime of kidnaping.

Similar, the convener of the Bring Back Our Girls (BBOG) group, Oby Ezekwesili, said after her guided tour of the forest that, "the Sambisa forest is 18 times as large as Lagos State. Tweeting via her Twitter account, she spoke about the massive expanse of land the dreaded Boko Haram sect had been occupying for years. "Dreaded Sambisa is massive. 60 000 square kilometers. 18 times the size of Lagos State! All of Lagos is 3,345square km. #BBOG" Ezekwesili wrote". Thus, this massive expanse of land which are not under the full control of the government is under the control of criminals. It unfortunate that is has to be so but that is the situation we find ourselves. Still on Sambisa, a TV presenter has this to say: "at every mention of the Sambisa Forest being the hideout of Nigeria's Boko Haram and criminals, one can be forgiven for asking what then stops the military from simply smoking the insurgents out of their lair and end their reign of terror? But it's not that easy. Covering an area approximately 60,000 square kilometers in Nigeria's northeastern region, Sambisa is three times the size of Israel" he said.

Also, Niger State alone is more that the entire South East and South West states combined excluding Ekiti State analyzes said. It is the largest state in Nigeria in terms of land mass, occupying a space of 76,363 square kilometers. Because of its size, massive expanse of land and forest abounds for criminal activities and victims are taken to these forests for safe keeping pending when ransoms are paid. The security agencies dare not enter some areas, they are left ungoverned. This is not peculiar to only this two states, such situation can be visible all over the country which now serve as havens for criminals. At the South - South region, the water ways and difficult terrains in the forest are homes to militants who almost operate a government within a government. Thus,

ungoverned spaces significantly influences kidnapping for ransom and national security.

In a quick response, one of the security personnel interviewed said:

Tell me how on earth we are to go into these large areas and rescue these victims. Do you know that we drive hours down some areas without a single occupant? The place is too big to be secured, the thing with security is that, everyone expects you to do magic, but there is no magic in this. We too have blood in our veins, this people live there and make their homes. They seem to be in their territory in these places, so going into the bush there is like just running into their hands to kill. They often hide in trees and see you from distance that you cannot see, so before you reach them, they have attacked already. That is why you see our men suffer casualties some of the times. It is not easy with the massive ungoverned spaces in this area. We will continue to try but it is a difficult fight. (KII_NIGER_2021)

Again, this is a confirmation of what others have been saying in literature, that the ungoverned spaces significantly influences kidnapping for ransom and national security because it serve for them a haven. The null hypothesis is therefore rejected and alternate hypothesis retained.

5.1.4 Hypothesis four

Ho4 There is no significant influence of failure of governance on kidnapping for ransom and national security in Nigeria.

Hi4 There is a significant influence of failure of governance on kidnapping for ransom and national security in Nigeria.

The secondary and primary data gathered under this variable were also present side-by-side to test this hypothesis whether failure in governance have significantly influenced the spite of kidnapping for ransom and threat to national security in Nigeria.

In line with the hypothesis and when being asked, one of the respondents in the interview, a parent of a kidnap victim in Anambra State have this to say:

There is a complete collapse of governance, right from the federal, state and down to the local government, no single one is working and the people are dissatisfied. The people are tired and are no longer patient with this current government. Truth be told, I know as you said, you are talking about kidnapping, but let me tell you, if nothing is done quickly to change the trend of things, every other crime and not only kidnapping will consume Nigeria. The situation is terrible, the government has failed in every single thing they promised to do.

Look at security that was the propaganda that gave the current government victory, I call it propaganda because, if they ever have security blueprint for this country before coming to power, the situation will not be as bad as we have it now. In all the zones, North, South, East and West, nothing is working, nowhere is safe, not a single place, not even in our bed rooms. Here in Anambra, if you are a target, boys will walk into your bed room and pick you up to their den without any challenge. What a government? We have never had it this bad.

Let me be sincere with you, the failure of the local government system particularly which is the nearest to the people is responsible for more than 50% of the crimes we are experiencing today. Walk into the local government secretariats in Anambra here and you will realize they have been overgrown by weeds. No activity goes on there, the small projects they use to implement which most times have direct impact on the people are lost. That direct control the local governments have over the people in terms of crime control has been disconnected. The people feel alienated from government and that is the result of the agitations you having here and there.

What exactly is this government getting right? Look at the economy, we are now the world poverty headquarters, our per capita

income is at its lowest, our GDP is nothing to write home about, the unemployment figures are ragging, inflation has reached the highest in the history of this country, our misery index will make you cry. Nigeria is now the third most terrorist country in the world. The country is in a full blown war and all these are indices of a failed state with no apologies. Look at the country we are living, policies are made retrogressively and Nigeria has slid into recession more than three times in four years. I get too emotional when discussing Nigeria's problem. My brother the failure of governance is completely responsible for the kidnapping for ransom, killings, insurgency and anything you can talk of in this country. The youths are hungry, unemployed and angry, so by the mere fact that you are living well and they are not makes you a target, but this is not supposed to be the case. This government has failed to say the least. I don't want to talk about our south east governor because they are the bigger problem, but government is government whether federal or state. (IDI_ANAMBRA_RELATIVE_2021)

Going through the emotional narrative of respondents, a senior civil servant, the researcher could deduce colossal failure of governance described and the respondent continuously made reference to the failure as being responsible for the rate of kidnapping and other criminalities in the country. The lamentations are evidence of failure in governance and the direct linkage of this failure to crimes and particularly kidnapping for ransom is a clear significance. Another security personnel in Cross River State said:

A quick example of this failure I want to give you is the case of #ENDSARS. It all started like a fight against police brutality in the country, but soon after it started, the agitations went beyond #ENDSARS and good governance became more the issue on the front burner than the initial #ENDSARS. Now I will tell you as a security personnel, things got worse because of the way the government of the day handled it.

The issue of the hidden palliatives discovered across the country made things worst. The looting and destruction started when the people became very angry with government. We agree it was a criminal act, but by the way the target of the looting was coordinated, you can see a people angry with government and politicians for failing them. So failure of governance is at the heart of most crimes today.

The government has failed to provide jobs for the people, they are idle and anything that comes their way is good enough to earn a living not minding the legitimacy. Out of school children in the north is giving a great harvest to the armies of insurgents as they are easily recruited as Boko Haram fighters or can easily take to crime. No social infrastructure in rural communities, every young person is moving to the city to have a good life whether he/she has what to do there or not. Some of these people come into the city, get frustrated and take to crime, so the government has failed in so many fronts honestly and that failure is what you see being expressed in the increased crime rate. Our state here is not spared either, we are having our own share of the crime wave. You heard that they have kidnapped the NLC chairman of the state again for the second time and many others we are fighting. It is really a difficulty time for us as officers and men of the Nigerian Police. (KII_CROSSRIVER_PERSONNEL_2021)

The story is similar to the one painted earlier as a clear admittance of government failure being responsible for the many crimes in the country including kidnapping for ransom. Given the example of the #ENDSARS, the researcher can independently confirm from various analysts that good governance became the major agitation and not only an end to policy brutality. To this, the null hypothesis is then rejected and the alternated hypothesis retained that, failure in governance significantly influences kidnapping for ransom in Nigeria and a threat to national security.

5.1.5 Hypothesis five

Ho5 There is no significant influence of value system/corruption on kidnapping for ransom and national security in Nigeria.

Ho5 There is a significant influence of value system/corruption on kidnapping for ransom and national security in Nigeria.

The variable of value system and corruption is taken together as one, thus the data gathered on them will be treated as one. Both the primary and secondary data will be presented side-by-side. Talking about value system, Inyang (2009) opined that, in Nigeria society, some people just emerge rich anyhow without anybody asking question how such individuals got their money. Everybody is a businessman; nobody questions the nature of the business or how some people acquire their wealth. That it is easy in Nigeria to see a poor young college dropout today build a 'Ten Storey-Building' without the government or private citizens questioning how such a youth made that kind of money. And because of this mentality of being like them, a lot of youths would take to crime. The new orientation is "get rich or die trying" therefore people do anything to get rich which was not the case in the past. So many values that was important to this country has been lost. The value of integrity, honesty, hard work, respect for elders, and dignity of labour and so on is seen as "old school" to the youths today. This has made it very easy for most of them to take to crime without thinking twice. Once the money comes, they are in for anything. In an interview, a parent in Abia has this to say:

If I must ask, what is our national value system as at today being a Nigerian? Do we still have and agency in charge of national orientation as it was in the past? Are the children taught about the significance of our national anthem, pledge, symbols and those things that unit us as a

people? Who cares today about hard work, when they hear and see politicians steal billions and launder it around, young men who are into crimes are peddling their wealth around for everyone to see. These things have changed the way young persons' think. We were taught, but who is teaching them today? The national orientation agency is only heard of but never seen doing anything.

Our community taught us the value of hard work; criminals were never celebrated as it is done today. Check the people receiving titles and awards, check who they are, check their character, you will understand what am saying. So our children want to be like them, they want to emulate them and live big life. I and you know that it comes with a cost. All these things are pushing them day by day into kidnapping, armed robbery, banditry, and the rest of it; this is just to make it. Hard word is now seen as being lazy and taking the old way. That is where we are. See the rate of corruption, in all facet of the society, people are stealing without fear. These things fuel crime (IDI_ABIA_RELATIVES_2021).

This is a proof that, there is a breakdown of value system in Nigeria now compared to the past. The respondent lamented the role of the National Orientation Agency which is an agency responsible for the inculcation of morals and values. This is not seen in the society today. Even criminals are forgiven and openly celebrated afterwards. All of these things may have culminated into the high rate of kidnapping and other crime wave in the country. Another respondent from Maiduguri had this to say in Hausa with the help of an interpreter:

Before you talk about the national values, how about our individual family values? Things have changed, before children were taught properly from the home, but today, how many of those children even have a home to sleep before talking about giving them home training. So you see, no child that is given the good Islamic values will go into crime, but because we have failed to give them these good moral values

from the home, they learn anywhere from peers and other extremist and they are easily lured to join Boko Haram and any of these group.

No parent in Islam which is a religion of peace will teach a child to commit crime, but you see, because we have failed first of all as parents to have the number of children we can control and train in a good Islamic way, they go outside and are taught by others. We have lost the family values and we are losing the Islamic values gradually to extremist teachings. For me, have must first get our individual family values right in line with what Islam teaches and be good Muslims (IDI_BORNO_RELATIVE_2021).

It can be inferred from what the respondent expressed above that, something is wrong with our value system. Our value system is not right at a moment and that may have significantly contributed to the rate of crime in the society today. Finally, in another interview, another personnel added in this way:

What is important to these boys today is not the same with the past, this Twitter generation whose priority is to be like one celebrity or the other, the follow them on Twitter and other social media platforms, they can tell you the number of shoes Davido has, but cannot tell you what happened in the news yesterday. They can analyze and tell the number of cars they have and what each of those cars is worth. When you meet them, their focus is completely different. They do not understand the difference between living a real life and a life of a celebrity, so they do anything they can to be like them.

When they gather, they talk about European football stories and argue their fan based preference. Look at the issue of Hush Puppi, check his fan base before that incident when he was exposed, how about Evans and many others, a lot of young people see them as a model and would copy anything they do without knowing how they are making it in life. That is the value system we have today, they do not give in to the real traditional virtues that we were taught.

Before if I come back home from school with a pencil that is not mine, I will not keep it in that house till the next morning, my parents would have me returned it before I can even eat. But today children come home or return from school for holidays with Iphones, and gadgets worth more than what their parents can afford and the parents will unfortunately celebrate them, we have lost it. What about some parents who begin to compare their children and make reference to the achievements of their mates around? All of these things have an effect on crime and criminality, particularly kidnapping for ransom which is seen as the easier way to get quick money.

The family have a lot to do honestly, also the National Orientation Agency has to wake up to its responsibilities, we need to go back and start teaching our children civic education, good morals and do a thorough value re-orientation. There is corruption in every sector beginning from the civil service to the politician, none is spared, there is deep corruption in our DNA. (IDI_CROSSRIVER_PERSONNEL_2021)

Therefore, from the last respondent and all other data gathered on this variable, the researcher found that, value system/corruption significantly influences kidnapping for ransom and threat to national security. Thus, the null hypothesis in this case was also rejected and the alternate hypothesis retained.

5.3 Discussion of findings

5.3.1 Socio-economic factors, kidnapping for ransom and national security in Nigeria

Findings on this variables from the researcher gathering from literature and the major in-depth and key informant interviews reveals that, socio-economic factors significantly influenced kidnapping for ransom and threat to national security in Nigeria. This was in line with majority of the literature and it was unanimous among respondents from the first to the last. Respondents in the interviews at some point became emotional

about their feelings concerning kidnapping and the general insecurity in the country. This is what seems to be in the lips of everyone in recent times which goes to strengthen the findings from literature.

The finding is in line with what SB Morgen (2020) reported in agreement that, the selection of victims is targeted and the kidnappers see it more as a business transaction, trying hard to extract money from their criminal activities. This means that the socio-economic factors have significantly influenced the unending kidnap cases across the country. More specifically, Hino (2005) agreed that, in Nigeria most indicators of social and economic progress, including real per capital consumption, literacy, access to clean water and income distribution, show that poverty has worsened since 1960, and in quest for the people to end a living, they have taken to all forms of crime and the reason why kidnapping for ransom is high. Thom-Otuya, (2010); Inyang (2009) and Ogbuehi, (2018) all attribute the upsurge of kidnappings in Nigeria to endemic poverty in the country which is central in discussing socio-economic factors.

A Voice of America report in 2020 again reiterated that, “one reason why kidnap for ransom has come to stay is the economics surrounding it. That kidnappers’ demand between \$1 000 to \$150 000 as ransom, depending on the financial status of the victims. That is kidnapping for ransom has become a big industry in Nigeria. Exploring the significance of socio-economic factors on kidnapping for ransom and national security, Emanemua and Akinlosotu (2016) reported that, “Kidnapping has recently become a profitable venture among youths in Nigeria. The researcher also got similar confirmations from oral evidence in general discussion with members of the public. The pulse of the

people is that, those who go into kidnapping do so for the socio-economic benefits but the crime is being enabled by other factors.

5.3.2 Failure of state security architecture, influences kidnapping for ransom and national security in Nigeria.

Findings on the variable here revealed that, failure of state security architecture significantly influenced kidnapping for ransom and threat to national security in Nigeria. The researcher can imply from all the interviews conducted on this sub-variable an apparent admittance of failure of the state security architecture in protecting lives and property leading to increase in kidnaping for ransom and threat to national security. Not minding whose fault it may be, whether it is because our leaders have failed in their role to do what they are supposed to do concerning security or not, like one of the respondent mentioned, "they have paid lip service to security for too long" what could be deduced is that, the security architecture have grossly failed in his own words. *"But I agree that this failure however have significantly influenced the rate of kidnapping and other crimes particularly in parts of the Northern region"* a respondent said. During the course of this study, the researcher encountered many security agents who spoke in confidence of the failure of the security system. That the current security arrangement cannot meet up with the new wave of crimes.

The finding is corroborating the earlier positions of Thom-Otuya (2010) that in most of the kidnaps carried out by the militant, their victims are always ferried to the creek for custody. He added that the Nigerian Navy does not have enough functional equipment to monitor and secure the porous water ways giving the criminals upper hands in their activities. Also Nnamani (2015); Chidi, Rose and Uche, (2015) advanced in

agreement another security failure in terms of drug control, they suggested easy access to hard drugs, proliferation of arms and military gadgets to be the major drivers of kidnapping for ransom in Nigeria which is a clear sign of security failure, where agencies responsible for checking those crimes have failed and the crime go on without control.

In the same vein, Inyang (2009) corroborated on his part that, the prevalence of kidnapping is as a result of the proliferation of arms in the country coming from failure to secure the country's borders. Nigeria is said to account for about 70% of illegal small arms in West Africa, Eribake (2016), supported. They said most of them come into the country through its porous borders not mounted by those responsible. The list is endless but it could be clearly implied from the study that, majority of respondents and literature both agreed that the state security architecture has failed and this has contributed greatly to the up surge of kidnapping for ransom in the control and other crimes.

5.5.3 Ungoverned spaces, kidnapping for ransom and national security in Nigeria

The researcher founds from literature and interviews conducted that, ungoverned spaces in the country significantly influence the rate of kidnapping for ransom and threaten national security. The findings implies that, the lack of government control of large expanse of lands across the country significantly influences activities of kidnapping because those spaces are used as havens for kidnappers and for hiding their victims and safe keeping during the period of negotiating for ransom. This is in line with Olaniyan (2018) who stated that, "the terrorists then set up various camps in the forest and made Camp Zairo (Zero) their headquarters. It was from the various camps that deadly plans of attack were made. These include: launching deadly raids on towns and villages for the purpose of killing and pillaging; abduction of women and children for rape, forced

marriage, sex slavery, and suicide bombing missions; keeping kidnap victims for ransom or execution; building a factory to make materials for suicide attacks, as well as armories for looted weapons". That means this ungoverned space aid the activity of criminals.

This was also corroborated by Okoli and Lenshie (2018) when they found that Nigeria is a territorially challenged and fragile state. That it is characterized by "virtual territorial ungovernability". They stated that, this existential syndrome is evident in the near absence of governmental presence and control within critical domains of the country's wider territorial sphere. They again stressed that, Nigeria's territorial ungovernability is thus instantiated by the huge governance deficits in the country's physical and maritime boundaries, cyberspace, forest areas, as well as mainland, airways and waterways. Finally, Okoli and Ochim, (2016) corroborated perfectly that, there are vast expanses of rangelands and forests that are physically and functionally separated from the sphere of effective state control. These ungoverned spaces have often been occupied and utilized by criminals, insurgents and terrorists as operational strangleholds. The researcher found from oral evidence various names given to certain places that criminals have taken hold and even security agencies cannot dare step in, just like the "Camp Zero" in Sambisa, a respondent revealed that, there is a "Camp of no Return" in Bakassi area of Cross River, some have been designated artificial evil forest and so on.

5.3.4 Failure of governance, kidnapping for ransom and national security in Nigeria

The researcher again found that, the failure of governance is at the center of kidnapping and threat to national security in Nigeria. Failure of governance significantly influences the wave of kidnapping for ransom in the country. From literature and interviews, what remains loud in the mouth of all respondents is their gross

dissatisfaction with government and general conclusion that the government have failed. A respondent have this to say as earlier presented in transcript *“there is a complete collapse of governance, right from the federal, state and down to the local government, no single one is working and the people are dissatisfied. The people are tired and are no longer patient with this current government. Truth be told, I know as you said, you are talking about kidnapping, but let me tell you, if nothing is done quickly to change the trend of things, every other crime and not only kidnapping will consume Nigeria. The situation is terrible, the government has failed in every single thing they promised to do”*.

The lamentation was endless when they all attributed all manners of crimes to the failure of governance. The statement here is a vivid expression of government failure; *“Let me be sincere with you, the failure of the local government system particularly which is the nearest to the people is responsible for more than 50% of the crimes we are experience today. Walk into the local government secretariats in Anambra here and you will realized they have been overgrown by weeds. No activity goes on there, the small small projects they use to implement which most times have direct impact on the people are lost. That direct control the local government has over the people in terms of crime control has been disconnected. The people feel alienated from government and that is the result of the agitations you are having here and there”*. There is no better way to say that than this in order to express the government failure.

The finding is also corroborated by Arewa (2013) who pointed out that, consequently upon the collapse of the parliamentary system in Nigeria in 1966 through degeneration and revolutionary ouster, the state, its laws and institutions became dedicated instruments of despots and political forces and allowed to slip deeper and deeper in the mire of corruption and malfeasance far beyond the transformation. The state of the Nigerian economy is very worrisome. There is social infrastructural decay and inability of governments to provide the needed dividends of democracy. State funds and

resources are embezzled by individuals in highly placed positions of political authority. Funds meant for state projects are often misappropriated. This often has a far reaching effect on the citizens. Greed, moral decadence and the quest to get rich quick syndrome have been identified as factors motivating kidnapping were all advanced in support of the finding by (Ogbuehi, 2018; Inyang and Ubong, 2013; Inyang, 2009; Nnamani, 2015).

5.3.5 Value system/corruption, kidnapping for ransom and national security in Nigeria.

Findings on this sub-variable of the study suggest that, both primary and secondary sources agreed to the position that, the kind of value system people have today significantly influences the rate of kidnapping for ransom and general criminality in the country. Respondents believed that, the value placed on human life has dwindled and people now use their fellow human being to negotiate for money which was not the case in the past. They feel the value placed on material things is what is driving young people into crime. They want to belong and be like others. *“Are the children taught about the significance of our national anthem, pledge, symbols and those things that unit us as a people? Who cares today about hard work, when they hear and see politicians steal billions and launder it around, young men who are into crimes are peddling their wealth around for everyone to see. These things have changed the way young persons’ think. We were taught, but who is teaching them today? The national orientation agency is only heard of but never seen doing anything” (Field work 2021).*

This finding agrees with the views of Onovo (2009) which says, looking at Nigeria today we have mortgaged our culture of respect, love for human lives, hard work, friendliness and receptiveness to strangers in exchange of the Western culture and ostentatious orientation. These have given birth to the modern crime and social evil

destroying the core value of our society. Added, the rising crime in the different regions is as a result of the celebration of fraudsters by leaders. He frowned at the appointment of individuals indicted of corruption as head of parastatals and various ministries of government. This was corroborated by Oyefusi (2008) who opined that, "greed and grievance are symbiotic." For kidnapping to occur, there must first be a grievance, some of which have already been identified and discussed. This will lead to connivance from an insider to facilitate kidnapping and sometimes the ransom shared among collaborators which is a clear show of the lack of respect for human lives to and corruption.

Corroborating with this finding, a parent during the field work said "*Before you talk about the national values, how about our individual family values? Things have changed, before children were taught properly from the home, but today, how many of those children even have a home to sleep before talking about giving them home training. So you see, no child that is given the good Islamic values will go into crime, but because we have failed to give them these good moral values from the home, they learn anywhere from peers and other extremist and they are easily lured to join Boko Haram and any of these groups*". It was unanimous that something is wrong with our value system and has fundamentally influenced the rate of kidnapping for ransom and threat to national security.

CHAPTER SIX

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

6.1 Summary

The study which was structured into six chapters evaluated and critically assessed kidnapping for ransom, as a threat to national security in Nigeria from 1999 -2020. Available data on kidnapping within the period under review were considered. Basically, the sub-variables evaluated were socio-economic factors, failure of state security architecture, ungoverned spaces, and failure of governance, value system/corruption and its influence on kidnapping for ransom and national security in Nigeria. Each chapter captured uniquely the requirements in line with theses writing in the University of Calabar.

Chapter one of the study, provided an all-inclusive background to the magnitude of the problem of insecurity generally and kidnapping for ransom in particular as the issue has become a monster and a thorn on the flesh of the citizenry. The research still in this chapter clearly outlined the objectives of the study and identified the variables considered, also stated were the research questions and hypothesis which guided the study. The objectives were five in number, put into five research questions answered and translated into null and alternate hypotheses to guide the research in searching for both primary and secondary data as used for the study.

Chapter two was specifically review of related literature. It gathered already existing theoretical and empirical literature on the sub-variables in the study. Data from reputable web sites and organizations in the area of security were explored. Particularly, the researcher dwelled on the issues of kidnapping for ransom and some enabling factors,

which have aided the crime in Nigeria and its implications for national security. Three theories provided the framework for this study, they are: the Anomie theory by Robert Merton 1938, the theory of Strategic Culture propounded by Collins Gray 2010, and Social learning theory by Albert Bandura 1977. These theories provided a theoretical perspective on why people take into crimes and how some of the attributes seen in the study are acquired.

Methodology of the study was captured in chapter three; it provided the procedures for which the study was conducted. This included the research design, the sampling technique, research sample, area of study, method of data collection and method of data analysis. It also described the nature of data collected for the study with the instruments utilized. The descriptive survey research design was employed in conducting the in-depth and key informant interviews during the field work. The researcher additionally utilized observational techniques with the secondary data in terms of meta-analysis. Primary data which was the interviews were mostly conducted through telephone conversations and few were one-on-one with respondents. The researcher adopted the telephone interview to reduce the physical contact in line with the COVID-19 safety protocol in data collection. In addition to the secondary data used, the researcher conducted 20 IDIs and 15 KIIs at the end of the study. They were reported in parts and some interviews with similar ideas merged for ease of transcript and interpretation. Respondents were purposively reached through available contacted persons across the areas covered for the study. The respondents were difficult to reach, because of the nature of the study, but through key informants, most of them were reached. The interviews were put in transcript and interpreted in line with the various sub-variables.

Chapter four is a careful historical background of kidnapping for ransom as a crime in Nigeria. From a historical perspective, it was revealed that, the modern trend in kidnapping has taken after what started in the Niger Delta some years ago. It states that, the usual victims were foreign nationals working in the oil companies and the culprits were the oil militants demanding control of the natural resources in the oil rich region. It has since become pervasive and commercialised. It has spread from the Niger Delta to virtually all parts of the country, with some states of course being the epicenter. In same vein, their victims have changed from being predominantly foreign oil workers to Nigerians, including parents, grandparents, kids and anyone who has a relative that could be blackmailed into coughing out a ransom. By 2014, school children became targets to blackmail government and state structures into paying ransom. Evidence revealed that, those behind the recent wave of the despicable act have also changed from being exclusively Niger Delta militants to dodgy elements from different walks of life - armed robbers, unemployed, professionals and in some cases, security personnel as collaborators. Even in parts of northern Nigeria, the terrorist groups are now also into kidnapping for ransom to enable them finance their religious war.

Chapter 5 presented the data gathered in the course of this study. But primary and secondary data were presented to answer the research questions and test the hypotheses posed for the study. The interviews conducted were transcribed and presented side-by-side with the content analysis conducted. From the analysis, the researcher obtained results, discussed them and conclusion based on these results. The following findings were reached from the study that:

1. Socio-economic factors significantly influences kidnapping for ransom and is a threat to national security in Nigeria.

2. Failure of state security architecture significantly influences kidnapping for ransom and is a threat to national security in Nigeria.
3. Ungoverned spaces significantly influence kidnapping for ransom and is a threat to national security in Nigeria.
4. There is a significant influence of failure of governance on kidnapping for ransom and is a threat to national security in Nigeria.
5. There is a significant influence of value system/corruption on kidnapping for ransom and is a threat to national security in Nigeria.

The study found that, all the five sub-variables under considerations all significantly influences kidnapping for ransom in the country and has become a serious threat to national security.

6.2 Conclusion

Based on data and evidences presented in this study, the researcher first of all concluded that, the wave of kidnapping for ransom in Nigeria constitute a serious threat to the national security of Nigeria as at the time of this research. It is evidenced that, the rate of kidnapping has reached a point where the nation need to declare a state of emergency on security to safe guard the nation. That the call for the declaration of the state of emergency has been pronounced so much so that the National Assembly, both Senate and House of representatives have joined the called particularly due to the raising kidnapping of even school children and now university students.

The study again concludes that, no part of Nigeria can be regarded as a safe location or immunized from kidnapping. It is going on in all the zones in the country. And the people have attributed this to several factors including socio-economic factors, failure in

the security architecture of the state, failure of government, ungoverned spaces and poor value system/corruption among others. The 'get rich quick syndrome' was seen as a major driver of all crime and criminalities in the country. And finally, it was concluded that, the crime of kidnapping is not committed in isolation, other crimes are also in the increase in the country.

6.3 Recommendations

Based on the findings from the study, the researcher made the following recommendations which may directly and indirectly have implications for policy and governance:

1. The government should as a matter of urgency address the ever widening gap between the rich and the poor in the country. The citizens, particularly, the youths should be meaningfully engaged to earn a decent living without resulting to crimes. Since it has been established that socio-economic gains is one of the factors pushing young people into crime, the state should legitimately enact policies that may improve the socio-economic status of the citizenry. They have to be deliberate about it.
2. That the government should as a matter of urgency reorganize the security architecture of the state to embrace the use of technology and reflect the modern security strategies. The use of intelligence gathering and community engagement to rejuvenate the already failing security architecture.
3. Government and the community should collectively make effort to secure ungoverned spaces and dislodge criminals from their strongholds to make the

people around such areas more secure. The government and security agencies should make those spaces more secure.

4. The government should keep their political promises to the people, deliver the dividends of good governance and improve the lives of the people to take them away from crime.
5. The national orientation agency should rise up to their responsibility of coordinating the value reorientation of young Nigerians. Also families should teach children good virtues and value for human life.
6. Our security personnel should be trained and well equipped to face the current security challenges in the country.
7. The current legislations on kidnapping should be strengthened and the process of implemented be made to serve as a deterrent to kidnapers.

6.4 Recommendations for further research

Based on the findings and recommendations made from this research, it is further recommended that future researchers should look critically into the areas of collective security effort, especially in the ungoverned spaces. Also the aspect of the role of the security agencies in handling proceeds from kidnapping has to be looked into, because unremitted proceeds has a way of facilitating constant reoccurrence of kidnapping for ransoms. Also the impact of government legislation on kidnapping for ransoms is an issue that should be looked into to ensure that, it is not all about making beautiful legislations that has no direct impact on the crux of the matter.

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**HYDROGEOLOGY, HYDROCHEMISTRY AND CONTAMINANT
TRANSPORT ESTIMATION AROUND A MUNICIPAL WASTE
DUMPSITE CALABAR, SOUTH EASTERN NIGERIA**

BY

**OCHELEBE, IBU
GLG/Ph.D/15/002**

**A PhD DISSERTATION CARRIED OUT IN
THE DEPARTMENT OF GEOLOGY
FACULTY OF PHYSICAL SCIENCES
UNIVERSITY OF CALABAR
CALABAR, NIGERIA**

SUBMITTED TO

**GRADUATE SCHOOL
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**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
AWARD OF DOCTOR OF PHILOSOPHY DEGREE (Ph.D) IN
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TRANSPORT ESTIMATION AROUND A MUNICIPAL WASTE
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This is to certify that all corrections pointed out by the Graduate School Vetting Committee for the above-named student have been carried out to my satisfaction.

With thanks.








Prof. E. I. Enang

Chairman, Faculty Graduate Committee

Date: 23th June, 2021.

CERTIFICATION


We certify that this thesis entitled “Hydrogeology, hydrochemistry and contaminant transport estimation around a municipal waste dumpsite Calabar, South Eastern Nigeria” by Ochelebe, Ibu (GLG/Ph.D/15/002) carried out under our supervision, has been found to have met the regulations of the University of Calabar, We, therefore, recommend the work for the award of the Doctor of Philosophy (Ph.D) degree in Environmental hydrogeology.

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DECLARATION

I, **Ochelebe, Ibu** with registration number **GLG/Ph.D/15/002**, hereby declare that this thesis on **Hydrogeology, Hydrochemistry and Contaminant Transport Estimation Around a Municipal Waste Dumpsite Calabar, South Eastern Nigeria** is original, and has been written by me. It is a record of my research work and has not been presented before in any previous publication.

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ABSTRACT

Hydrogeological, hydrochemical and contaminant transport studies were carried out around an active municipal waste dumpsite in Calabar, to assess the leachate released from the dumpsite and identify the processes governing the transport of the contaminants. The groundwater flow pattern, aquifer characteristics, extent of the leachate migration, physicochemical and bacteriological characteristics of the groundwater were studied. The investigation involved, borehole drilling, eighty-five unconsolidated borehole cuttings, six aquifer test, eighteen monitoring wells, 2-D electrical resistivity imaging, twenty-nine groundwater samples, seven surface water samples, three leachate samples and geochemical modelling with the computer software PHREEQC. The groundwater, surface water and leachate samples were analysed for physicochemical parameters, heavy metals and indicator organisms using standard techniques. Sieve analysis was carried out on the unconsolidated samples. Results of aquifer test, sieve analysis and monitoring wells were used to calculate the aquifer parameters. Hydrogeological data suggest aquifer heterogeneity with thickness of 18 m to 42 m, extending beyond the study area. The static water level ranged from the surface to 44.5 m. the hydraulic gradient varied from 1.00×10^{-2} to 1.38×10^{-1} with average flow velocity of between 0.53 m/d and 2.76 m/d. Transmissivity ranged between 179.84 m²/d and 1280.63 m²/d. And specific capacity ranged between 48.92 m³/d/m and 205.82 m³/d/m. Hydraulic conductivity measured by the Hazen method ranged between 8.64 m/d and 486 m/d. The result of the 2-D resistivity imaging shows that the leachate is migrating into the subsurface and the influence is decreasing with distance from the dumpsite. The level of the parameters investigated were higher in the composite leachate compared to the groundwater and surface water. The levels of physicochemical parameters and heavy metals were not significantly different in the groundwater sampled

around the dumpsite and control, however the levels of microbiological contaminants were significantly different. The major water types identified based on Piper trilinear and modified Chadha diagram are Ca-HCO₃, Ca-Mg-Cl, Ca-Na-HCO₃ facies. Styfzand classification shows that the water was fresh to fresh-brackish and soft to moderately hard. Gibb's plot suggests rock weathering and precipitation as source of ions. While the results from cross plots, ionic ratios and chloro-alkali indices indicates that carbonate weathering and ion exchange are major processes controlling the groundwater chemistry. Correlation analysis of the groundwater samples shows positive correlation for Cl,CO₃,HCO₃,SO₄ and Mg,Ca with negative correlation between DO and Ca,Mg,CO₃,HCO₃,SO₄,NO₂. The result of principal component and hierarchical cluster analysis suggests carbonate weathering, ion exchange, precipitation of Mn and Fe, and seasonal influence on the chemical composition of the water. Speciation modelling calculation shows that most of the minerals were undersaturated in the groundwater. Batch reaction modelling suggests contaminant attenuation through denitrification and precipitation of pyrite and sphalerite. Inverse geochemical modelling favoured carbonate dissolution and sulphate reduction as well as the contribution of other minerals like silvite, halite, hydroxyapatite along with NH₃ and CO₂ to the reactions. Results of 1-D transport models suggest dilution and sorption of the contaminants by the aquifer materials.

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CHAPTER ONE

INTRODUCTION

1.1 Background of study

Waste disposal has always been an important issue for human societies. In most developing nations solid wastes are being discarded on land surface without the adoption of any adequate sanitary landfilling practice (Gomez *et al.*, 2014). It is the most widely used means of municipal waste disposal. According to Kurniawan *et al.* (2006) it accounts for about 95 percent of the overall waste collected globally, because it is one of the most inexpensive means of discarding municipal waste. They are located wherever land is available, without considering its impact on the environment. In most cases the wastes are not treated and the normal protective clay linings are not put in place to prevent the leachates from making contact with the surrounding. Hence, the administration of waste and associated environmental effects pose a huge challenge to developed and developing nations and have provoked social and environmental attention in modern times. Amongst the problems, disposal of solid and liquid wastes in landfills is a considerable source of water contamination (Nazir *et al.*, 2014). Hence, unrestricted attention has been given to groundwater contamination by leachates from dumpsites.

Once waste is dumped in a site, it goes through a series of physical, chemical and microbiological transformation. These changes within the landfill promotes the degradation of the wastes leading to release of contaminants. These contaminants which are in various forms are capable of degrading the environment in many ways. One of the major sources of contaminant from waste dumpsites is the leachate which can find its way into surface water and groundwater systems. In the subsurface, the various contaminants in the leachate go through intricate physical, chemical, and biological

transformations (Unnisa & Bi, 2017). Chemical substances in the water frequently interact with each other and with the soil, particularly with the clay and organic components. Additionally, within the subsurface, the contaminants are being redistributed via the convective transport of the groundwater, dispersion, diffusion, matrix diffusion, sorption and breakdown resulting in the retaining of dissolved substances and a decrease of the concentration of the contaminants in water, as well as bring about different migration velocities for the diverse contaminants (Goldberg *et al.*, 2007). The reduction in the concentration of contaminant is dependent on several factors such as, time, nature of the contaminant, chemical composition and hydraulic properties of the Vadose zone and underlying aquifer. The presence of contaminants leads to deterioration of surface and groundwater quality which normally result to an increase in total salinity, or as increases in concentration of nitrates, indicator organisms and other undesirable chemical substances. The evaluation of the degree of contaminant in groundwater is established on its concentration in the normal groundwater composition (geogenic background), a shift from this background value indicates contamination.

Poor sanitation around the municipal dumpsite located along the LEMNA road is one of the major environmental concerns. The untreated solid and liquid wastes are frequently dumped in the site. This could result to an excessive release of nutrients directly into the source of water in the area. Excessive nutrient leads to eutrophication of surface water bodies leading to series of environmental problems such as accumulation of toxic substances and reduction in water quality due to anaerobic conditions. Some users of borehole water around the dumpsite have complained of poor groundwater quality, in terms of odour and colour of the water from some of the

boreholes. Also the Cross River State Water Board has complained of poor quality of the intake water located within the area (Personal communication with residence).

Sustainable management of waste involve the selection of treatment and disposal methods base on the form, composition and magnitude of the waste substance such that the impact on the environment is minimal. Treatment technique is applied to lessen the toxicity and volume of the solid waste and transform it into a more suitable form for discarding.

Leblanc (2019) listed the main waste treatment and disposal techniques. That thermal and biological waste treatment are the two major treatment techniques. thermal treatment involves the use of heat to treat waste materials. Thermal treatment could be done by incineration, gasification, pyrolysis and open burning. While biological waste treatment involves the organised aerobic decomposition of organic waste materials by the action of small invertebrates and microorganisms. After treatment the waste are disposed through landfills and dumps. Sanitary landfill is the most frequently used waste disposal plan, which are designed to reduce or eliminate the threat of environmental or public health hazard. The landfill sites are located where land features work as natural barriers between the environment and the landfill. For example, the landfill region can be made of clayey soil, which is reasonably impervious to harmful waste or is characterised by lack of surface water bodies or a shallow water table to prevent the threat of water pollution. Another method is the bioreactor landfills, which use higher microbiological process to quicken the disintegration of the waste materials. The main feature of this method is the adding of liquid to maintain optimal moisture for microbial breakdown. The liquid is introduced by re-circulating the landfill leachate. Dumps conform with lots of the demands of sanitary landfill, but may lack one or two of the requirements. The practise of hygienic landfill offers the least health and

ecological risk, but the price tag for building it is relatively greater than other waste disposal techniques, hence most developing countries hardly apply the method in the disposal of their waste.

The LEMNA road dumpsite in Calabar was established over twenty years ago and thousands tons of waste have been dumped there over these years. Currently, an average of forty truck load of solid waste is being dumped there daily with an average of four (4) tanker load of liquid waste weekly. The waste here is not treated before disposal in an open dump.

1.2 Problem statement

The rapid development of Calabar the capital of Cross River State due to expansion has led to high level generation of wastes. These wastes are dumped in an open dumpsite along LEMNA road within the metropolis. The production and migration of leachates from the waste materials can deteriorate surface and groundwater systems. This may give result to a variety of water quality issues like depletion of oxygen levels, introduction of contaminants and asphyxiation or death of aquatic organisms. This can threaten the health of those who depend on these fresh water bodies for domestic supply, fishing or recreation. In fact, water supply based on these water resources may in a long-run become unmanageable due to water quality decline. To correctly comprehend the environmental risk and resolve the problems in the water systems, it is essential to have information on the processes affecting the contaminants from the source where they are released to the discharge points. However, no detail study has investigated the aquifer characteristics and processes governing the transport of contaminants in groundwater around the LEMNA road dumpsite which is receiving over seventy tons of waste per day (Personal communication with waste management

agency staff). Available studies in literature in Calabar and around the LEMNA road dumpsite in particular, to the best of my knowledge have focused on; delineation of the shallow groundwater aquifers, vulnerability of the aquifers, hydrochemical processes, speciation studies and the quality of the water for domestic and agricultural usage based on water quality assessment of the Calabar coastal plain sand generally, (Edet & Okereke, 2002; Ugbaja & Edet, 2004; Edet *et al.*, 2004; Edet, 2004; Edet & Worden, 2009; Edet *et al.*, 2012; Edet, 2014; Eni *et al.*, 2014; Ekwere & Ekwere, 2015). This study therefore is focused on, the characterization of the aquifer around the dumpsite and identifying the processes governing the transport of contaminants related to the dumpsite effluent on the groundwater within around the LEMNA road dump site, through the use of an integrated approach.

1.3 Aim and objectives

This study is aimed at identifying the processes that govern the transport of contaminants released from the dumpsite leachate into the groundwater system. The objectives of the study include:

1. To characterize the aquifer.
2. To simulate the groundwater flow pattern around the dumpsite.
3. To assess the extent of the leachate migration.
4. To assess the distribution of contaminants in the leachate and groundwater.
5. To identify the mineral phases, present in the aquifer.

1.4 Justification

Groundwater is an essential natural resource. In the environment, groundwater is the major source of drinking water, irrigation water and industrial water and also recharge for river water. Approximately one-third of the world's populations use groundwater for drinking (United Nation Environmental Program, 2013). The quality of

groundwater is therefore essential for the functioning of the hydrological cycle and ecological systems as well as for the human health. However, groundwater can easily become polluted, primarily because of human activities such as waste disposal. Understanding the hydrogeochemical processes occurring alongside the fate and transport of contaminants from waste disposal into groundwater is crucial for predicting risk and protecting groundwater quality. However, there is a huge gap in research in this regard, this study therefore, is an attempt at bridging this gap in the area of study.

1.5 The study area

1.5.1 Location and accessibility

The study area, LEMNA road dumpsite, is over twenty years of age, and is located in Ikot Efangha Mkpa within Calabar, the Cross River State, Nigeria. The dumpsite lies approximately within Longitudes 8⁰21'45" to 8⁰ 21 '59" East and Latitudes 5⁰02'15" to 5⁰02'25" North (FIG. 1). The area is bounded by Ikot Enobong, Esuk Otu, the Great Kwa River and Ikot Ansa to the north, west, east and south respectively. The area is accessed by the Cross River State Water Board intake road, which is linked to network of other roads such as, LEMNA road, Murtala Mohamed highway and other minor roads, footpaths and tracks. All these roads provided access to sampling points. The north eastern part of the dumpsite is bounded by a swampy ground which is water logged throughout the year.

1.5.2 Climate and physiography

The area is located within the tropical climatic zone, marked by distinct rainy and dry season. The wet season normally spans from March to September while the dry season is from October to February. The area has a mean annual precipitation of 2508.11mm and mean annual air temperature of 27.07⁰C (Edet *et al.*, 2013).

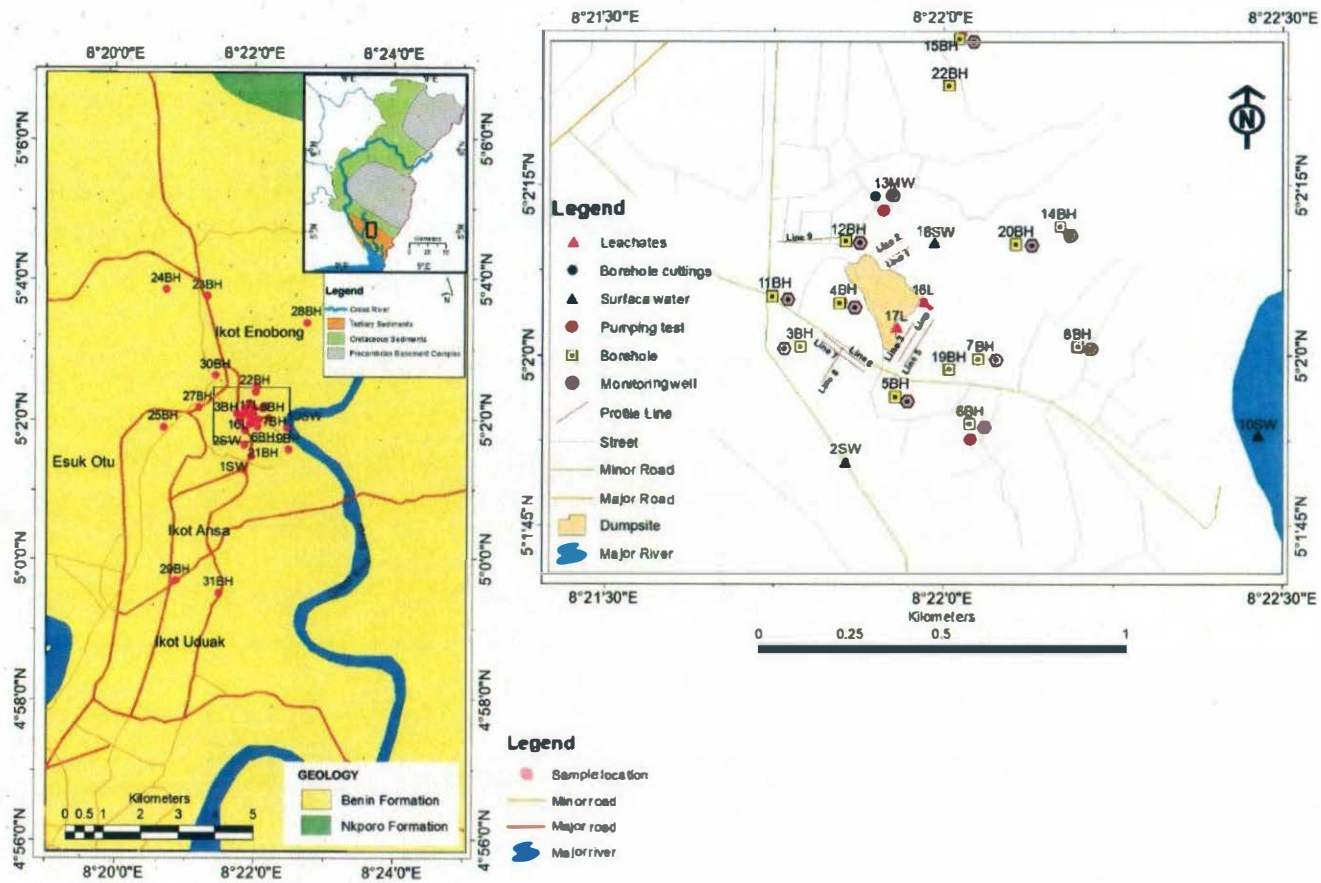


FIG. 1: Map of the study area showing dumpsite and sampling points with an inset generalized geologic map of Cross River State

The climatic data recorded during the study period by Nigerian Meteorological Agency station at Margaret Ekpo International Airport, Calabar, shows that the average temperature for 2016 and 2017 was 27.55°C and 27.41°C respectively. While the total rainfall recorded were 2452.70mm and 3119.60mm for 2016 and 2017 respectively. The average relative humidity for 2016 and 2017 were 85.58 percent and 86.83 percent respectively. Also the average evaporation recorded were 2.62 mm/d and 2.54 mm/d for 2016 and 2017 respectively. The summary of the data is given in Table 1, while the detailed climatic data obtained during the study period is given in Appendix 1. The 1:100,000 topographic map sheet 323, shows that the area is generally low-lying and relatively flat with elevation ranging from below 15 m to above 60 m (Federal Surveys, 1967). This is within the range of the GPS elevation taken during the mapping, which ranged from 7 m to 78 m. The major drainage system is the Great Kwa River.

1.5.3 Geology

The dumpsite located within the Niger Delta sedimentary Basin, the stratigraphic sequence of the Basin is comprised of an ascending coarsening regressive association of Tertiary clastics, up to 12km thick (Weber & Daukoru, 1975; Evamy *et al.*, 1978). Three lithostratigraphic entities have been documented in the subsurface of the Basin (Short & Stauble, 1967; Avbovbo, 1978) they are, from the youngest to the oldest, the Benin, Agbada and Akata Formations. The Benin Formation underlies the entire study area. The Benin Formation which is Oligocene to which is Oligocene to Recent in age is composed of medium to coarse sandstone, sand, shales and gravel (Edet, 2017). The Benin Formation, formally referred to as Coastal Plain Sand (Reyment, 1965), is marked by lacustrine and fluvial sands, pebbles, clay, lignite and alluvium in the study area.

TABLE 1
Summary of climatic data during the study between 2016 and 2018^a

PARAMETER	PERIOD		
	2016 (Jan –Dec)	2017 (Jan – Dec)	2018 (Jan - July)
Mean annual maximum Temperature (°C)	31.66	31.38	31.90
Mean annual minimum temperature (°C)	23.44	23.43	23.8
Total rainfall (mm)	2452.70	3119.60	129.8
Mean annual rainfall (mm)	204.39	259.97	247.11
Mean annual relative humidity (%)	85.58	86.83	84.71
Mean annual evaporation (mm/d)	2.62	2.54	2.67

^aNigerian Meteorological Agency, Calabar.

The alluvium consists of lagoonal and tidal sediments, silts, sands, pebbly beds, lignite, clay and beach sands. The sands are medium to coarse grain, poorly sorted and contain lenses of fine grained sands and sandy shales, shales, siltstone and mudstone in some layers, a typical section is shown in Plate 1 taken by road cut in Parliamentary extension road 425 m South West of the dumpsite. Edet and Okereke (2002) stated that 'well/borehole data from the area indicates that the subsurface geology is composed of interchanging sequence of gravels, sands, silts, clays and lignites appearing at various levels with variable thicknesses'. The shales, siltstone, mudstone, clays and indurated sandstones constitute the aquitard systems in the area. These aquitards can be grouped into two classes based on geologic origin, that is, common unlithified aquitards (clays) and the common indurated sedimentary aquitards (mudstone, siltstone and indurated sand stone) (Cherry *et al.*, 2006). Essien & Okon (2016) reported that fluvial processes were dominant during the deposition of the sediments in a high energy environment. The generalised geological map of the State showing the study is shown in FIG..1.

1.5.4 Hydrogeology

The aquifer within the study area is of variable thickness, highly prolific and consists of sandy-gravelly sediments and heterogeneously distributed silts and clay lenses. The occurrence of silt and clay layers at various levels and thickness from one locality to the other results in localized confined units thus giving rise to a multi-aquifer system (Okereke *et al.*, 1998). Edet *et al.* (2012) reported that the aquifer is composed of unconsolidated and loose sediments, majorly gravels, sands, silts and clay of Tertiary age. That the sand which are largely medium grained make up over 80 percent of the aquifer materials. Edet and Okereke (2002) defined aquifer systems for Calabar area and also reported that, 'water level varies from a minimum of 4.6m to a maximum of 70.2m with a mean value of 44.5m.



PLATE 1: Photograph of an alternating sequence of sand, followed by indurated sandstone, yellowish and dark grey clay at the base of the exposure along parliamentary extension road (N 5° 1' 11.52", E 8° 21' 16")

Hydraulic conductivity range between 61.2 and 180 m/d with transmissivity of 22.2 to 61.2 m²/day'. Edet (2014) reported that 'well discharge varies between 360 to 2760 m³/day, the depth to water level fluctuates from less than 5 m to over 70 m, hydraulic conductivity ranged between 110 and 285 m/day and that transmissivity range from 1957 to 24748 m²/day'.

CHAPTER TWO

LITERATURE REVIEW

2.1 General background

Indiscriminate disposal and inappropriate administration of Municipal waste in Africa has given rise to severe ecological and environmental issues. One of the main environmental challenge regarding the operations of dumpsites is the leaching and transport of contaminants into nearby surface and groundwater. As many of the waste dumpsites are open and leachate generated due to the oxidation-reduction reaction becomes a potential treat to both surface and groundwater. The impact of the leachate on water sources is a function of the quantity and type of the contaminants in the waste and the chemical reaction that takes place when the leachate encounters the water. Factors that affect the leachate composition are numerous and they consist of; the type of waste deposited, hydrology of the site, age of the dumpsite, and where obtainable, the site plan and type of liner used (Ofomola, 2018)

Chemical reactions control the existence, dissemination and behaviour of aquatic species in water. The aquatic species ($<1\text{nm}$) is defined as 'organic and inorganic substances dissolved in water in compare to colloids (1-1000nm) and particles ($>1000\text{nm}$) in size'. This definition according to Merkel and Planer-Friedrich (2008) embraces free anions, cations as well as complexes. The interactions of the different species among themselves and with gases, solid phases (minerals) along with transport and decay processes (biological decomposition, radioactive decay) are essential in defining the hydrogeochemical content of surface and groundwater. When the concentration of aquatic species in water is at a level that makes the water unfit for the purpose it is meant for, the species is referred as a contaminant. These include pathogens which are indicators of microbial pollution.

A lot of processes control the distribution and level of contaminants in underground water from the source to point of discharge. These processes include, convective transport through the groundwater flow, spreading, diffusion, medium diffusion, filtration, sorption, ion interchange, dissolution, precipitation, microbiological transformation, acid-alkali reaction, oxidation-reduction and dissociation of dissolved substances, all these processes result in the retention or reduction of the contaminant concentration, these processes are controlled by geology and geochemistry of the host rocks as well as a number of hydrodynamic causes (Knodel *et al.*, 2007).

2.2 Review of previous work

Geophysical investigation of areas around dumpsites is widely applied in the monitoring of contaminant plume in the subsurface. Meju (2000) listed geoelectric method as one of the most prevalent geophysical methods use to characterise landfills. owing to the relatively low cost and its capability to identify variations in electrical resistivity, which shows a relationship with moisture content and chemical content of the pore water. Degnan and Harte (2013) also noted that leachates at dump sites frequently leads to plumes of high specific conductance that can be identified with electrical geophysical techniques.

In the Coastal Plain area, George, Ubom and Ibanga (2014) applied surface resistivity measurements to study the effects of leachate on underground water around Ikot Ekpene dump site in Akwa Ibom State, Nigeria. The study attributed the low resistivity values to the presence of the leachate loaded pollution plume within the subsurface.

lyoha *et al.* (2013) investigated a solid waste landfill site in Ikhueniro municipality in Edo state using 2D resistivity imaging and identified two distinct plumes around the landfill which is linked to the gas and leachate emanating from the landfill. Also in Kaduna *et al.* (2011) investigated the Unguwan Dosa waste disposal site using 2D

electrical resistivity imaging, and reported that the resistivity imaging was able to delineate the leachate plume as low resistivity zones.

In other parts of the world, a lot of work has been done with the use of geophysical techniques in the study of dump sites, these include the work of Yin *et al.* (2017) who applied electrical imaging and multiple analysis of surface wave with limited geotechnical boring in monitoring an old landfill in Singapore. The study revealed that the subsurface profile can be well appreciated with the combine tools as they were able to determine with improve details; area of soft material accumulation, isolated pockets, moisture retention capacity and leachate accumulation. Also, Radulascu *et al.* (2007) investigated time-lapse electrical resistivity abnormalities owing to contaminants transport around landfill sites. The study which combined the use of hydrogeological numerical simulation, revealed that the image acquired from geophysical inversion of the electrical data was similar with the earlier hydrogeological model defined by the distribution of the leachate concentration.

Monitoring wells has also been applied in the investigation of groundwater contamination around waste dumpsites. Nyaje (2014) monitored a network of 26 wells in Kampala, Uganda, to appreciate the chemical composition and fate of nutrients in the shallow underground water around a poor sanitation urban slum catchment. The study revealed the presence of contaminant trail along the direction of underground water flow, characterise by declining electrical conductivity and chloride concentration. Ugbaja and Edet (2004) investigated groundwater pollution near shallow waste dumps in form of pit latrines in southern Calabar, Nigeria. The investigation reported that groundwater in shallow aquifers located in areas with high concentration of pit latrines were moderately to highly polluted compared to areas with lower number of pit latrines, while areas with deep aquifers and low number of dumps were not affected.

Aderemi *et al.* (2011) carried out an assessment of groundwater contamination by leachate near a municipal solid wastes landfill in Lagos, Nigeria. The result shows that the concentration of some physico-chemical and microbiological parameters in some of the groundwater sampled were above the World Health Organization (WHO) tolerance limits. However, the study concluded that the leachate from the dump site has a slight impact on the underground water resource due to the natural reduction of the leachate into underground water arising from the clay content of the soil. Similarly, Akinbile (2012) carried out an environmental effect of landfill on groundwater quality in Akure, Nigeria. The study shows that the contaminants concentration of the waste materials in the dump site had steadily contaminated the groundwater overtime.

Sholichin (2012) in his field investigation of groundwater from solid waste landfill in Malang, Indonesia, reported that groundwater, surface water and urban water wells around the landfill area had been contaminated by leaching from the solid waste landfill, as all the water quality parameters investigated were higher than the standard regulation of water quality.

Odunlami (2012) investigated groundwater quality near a municipal landfill site in Lagos. The results revealed that the concentration levels of pollutants look at in groundwater samples fall within the maximum tolerable concentration specified by WHO and National Agency for Food Drugs Administration and Control (NAFDAC).

In Malaysia, Syafani *et al.* (2014) carried out isotopic and hydrochemical fingerprinting of leachate movement into shallow underground water at controlled and uncontrolled dump site, the investigation revealed that heavy metals have been released into the environment due to the infiltration of landfills leachate.

Gupta and Rani (2014) evaluated the effect of landfill leachate on underground water quality around the of landfill in New Delhi, India. The investigation revealed high

concentration of physicochemical parameters in the groundwater samples due to the leachate released from the landfills. Also, Eshanthini and Padmini (2015) investigated the impact of leachate on groundwater quality near Kadungaiyur dumping site in India, and reported high concentration of Cl^- , TDS, NH_4^+ and SO_4^{2-} in the groundwater.

In Belfort, France, Grisey and Loffi (2016) studied the quality of groundwater around a landfill over a period of four years, using Chloride as an indicator of anthropogenic contamination. The result shows that the influence of the landfill on the groundwater quality is minimal.

Hube *et al.* (2011) investigated the natural attenuation in groundwater near a landfill and its implications for post-closure. The results from geological, geophysical and geochemical surveys performed provided an indication of an insignificant influence of the landfill on the groundwater and surface water within its vicinity, but that isotopic ratios showed a signature of the landfill in the water in its vicinity. The study concluded that the contrast between isotopic and chemical signatures could be an indication of attenuation mechanisms.

Furthermore, the presence of certain pathogenic microorganisms in groundwater is an indication of groundwater contamination. Underground water for a sometime has been believed to be free of microbial pollutants and viruses, relying on the fact that vertical passage times are long enough, and microbial survival is short to arrive the groundwater system. But this is not the case as the risk of water contamination are obvious considering the manifold occurrences of diseases from pathogenic microbes and viruses which could be connected to consumption polluted groundwater (Craun *et al.*, 2010). As presented in Table 2, numerous pathogenic bacteria are responsible for some severe gastrointestinal ailments. The occurrence of the disease is initiated through growth inside the host (example *Salmonella*) or by discharge of toxins (example *Shigella* and

TABLE 2

Sources and major diseases cause by some pathogens in underground water

Pathogen	Main diseases	Sources
<i>E. coli</i>	Gastroenteritis, Hemolyticuremic syndrome (enterotoxigenic <i>E. coli</i>)	Human feces
<i>Salmonella</i> spp.	Enterocolitis, endocarditis, meningitis, pericarditis, pneumonia, reactive arthritis	Human and animal feces
<i>Shigella</i> spp.	Gastroenteritis, dysentery, reactive arthritis	Human feces
<i>Vibrio cholera</i>	Cholera	Human feces and fresh water zooplankton

*Modified from Steffen and Christian (2011).

E. coli). The presence of microbial contaminants in groundwater has been investigated by many workers across the globe.

Steffen and Christian (2011) noted that, there are multiple sources of contamination arising from growing populations and expanding land use, leading to steady increase in sources of pathogen contaminated waste. The prospective contamination of underground water resources with contagious agents all round the world has increased due to fecal contamination originating from poor disposal of human and animal faeces. The study also listed factors that affect movement and reduction of microorganisms and viruses in underground water into two categories; the first category depends on the physical appearances of the pathogen, which include size, form, kind of organism, cell motility, density, growth phase and physical filtration. And the second category which depended on aquifer characteristics such as the nature of the aquifer materials, underground water flow velocity, physical and chemical properties of the underground water. Soils and the vadose zone are active natural barricades acting as mechanical and biological filters.

Also Uzoigwe and Agwa (2012) carried out an assessment and comparison of microbiological quality of groundwater around refuse dumpsites in Port Harcourt. The report indicated that the water sampled around dumpsites had high count of faecal coliform (*E. coli*), and pathogens (*Salmonella*, *Shigella* and *Vibrio cholera*).

Modelling is an essential additional tool used in evaluating the mobilization and transport behaviour of contaminants. Modelling enables the composition and concentration of substances involved in underground water and seepage water as well as the medium to be generated under constant or adjustable chemical environmental settings. Modelling is based on the law of mass action and the Debye-Hukel theory,

with the requisite input data taken from the chemical examination of the underground water, seepage water and data base of the numeric code (Appelo & Postma, 2005).

The mass action equation for aqueous species is

$$K_{ia} = \mathcal{A}_{ia} \prod_e \mathcal{A}_e^{-ce,ia} \quad 1$$

where K_{ia} is the equilibrium constant of the i specie in a phase, \mathcal{A}_{ia} is the activity of the i specie in a phase and c is the stoichiometric coefficient.

In the framework of geochemical modeling, species can be represented by a minimum number of master species or components in a linearly independent set of mass action equations (Wissmeier *et al.*, 2009). Table 3 illustrates the hierarchy of master species, which form species through association and speciation reactions, and then belong to either the liquid or solid phase.

Activity of the aqueous and master species are defined by

$$\mathcal{A}_n = Y_n m_n \quad 2$$

$(n=ia,e)$

Where m_n is the molality of specie n and Y is the activity coefficient.

The activity coefficient Y is commonly calculated by the extended Debye-Huckle equation (3) and Davies equation (4).

$$\log Y_i = - \left(\frac{Az_i^2 \sqrt{I}}{1 + Ba_i \sqrt{I}} \right) + b_i I \quad 3$$

$$\log Y_i = -Az_i^2 \left(\frac{\sqrt{I}}{1 + \sqrt{I}} - 0.3I \right) \quad 4$$

where A and B are temperature dependent parameters, z_i is the ion charge number (valence), a_i and b_i are ion specific fit parameters which depends on ionic radius and I is the ionic strength of the solution.

TABLE 3

Relationship between master specie e , species i and phases a (Adopted from Wissmeier *et al.*, 2009)

E	I	A
Master specie e Including exchange and adsorption sites	solution specie ia exchange specie ix surface specie iy Equilibrium phase im Kinetic phase ik	Mobile aqueous phase a Immobile solid phase s

*The master species are often elements (left column) this combine into (or appear directly as) species, which are found in solution or in the solid (mineral) phases (middle column). The species taken together, form the solid and fluid phases (right column)

The γ of a given solute is the same in all solution of the same ionic strength and ionic strength is defined by the relation (Merkel & Planer-Freidrich, 2008)

$$I = \frac{1}{2} \sum m_i z_i^2 \quad 5$$

From equation 1 the moles of aqueous species in the system n_{ia} can be calculated according to

$$n_{ia} = m_{ia} w_{aq} = \frac{K_{ia} w_{aq}}{\gamma_{ia}} \prod_e A_e^{ce,ia} \quad 6$$

For equilibrium reactions in pure mineral phases the mass balance equation becomes

$$K_{im} = \prod_e A_e^{ce,im} \quad 7$$

Since, with the common thermodynamic definition of the standard state, the activity of a pure phase is always unity. The number of moles of mineral is worked out by stoichiometric adjustment of ion concentration in solution according to the target saturation index (SI) as

$$SI = \prod_e A_e^{ce,m} \quad 8$$

The mass action equation for cation exchange reactions at equilibrium is given by

$$K_{im} = A_{ix} \prod_e A_e^{-ce,ix} \quad 9$$

With moles of immobile exchange species given as

$$n_{ix} = \frac{K_{ix} T_x}{\gamma_{ia} b_{ix}} \prod_e A_e^{ce,ix} \quad 10$$

Where b_{ix} is the total exchange sites engaged by exchange species ix and T_x is the total sum of the exchange sites.

For the definition of the standard state of exchange species, where the activity is unity, several conventions can be employed. The most common ones are that of mole fractions, fraction of exchange sites, or equivalent fractions. A basic theory for surface complexation reactions and associated effects of electrostatic potentials. Following the diffuse double layer model of Dzombak and Morel, the mass action equation for the adsorption of ions onto variable-charge surface sites is expressed as (Appelo & Postma, 2005)

$$K_{iy}^{int} = \left(A_{iy} \prod_e A_e^{-ce, iy} \right) \exp \left(\frac{F\Psi}{RT} \Delta z_{iy} \right) \quad 11$$

Where K_{iy}^{int} is the modified intrinsic equilibrium constant, F is the Faradays constant (Cmol^{-1}), R is the gas constant ($\text{Jmol}^{-1}\text{K}^{-1}$), Ψ is the surface potential (V) and Δz_{iy} net change in surface charge owing to surface species creation.

Number of moles of immobile surface species can be calculated from (Parkhurst & Appelo, 2017)

$$n_{iy} = K_{iy}^{int} T_y \exp \left(-\frac{F\Psi}{RT} \Delta z_{iy} \right) \prod_e A_e^{ce, iy} \quad 12$$

Where T_y is the total quantity of equivalents of surface sites

All the above reactions employ mass action equation and therefore assume local equilibrium. However, if the timescale of transport is in the range of the time scale of reaction, the kinetics of the reaction process has to be considered. Because of the many, often nonlinear, dependences of reaction rates on geochemical properties, such as saturated indices, ionic strength, temperature and pH, and because of the ongoing increase in knowledge of reaction processes, no universal rate law has been formulated. The most general formulation of kinetic reaction is (Wissmeier *et al.*, 2009)

$$\frac{dm_{e,ik}}{dt} = C_{e,ik} R_k \quad 13$$

where M_e is the change of master species with time (mol), dt is the change in time (T), R_k is the reaction specific rate (molT^{-1}) and C_{eik} is the stoichiometry of the charge balanced kinetic reactant ik .

For most applied problems, due to heterogeneity of the considered entity and the crooked shape of its boundaries, it is impossible to resolve the mathematical simulations analytically. As an alternative, the mathematical model is converted into a numerical one that can be solved by means of computer programs. Definitely, superb computer programs have been designed for this purpose, and have been used for numerous studies.

The governing equations presented above are solved by carrying out a numerical solution of the moisture based form of Richard's equation in the geochemical modeling framework PHREEQC (Parkhurst & Appelo, 2017). Straight integration of the flow and transport into the unmodified PHREEQC source code, without coupling to other codes, provides access to the entire set of geochemical reactions and databases that are presently implemented in PHREEQC, and also secures compatibility with future versions.

According to Parkhurst and Appelo (2017) PHREEQC version 3, has the capability of performing up to twelve types of calculations or data operations management in the following order; Speciation, Initial ion exchange, Initial surface, Initial gas phase, Batch reaction, Inverse modelling, Advective-transport, Advection-dispersive transport, Cell batch-reaction calculations, with copy, Dump and delete operations. Speciation modelling utilizes the result of a chemical data to compute dispersion of aquatic species by means of ion-association aqueous model. The essential result of this calculation is the SI's of minerals that shows if a mineral will dissolve or precipitate out of solution.

Batch reactions model can be grouped into two; equilibrium and non-equilibrium reactions. Equilibrium reactions comprise equilibration of a solution using an assembly of minerals and stated pressure gases, surface complexation and ion exchange sites, with fixed gas phase and solid solutions. While non-equilibrium reactions comprise kinetic reactions, adding or exclusion of solutions, mingling and altering temperature. Batch reaction modelling could be useful to issues in laboratory, natural or polluted systems. Inverse modelling on the other hand, computes reactions that gives explanation for the alteration in elemental configuration of water along its flow path. For this modelling two set of elemental analysis for water at the two points along the are required, and a set of minerals and gases that are possibly reactive. The method gives explanation for uncertainties in analytical data. Inverse modelling according to Sracek *et al.*, (2013) 'can be used to infer geochemical reactions and mixing in local and regional aquifers. Reactive transport modelling mimics advection, dispersion and reactions as water moves along a one dimensional column. Which is separated into cells, and reactant compositions and non-equilibrium reactions can be specified for each cell. All of the reactants can be applied to the cells for transport modelling'. And transport modelling according to Steefel *et al.* (2014) 'can be used to investigate contaminant migration of nutrients, metals, organic compounds, chemical evolution of natural systems and laboratory column experiments'.

Merkel and Planer-Friedrich (2008), noted that hydrochemistry model has been used since the 1960's to investigate natural and manmade environmental effects on aquatic systems. Hydrochemical models offer valuable information on the geochemical processes that controls the spatial and temporal distribution of chemical species in groundwater. Hence groundwater modelling has become an essential part of water

resources valuation, protection, restoration studies, regulation and engineering design (Kumar, 2012).

Earlier workers in the area, such as Edet *et al.* (2004) applied the computer software package PHREEQC to model the dispersion, chemical speciation and mineral SI's in the fresh underground water in Calabar generally. The result shows that the Calabar coastal plain sand had very low contamination risk, and they attributed this to the small mining activity, low level of elements, species immobility under the prevalent Eh-pH settings, dilution and reduction of the minerals. Ekwere and Ekwere (2015) carried out heavy metal assessment of groundwater within the vicinity of dumpsites in Calabar metropolis incorporating modelling. The study revealed that metal speciation in groundwater was controlled by dumpsites longevity, refuse type and associated activities.

Ujile (2013) applied the principles of mass transfers to evaluate groundwater contaminants flow model, to determine the concentration of contaminants in groundwater in Yenogoa, Nigeria. The study concluded that, the variation of porosity values caused significant changes in the concentration of the contaminants. And recommended the application of the analysis in the design of natural attenuation for landfill, for both municipal and industrial waste.

Similarly, Ofomola (2018) carried out a study on the Ujevwu dumpsite in Delta state using groundwater/contaminant modelling with VISTA, to assess groundwater condition and flow direction/velocity. The study concluded that the groundwater around the dumpsite is contaminated compared to the control site and recommended an immediate evacuation of the dumpsite.

In other parts of the world, Gomez *et al.* (2014) applied the computer program PHREEQC, to model the geochemical process guiding the transportation of pollutants

released by a dump site, in an arid province of Mexico, into groundwater. The result of their model indicated that evaporation of the polluted waters circulating under the landfill, was the basic process that explained the increase concentration of pollutants in groundwater and its seasonal variation. Jeong and Jean (2016) also examined the geochemical connections amongst the seepage water from a mine waste rock dump and aquifer materials, with the aid of laboratory test and reactive transport modelling. The investigation shows that, the extent of both pH cushioning and metal retention were found to increase with the solid/water ratio, and concluded that, dissolution of carbonate rocks is largely accountable for the pH neutralization and reduction of metals through precipitation as secondary minerals.

In Brazil, Barella *et al.* (2013) applied the program PHREEQC to determine the saturation indexes of minerals in groundwater around a landfill, and the result showed that pyrite precipitation is responsible for the removal of some chemical species from the system.

Parameswari and Mudgal (2015) applied a modular finite-difference underground water flow model, and modular 3D multi-species transport model in the assessment of pollutant movement in a shallow aquifer within the vicinity of an open dump site, at Perungundi in the southern part of Chennai metropolitan area. The study revealed that, the stagnation of water throughout the year around the dumpsite which is located in a marshy area, facilitated attenuation and movement of the leachate at high level, the model was also applied to predict that the groundwater quality will increase in within 10 years by natural processes, due to recharge and flushing, if the dumping of refuse stopped immediately.

Adjelkovic *et al.* (2012) studied the leaching of chromium from chromium contaminated soil using speciation and geochemical modelling. The investigation

revealed that, the level of chromium transport in soil columns was a function of the mobility of the organic matter-metal complexes and that the mobility depended on a variety of factors such as, the extent of soil contamination by chromium, the metal valence state, soil organic matter content and the rain water acidity. The study also revealed that, the experimentally and theoretically derived impacts of pH and content of soil organic matter were in agreement.

Lucas *et al.* (2017) carried out the hydrogeochemical modelling of spring and deep groundwater composition in granitic Ringelbach catchment, located in Vosges Mountain, France, using the computer code KIRMAT. The study revealed that, the flow path, residence time and water-rock interactions were the major controls on the chemical composition of water in the area. Earlier, Zhu *et al.* (2001) also applied a computer code PHREEQC, to simulate the natural reduction of an acidic plume in the aquifer beneath a uranium mine tailing ponds in Wyoming, USA. Their findings indicated that, the intricate interaction between physical transport processes and chemical reactions produced several concentration waves, which they attributed to advection-dispersion, precipitation and dissolution of gypsum for the transport of sulphate in the area. The study concluded that the modelling predicted numerous levels of geochemical evolution all through the flushing of polluted sediments by unpolluted up gradient water and the distribution of some species in distinct geochemical zones.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Field investigations

A reconnaissance visit was made to the study area in September 2016 to obtain permission from well owners and government agency managing the dumpsite. After obtaining permission, inventory of the existing wells was taken and potential sampling points were identified and documented. The area was mapped to determine the physical features. The mapping involved determination of the extent of the dumpsite, distribution of boreholes, streams, rivers and other drainage channels as well as the recharge and discharge areas. The assessment was done through visual observation, measurements of water level, latitude, longitude, elevation, sketching and collection of samples for analysis. The global positioning system (GPS) was utilized to geo reference; monitoring points, sampling points, geophysical points and pumping test points (Appendix 2). Compass clinometer was used to measure strike and orientation of the profile lines.

3.1.1 Borehole drilling

Five boreholes were drilled into the unconsolidated aquifer. The drilling was aimed at obtaining the drill cuttings to be used in the estimation of some aquifer parameters such as the hydraulic conductivity. Direct rotary method was used to drill a hole to accommodate 4.5-inch diameter polyvinyl chloride (PVC) casing and screen. A total of 85 unconsolidated samples were collected at interval of 10 ft. (approximately 3 m) down the hole, from the 5 boreholes. The samples were collected while the drilling was going on and the cuttings were being flushed out along with the drilling fluid. The cuttings and the fluid were collected into sack bags and the drilling fluid was allowed to drain out of the sack leaving the moist cuttings behind. The moist samples were air dried and prepared for grain size analysis. The lithological logging of the holes was

done in the field while the holes were being drilled. The location of the logged holes (9BH, 13BH, 21BH, 22BH and 27BH) is shown in FIG. 1. The materials from the borehole drilling were also recovered to get a precise lithologic examination of the sediments, this was used in the delineation of the aquifer and generation of the physical framework of the subsurface around the dump. The elevation of the locations with respect to mean sea level was used to model the aquifer.

3.1.2 Pumping test

The test was carried out in the month of September 2017. The exercise was carried out using constant discharge test. The wells were pumped at constant rate and the water draw down measured at intervals. The measurement schedule was every one minute in the first ten minutes, every two minutes in the next ten minutes, every five minutes in the next 40 minutes and every ten minutes in the remaining period. The same pumping well was monitored using water level probe until the water level remained constant. The total duration of time for the test was two hours. This test was carried out at six selected sites (PT1, PT2, PT3, PT4, PT5 and PT6 (Appendix 2), corresponding to locations (6BH, 12BH, 28BH, 29BH, 30BH and 31BH) distributed around the study area (FIG. 1). The pumping was carried out using submersible pumps. Single hole aquifer test was adopted because throughout the pumping period of two hours, no drawdown was recorded in an observation well located 9 meters away from one of the pumping wells. After the exercise the data were plotted in semi-log graph to obtain a time draw down curve, and the draw down in one log cycle was determined and used in the computation of the aquifer parameters. The Jacobs approximation method was used in determining the aquifer parameters because it is built upon the most simplifying assumptions. The data from the aquifer test was employed to estimate Transmissivity (T), Specific capacity (SC) and Hydraulic conductivity (K) of the aquifer.

3.1.3 Grain size analysis

The 85 unconsolidated samples were used to estimate the hydraulic conductivity using Hazen method and coefficient of uniformity from grain size distribution curve, which relies on the effective grain size (d_{10}). The grain size distribution curve was determined through sieve analysis. From the result of grain size analysis, the semi logarithmic plot of grain size against percentage finer was plotted and the effective diameter was determined. This was used in the estimation of the hydraulic conductivity (K) through the Hazen method (Freeze & Cherry, 1979), based on equation 14;

$$K = A(d_{10})^2 \quad 14$$

Where A is Hazens coefficient = 100 and d_{10} is the effective grain size in mm.

Also, the uniformity coefficient (U) that determines how poor or well sorted the sediment is, was calculated. This parameter plays a vital role in the measurement of porosity and K. The scheme is valid to sands with a d_{10} of between 0.1 and 3.0mm and U less than 5 (Knodel *et al.*, 2007).

3.1.4 Groundwater monitoring

Groundwater monitoring was carried out in two seasons (dry and wet). The monitoring network consisted of 18 boreholes distributed randomly around the dumpsite. The elevation of each well was determined with the GPS. The process involved lowering the probe which is attached to the end of a non-stretch measuring tape down the hole, once the probe touches the water it completes an electric circuit and beeps and the depth to the groundwater is recorded (Plate 2). The hydraulic head was taken as the difference between the static water level and measured elevation and were used to create equipotential lines by means of kriging interpolation method. The equipotential lines were used to simulate the groundwater flow direction and head gradients.



PLATE 2: Typical static water level measurement using water level probe at location 6BH (N 5° 1' 54.0", E 8° 22' 2.4")

The hydraulic gradient was estimated by taking two points along the flow line and the change in hydraulic head amid the two points all over the horizontal distance between the two points was taken as the estimated hydraulic gradient.

3.1.5 Geophysical survey

Geophysical survey employing the use of electrical resistivity tomography (ERT) was used to acquire an impression of the subsurface characteristics. The geophysical method utilizes the apparent resistivity values obtained on the ground surface to acquire 2D (two dimensional) image of the actual resistivity distribution of the subsurface. The method basically consists of introducing an electrical current (I) through two metallic rods (current electrode) and assessing the potential difference (ΔV) between two other rods (potential electrode). The apparent resistivity (ρ_a) is given by the relationship (Krishner *et al.*, 2009):

$$\rho_a = K \left(\frac{\Delta V}{I} \right) \quad 15$$

with K a geometrical factor which depends on electrode position.

The electrical tomography survey was carried with Resistivity meter model SSR-MP-ATS (Plate 3). The Wenner electrode configuration was adopted. In this configuration, the spacing expands around the array midpoint though maintaining an equivalent spacing amongst the electrodes. FIG. 2 shows the electrode arrangement and sequence that was used for the 2-D electrical imaging. To produce a cross-sectional appearance of ground resistance, a sequence of electrodes is installed along a straight line with an electrode separation of "a". Once a reading of ground resistance has been obtained for one set of four electrodes, the subsequent set of four electrodes is connected and the measurement of resistance is taken. This procedure is repeated until the end of the profile line. The process is then repeated with an electrode separation of 2a, 3a, 4a, and so on. For each increment in electrode spacing, a corresponding increase

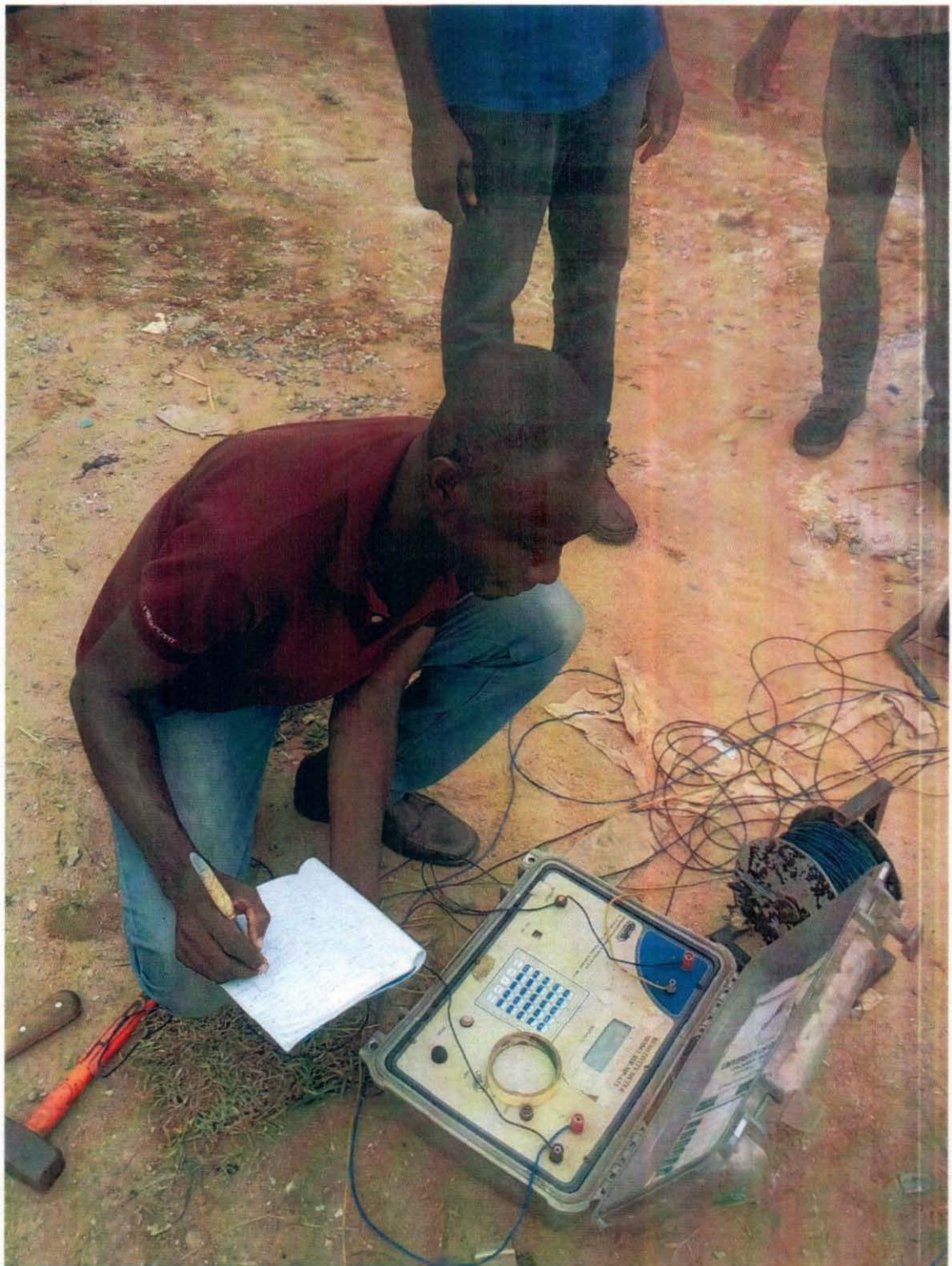
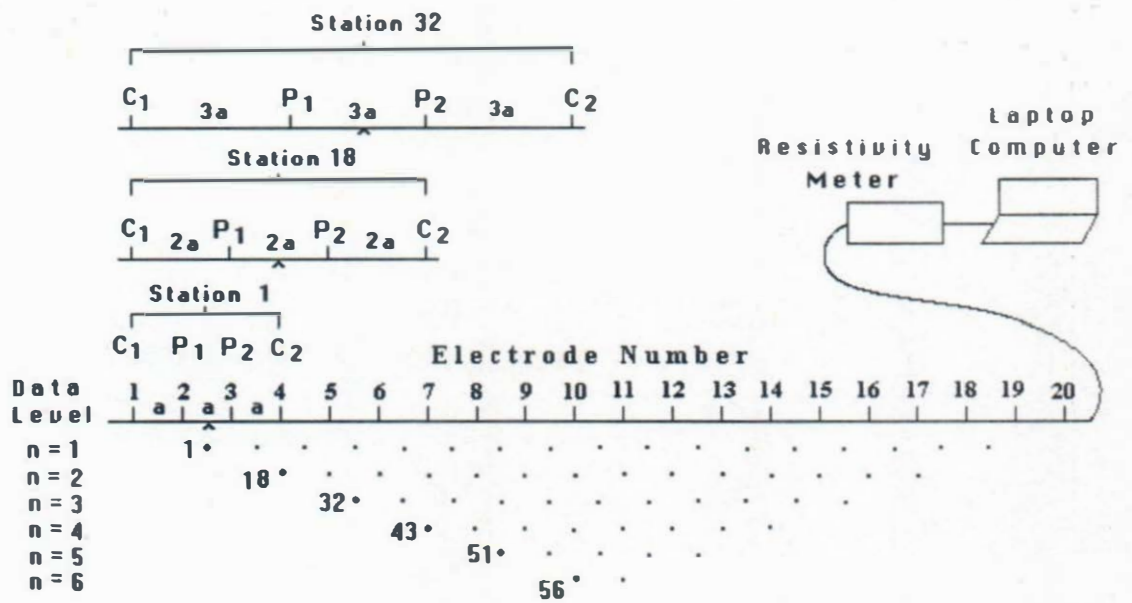


PLATE 3: Typical data acquisition using resistivity meter model SSR-MP-ATS at one of the location (profile line 7, N 5° 1' 59.10", E 8° 21' 52.10")



C₁C₂ – Current electrodes
 P₁P₂ – Potential electrodes
 a – Electrode spacing

FIG. 2: The arrangement of electrodes for a 2D electrical survey and the series of measurements made to construct a pseudosection for the Wenner electrode arrangement (After Loke *et al.*, 2003).

in the effective depth of investigation is obtained. The acquired resistance values are changed to values of apparent resistivity, " ρ_a " (in ohm-meters) which is then utilized modeling of the true subsurface resistivity distribution.

A total of nine profiles were carried out; the profiles were of different length depending on availability of space. Electrode separation of three meters were adopted for two profiles, while five meters were maintained for the remaining seven profiles (FIG. 3). The profiles of the resistivity investigation were placed in such a way that they could offer information on the migration of the landfill leachate and possible contamination plume.

The data were acquired at different levels as shown in FIG. 2, at level one, the electrode spacing is "a" meters apart, at level two the electrode spacing is "2a" meters apart and so on. As the data level increases the electrode spacing increases with corresponding increase in the depth of investigation. Once the apparent resistivity, electrode spacing and distance locations in a test file is imputed into the Res2DInv software, apparent resistivity pseudo-section is created. The inversion process continues until root mean square (RMS) error amongst the computed and measured apparent resistivity is substantially reduced. The obtained pseudo-section of the apparent resistivity serves as a means of displaying the measured field values which assist in providing the information needed for the interpretation of the subsurface condition. In each section, the horizontal axis represents distance along the surface and also spacing between electrodes while the vertical axis represents depth. The colour legend at the bottom of the section represents apparent resistivity values.

3.2 Sample collection

Surface water, groundwater and leachate samples were collected during the two sampling episodes in January and September 2017 for dry and wet seasons respectively.

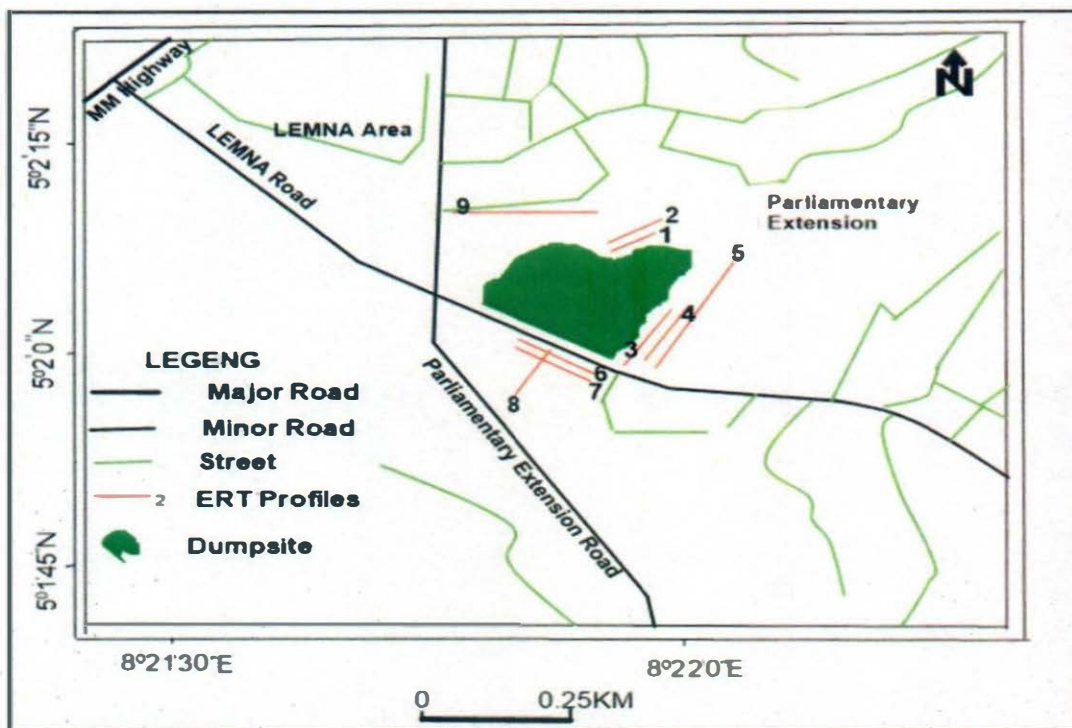


FIG 3: Map of the study area with orientation of ERT profiles around the Dumpsite

The underground water samples were sampled from boreholes around the dumpsite and control points, Surface water samples were obtained from, streams and rivers within the vicinity of the dump site, while leachate samples were obtained from the dump site leachate (FIG. 1). A total of 29 groundwater samples, seven surface water and three leachate samples were collected for hydrochemical and bacteriological analysis. Before the collection of the water samples and leachates, the pH, electrical conductivity (EC), temperature and total dissolve solid (TDS) were carried out in the field by means of HANNA multiparameter probe (model HI 9813-5) and dissolved oxygen (DO) was determined using dissolved oxygen analyser model JPB-607A. The samples were collected into clean 25cl polyethylene bottles after rinsing with aliquot of the sample to be collected. To make sure the borehole samples were representative of the underground water, the boreholes were properly purged to remove all the stagnant water from the borehole, before sampling from the well head (Plate 4). The stream and river samples were collected by submerging the sample bottle well below the surface free from films that could be a possible source of heavy metal contamination (Hem, 1985). Duplicate samples were also collected at each sampling points. The duplicate samples were passed through a 0.45 μ m filter paper to separate suspended particles that may dissolve and affect the concentration of some metals. 2 ml of concentrated nitric acid (HNO₃) was used to acidify the samples in order to prevent precipitation of the ions. The samples were well labelled and preserved in coolers, the preserved samples were transported to the laboratory within 72 hours for analysis.

3.3 Sample analysis

93.3.1 Water and leachate sample

The acidified and filtered duplicate samples were analysed for heavy metals using solar



PLATE 4: Photograph showing purging and collection of representative sample from a borehole at location 6BH (N 5° 1' 54.0", E 8° 22' 2.4")

69 Atomic Absorption Spectrometer, thermo elemental, at Akwa Ibom State Research and Development Laboratory, Ministry of Science and Technology Uyo. The non-acidified water samples were analysed for major and minor ions and other parameters at University of Uyo Soil Science Laboratory. The various analytical methodologies used for analysing physicochemical parameters are presented in Table 4. Each of the analysis was repeated until concordant results were obtained and all analysis were done following to the standard methods (APHA, 1998).

The microbial populations were determined by the method of Chesbrough (2005). one ml of the water sample was passed through serial dilution to the sixth factor. 1 ml of the diluent was plated out on molten sterile algae (commercial grade) using the pour plate method. The pour plate was allowed to set (solidified) and incubated in the incubator for 24 hours at 37 °C (44 °C for *E. coli*) for the colonies to develop. After incubation the colonies were counted and reported, the results were multiplied by the dilution factor and the result presented in standard form. The microbial populations were isolated on different growth media which were prepared according to the manufacturer's specification and sterilized in the autoclave at 121 °C for 15 minutes at 15 psi, before they were used for isolation of the different microbial parameters as presented in Table 5. The different microbial species were identified by their colour and morphological examination.

3.4 Data analysis and interpretation

In order to achieve the set objectives, different interpretation tools were applied to the data acquired from the field and laboratory.

3.4.1 Pumping test and Static water level

Pumping test data was analysed using the Jacobs approximation method. The time-drawdown data were plotted on a semi-log graph paper to obtain the aquifer parameters.

TABLE 4

Laboratory equipment/method used for the analysis of different parameters in water and leachate

PARAMETERS	METHOD/EQUIPMENT
Temperature, pH, TDS, EC	HANA multiparameter probe (HI 9813-5)
DO	Oxygen analyser (JPB-607A)
Acidity, hardness, alkalinity (CO_3^{2-}), COD, Cl^- , Ca^{2+} , Mg^{2+} DIC, TDC	Titration Filtration and oxidation
K^+ , Na^+	Flame photometer (FP 640)
NO_3^- , NO_2^- , PO_4^- , NH_4^- , SO_4^{2-}	UV visible Spectrophotometer (752)
Cu, Pb, Zn, Cd, Mn, Cr and Fe	Atomic Absorption Spectrometer

TABLE 5

Growth media used in the isolation of microbial parameters in water and leachate samples

MICROBIAL PARAMETER	GROWTH MEDIA
Coliform bacteria	Macconkey agar
Total fungal count	Sabourand destrose agar
<i>E. Coli</i>	Eosin methylene blue agar
Vibro cholera	Tiosulphate citrate bile salt sucrose (TCBS) agar
<i>Salmonella and shigella</i>	Salmonella and shigella agar
Total coliform bacteria	Macconkey agar

While static water levels monitored from boreholes were used to determine the hydraulic heads and groundwater flow direction by means of kriging interpolation techniques.

3.4.2 Classification

The waters were categorised into hydrochemical facies representing water types based on the divisions of the Piper-trilinear diagram proposed by Back and Hanshaw (Hiscock, 2005). Piper diagram was prepared from the hydrochemical data to offer a clear representation of the prevailing water types. Also, for a better appreciation of the hydrochemistry and comparison of the water type, the revised Piper diagram by Chadha (1999) was employed. In Chadha diagram, the differences in milliequivalent proportion between alkaline-earths ($\text{Ca}+\text{Mg}$) and alkali-metals ($\text{Na}+\text{K}$) is plotted on the X-axis and the differences in milliequivalent proportion amongst weak acidic anions (CO_3+HCO_3) and strong acid ($\text{Cl}+\text{SO}_4$) is plotted on the y-axis. The point will fall in one of the four possible sub-fields and the hydrochemical processes and facies proposed by Chadha is inferred.

The water quality categorisation based on the Styfzand classification scheme (Styfzand, 2012), was used also as it takes into account uncommon water types which are typical of anthropogenic pollution. The Styfzand hydrochemical classification system combines the superior features of the existing classification with the new. This was utilized to group the water specimens into a number of water types. Obtaining a water type involves successively determining the main type, type, subtype and class of the water sample (Table 6). Separate levels of the unit contribute to the final naming of water type. The main type is obtained on the basis of chloride concentration in the water sample, there are six different types; Fresh (F), Fresh- Brakish (F_b), Brakish (B), Brakish-Salt (B_s), Salt (S) and Hyperhaline (H). The type is determined by the total

TABLE 6

Determination of symbols for Styfzand classification system (Modified from Styfzand, 2012)

Classification	Parameters	Units	Code-code name
Main type	Cl ⁻ (mg/l)	< 150	F-Fesh
		150-300	F _b - Fresh-brakish
		300-1000	B-Brakish
		1000-10000	B _s -Brakish-Salt
		10000-20000	S-Salt
		>20000	H-Hyperhaline
Type	Total hardness (mg/l)	<5	x-Very soft
		5-10	0-Soft
		10-20	1-Moderately hard.
		20-40	2- Hard
		40-80	3-Very hard
		80-160	4- 5- 6- 7- 8- 9- Extremely hard
		160-320	
		320-640	
		640-1280	
		1280-2560	
>2560			
Class	(Na+K+Mg) meq/l corrected	$< -(0.5Cl^-)^{1/2}$	(-)-(Na+K+Mg) _{deficit}
		$-(0.5Cl^-)^{1/2} \leq (Na+K+Mg) \leq (0.5Cl^-)^{1/2}$	(0)-(Na+K+Mg) _{equilibrium}
		$(Na+K+Mg) > (0.5Cl^-)^{1/2}$	(+)-(Na+K+Mg) _{surplus}

hardness which changes between very soft and extremely hard (Table 6). The most essential cation and anion determines the name of the subtype, firstly, the strongest ion is obtained equally for the cation (Ca+Mg, Na+K+NH₄ or Al+Fe+Mn) and anion (Cl⁻, HCO₃+CO₃ or SO₄+NO₃+NO₂) family, and then the strongest ion of both families is taken to form the combination (FIG. 4). Each subtype is further divided into three classes based on a new parameter; the sum of Na+K+Mg in meq/l adjusted for a contribution of sea salt, according to this relation given by Styfzand (2012).

$$(\text{Na}+\text{K}+\text{Mg})_{\text{corrected}} = (\text{Na}+\text{K}+\text{Mg})_{\text{measured}} - 1.016\text{Cl}^- \quad 16$$

The three classes are (Na+K+Mg)_{deficit} (-), (Na+K+Mg)_{equilibrium} (0) and (Na+K+Mg)_{surplus} (+).

3.4.3 Statistical analyses

Hydrochemical data was also interpreted using statistical methods, univariate methods including mean, range and standard deviation were used to analyse data. Multivariate statistical methods were also employed to determine detailed inter-relationship and associations between variables as well as the factors controlling the hydrochemistry of the area, correlation analysis, principal component analysis (PCA) and cluster analysis were applied. Correlation analysis is an initial descriptive method to evaluate the degree of relationship between the variables involved. The aim of the correlation investigation is to quantify the strength of association observed amongst two variables. Such connotation can be used to draw inference about casual relationship between the variables. PCA was employed to reduce many variables in the data set to a few, combined variables that signify water quality processes in the area. The PCA was used to identify relationships between these variables. The reduced observations were grouped into principal components, where connections amongst Hydrochemical variables can be recognised.

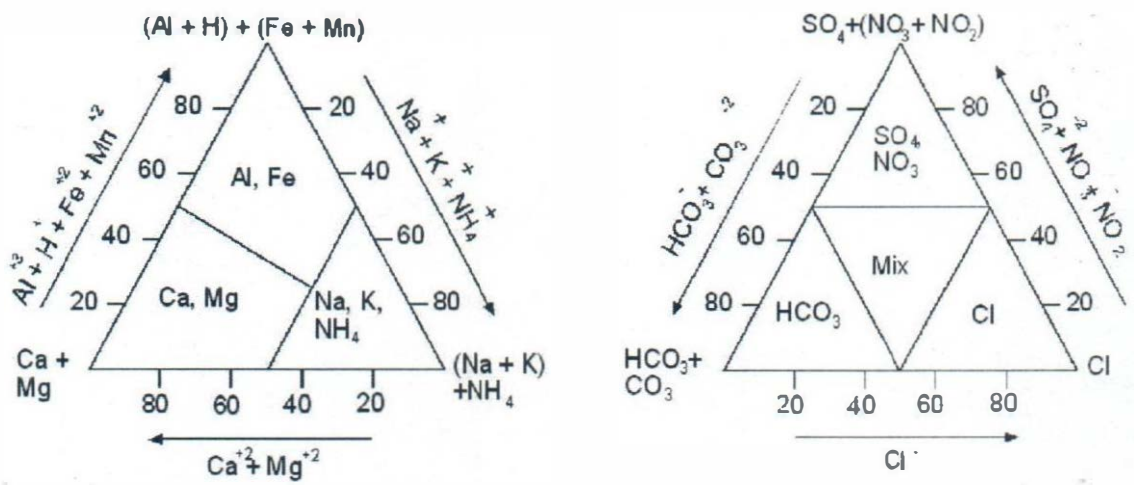


FIG. 4: Subdivision of types based on the proportionate portion of main constituents in the sum of cation (left) and anion (right) in meq/l (Styfzand, 2012)

The components could be applied in the understanding of the main mechanisms influencing the groundwater chemistry (Salifu *et al.*, 2012). These components can also be employed in the identification of the most important variables accountable for the major underlying natural or anthropogenic processes (Guler *et al.*, 2012).

Cluster analysis is a multivariate statistical classification technique that groups related observations (Belkhiri *et al.*, 2010). Hierarchical cluster analysis (HCA), which sequentially joins the most related observations, is commonly employed in hydrochemical analyses to categorise different chemical characteristics (Wu *et al.*, 2014; Askri, 2015). In this work, HCA was useful by means of Euclidian distance with Ward's linkage technique for computing cluster distance. Observations classified using this approach are more precise than single linkage, complete linkage, and average linkage techniques (Moya *et al.*, 2015). The Ward's technique takes on the nearest-neighbour chain process to find the optimal pair of groups for merge clustering, and creates the most unique hydrogeochemical signature clusters for groundwater samples, it identifies groups of water samples with similar hydrochemical characteristics. The PCA and HCA methods were used on the hydrochemical data set of the underground water samples. The Statistical Package for Social Sciences (SPSS) software version 20 was deployed to carry out the analyses.

3.4.4 Bivariate plots and ionic ratios

As underground water flows from the recharge points towards the discharge points it undergoes chemical changes due to the composition the aquifer materials, entrapped solutes and clayey deposits in sedimentary rocks. Cross plots and ionic ratio analysis were used to gather information on some of these reactions. Some samples with high ionic concentration were excluded and the concentration of the ions were converted to milliequivalent per liter (meq/l) in order to combine the various ions in a chemically

meaningful way (Nwankwoala & Udom, 2011). The plots were prepared between some major ions.

3.4.5 Hydrochemical modelling

Geochemical modelling is an instrument used in identifying geochemical processes and for forming their evolution in time and space. The computer software PHREEQC version 3 (Parkhurst & Appelo, 2017) was utilised to carry out geochemical speciation and to calculate the SI's of the mineral phases in order to forecast the phases likely to influence the occurrence of certain contaminants in groundwater. SI's are deployed to appraise the degree of equilibrium amongst water and mineral species. It is a useful factor for the evaluation of the nearness to equilibrium for several solubility reactions, relating the tendency of the solution to dissolve or precipitate a set of minerals. Batch reaction was modelled by mixing the leachate sample and the groundwater sample to analyse the likely reaction that may take place in the process. Inverse modelling was applied to calculate the chemical reactions that explains the change in composition of water along the flow path. Also reactive transport modelling was done to mimic the advection, dispersion and reactions as the water flows through a one dimensional flow line.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Hydrogeological characteristics

4.1.1 Aquifer characteristics and parameter

The schematic geological cross-section between the drilled boreholes is shown in FIG. 5. The results of lithological interpretation of the cuttings indicates that the aquifer is of varying thickness ranging from 18 m to 42 m and extend across the study area. This is differentiated into upper and lower aquifers due to the existence of confining strata in some parts. The aquifers generally were unconfined, and semiconfined. However, the presence of an artesian well identified close to the dump site (location 7BH) suggest the existence of a confined aquifer in the region. The confined layers are made up of clays in most part of the study area as observed in road cuts and drill cuttings. The aquifer materials consist of clayey sand to sand and varying proportion of gravel and organic matter in some areas.

The results of the aquifer test are presented in Appendix 3 and the time-drawdown curves of the discharging wells are presented in FIGS. 6 and 7. Transmissivity is evaluated from the slope of semi-logarithmic curve (FIGS. 6 & 7) obtain from a constant discharge test using equation 17.

$$T = 2.3Q/4\pi\Delta s \quad 17$$

Further simplification of the equation 17 yield

$$T = 2.3Q/4\pi\Delta s = 0.183Q/\Delta s \quad 18$$

Where Q is the constant discharge rate, Δs is the drawdown difference per log cycle of time. The estimated transmissivity values ranged between 179.84 m²/d and 1280.63 m²/d with average value of 667.02 m²/d (Table 7), indicating that the aquifer has high

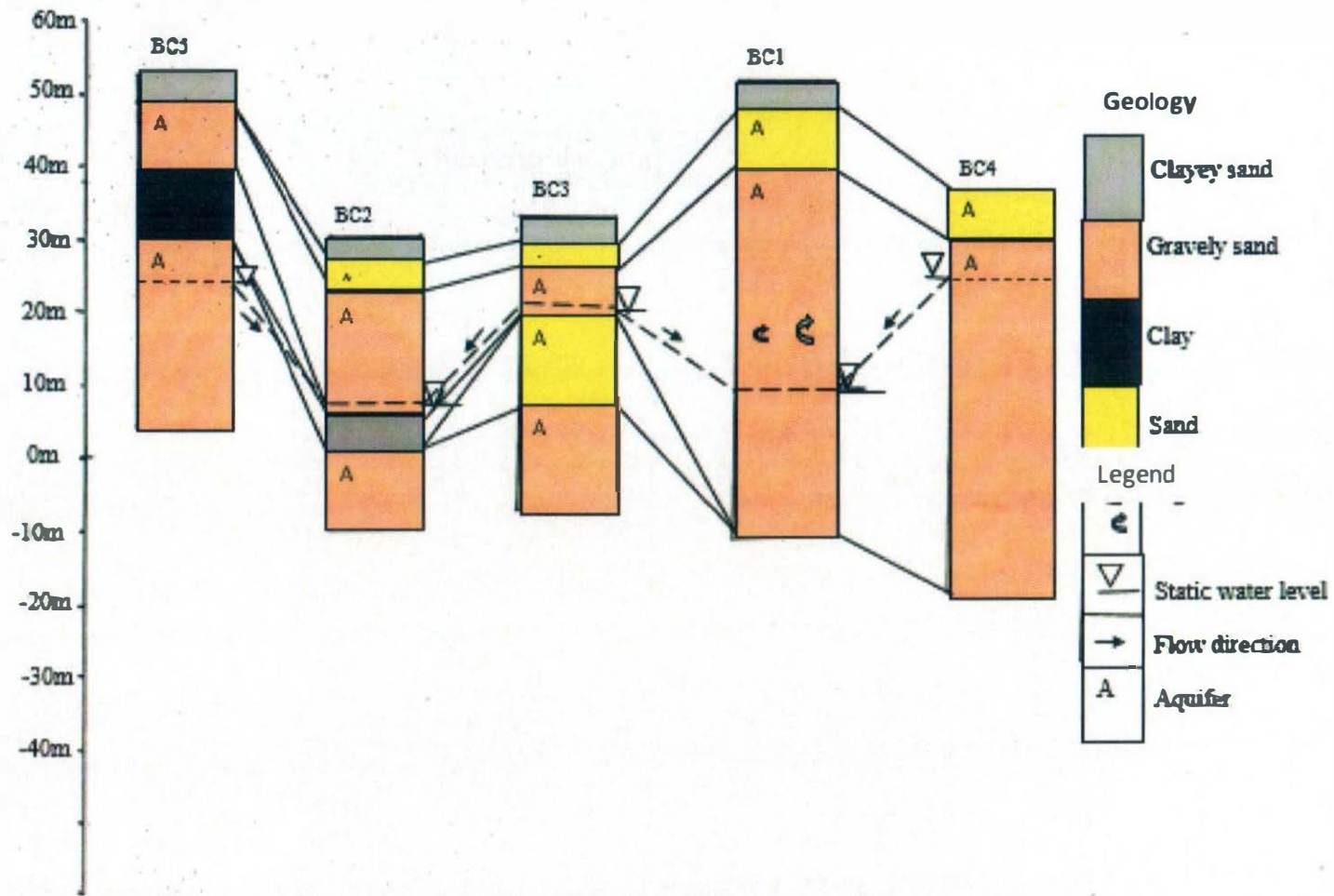


FIG. 5: Hydro-lithologic section across the study area, horizontal axis not drawn to scale

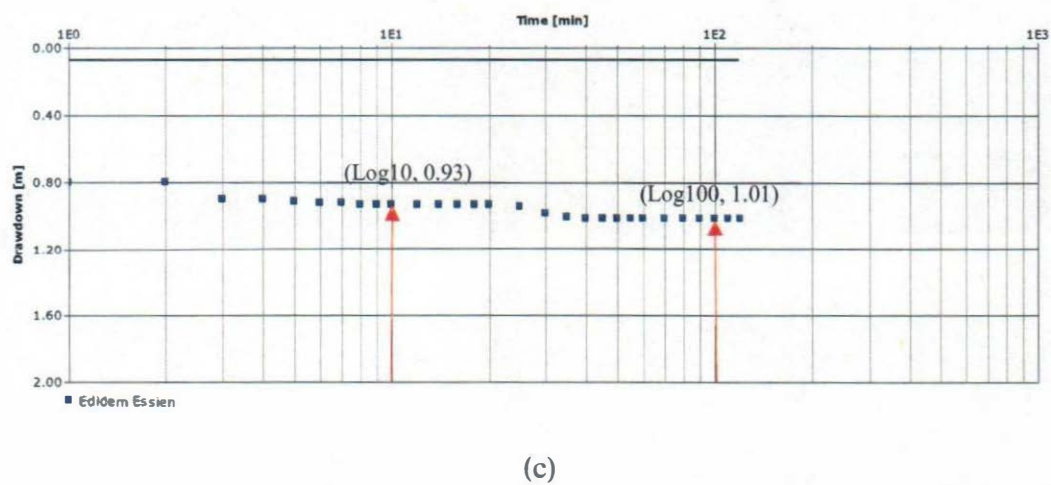
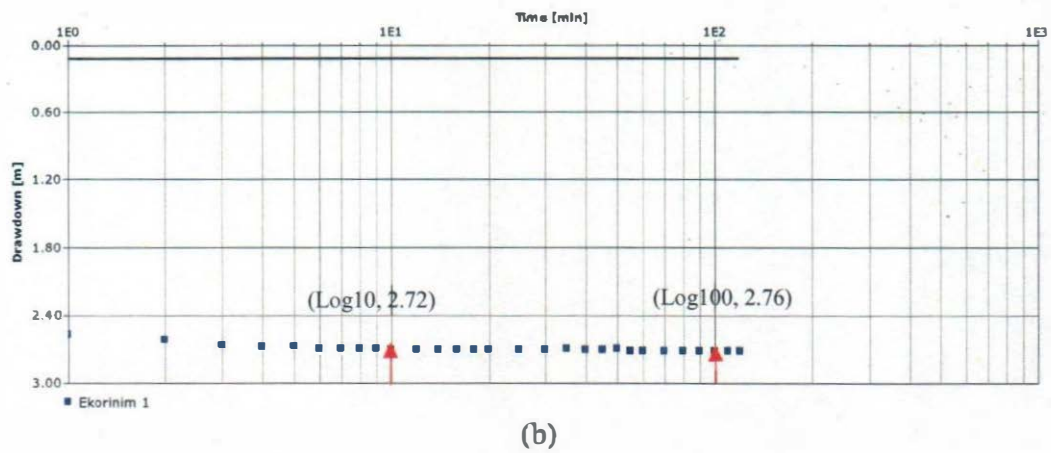
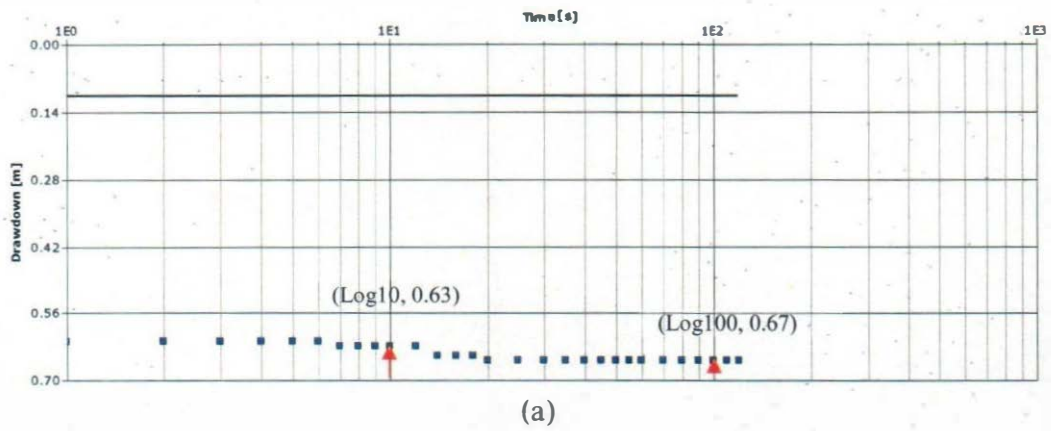
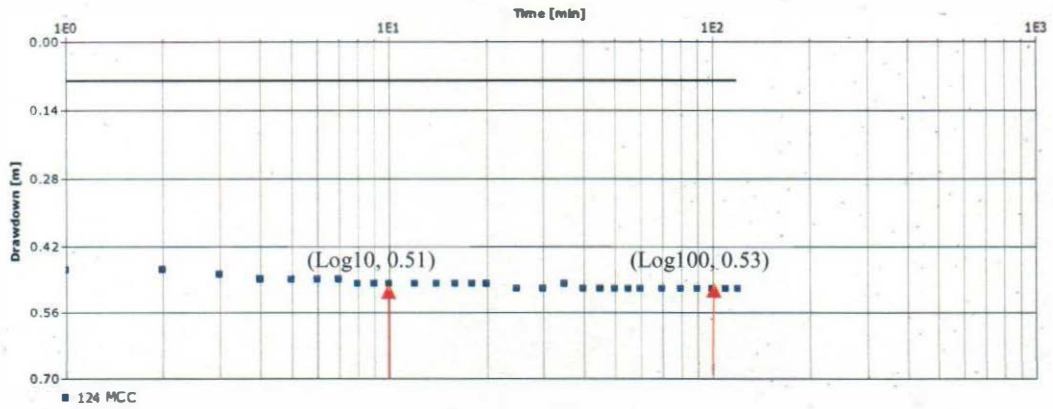
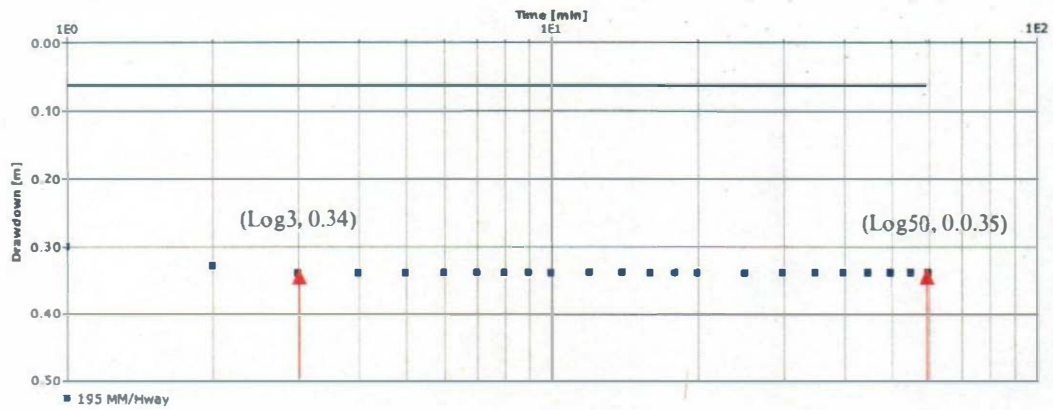


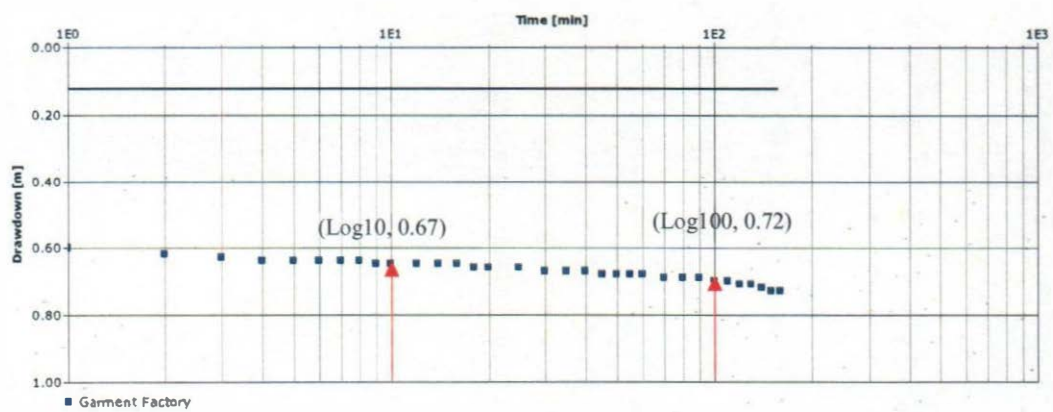
FIG. 6: Time-drawdown curve for the discharging well (a) PT1, (b) (PT2) and (c) PT3



(a)



(b)



(c)

FIG. 7: Time-drawdown curve for the discharging well (a) PT4, (b) PT5 and (c) PT6

TABLE 7

Aquifer parameters derived from pumping test data

Parameters	PT1 (6BH)	PT2 (12BH)	PT3 (28BH)	PT4 (29BH)	PT5 (30BH)	PT6 (31BH)	Max	Min	Average
Thickness (screened section) (m)	8	8	8	8	8	8	8	8	8
Transmissivity (m ² /d)	525.71	608.75	179.84	798.43	1280.63	608.75	1280.63	179.84	667.02
Specific capacity (m ³ /d/m)	174.11	48.92	77.84	171.1	205.82	182.27	205.82	48.92	143.34
Hydraulic conductivity (m/d)	65.71	76.09	22.48	99.80	160.08	76.09	160.08	22.48	83.38

transmissivity magnitude, suggesting that the groundwater yielding capacity is of lesser regional importance in terms of withdrawal (Krasny, 1993). Amah a Anam (2016) and Edet (2014) reported transmissivity of 485 to 1393.8 m²/d and 1957 to 24748 m²/d respectively, within the Benin Formation.

The SC is the discharge rate per drawdown and it is the expression of the well productivity (Freeze & Cherry, 1979) and is represented mathematically as;

$$SC = Q/s \quad 19$$

And Q is the discharge rate in m³/d and s is the drawdown in m.

The estimated SC of the wells ranged between 48.92 m³/d/m and 205.82 m³/d/m with an average value of 143.34 m³/d/m (Table 7) indicating that the wells in the area are very productive, these values are also within the range of 9.02 to 346 m³/day/m reported by Amah and Anam (2016).

4.1.2 Hydraulic conductivity

The hydraulic conductivity (K) was estimated through the Hazen method, from the results (Appendix 4), the effective diameter of all the samples ranged between 0.1 and 0.74 mm which is within the range recommended for use in the estimation of K, however, the U values of 9 percent of the samples were above 5 and so the K values computed from these samples were not considered (Freeze & Cherry, 1979). A small value of U means the soil is well sorted. Based on Casagrande standard, 72 percent of the samples are well sorted, 23 percent are moderately sorted and 5 percent are poorly sorted (Knodel *et al.*, 2007). The estimated K ranged between 0.0001 and 0.0056 m/s equivalent to 8.64 m/d and 486 m/day with geometric mean of 53.14 m/day. Also the established relationship between transmissivity and K given in equation 20 was applied to determine the hydraulic conductivity from the aquifer test results.

$$T = Kb \quad 20$$

Where, b is the aquifer thickness taken here as the borehole screen length of 8 m. From this relationship the estimated hydraulic conductivity based on the aquifer test data ranged between 22.48 m/d and 160.08 m/d with a mean value of 83.38 m/d (Table 7), which is still within the same range considering the fact that the screened section, which is within the saturated zone, is likely to have K value that lies above the average value derived from the Hazen method (Todd, 1980). This value is comparable with that of 110 to 285 m/d and 9.7 to 27.9 m²/d reported by Edet (2014) and Amah and Anam (2016) respectively. The K values from the study indicates high conductivity base on Reynolds standard classification of hydraulic conductivity values (Reynolds, 1993). The wide range of the hydraulic conductivity is an indication of the heterogeneous nature of the area, and it is a measure of the sediment capacity to pass on water. The sediments high conductivity suggest that the leachate will migrate quickly downward and reach the groundwater.

The hydraulic conductivity of porous media influences the displacement of fluids in the pores and affects the fate and transport of contaminants in the environment. The implication is that areas with low hydraulic conductivity has higher attenuation capacity and hence reduces contaminants transport within the system.

4.1.3 Groundwater levels and fluctuation

The groundwater fluctuation was monitored in the dry and wet period; the result shows lower level in respect to the ground surface in the dry period when compared to higher levels in wet period. Though not all the wells could be assessed in both seasons, for the wells assessed during the study, the depth to water table varies from 0 m to more than 44.5 m, this is within the range of that recorded by Edet (2014), which fluctuates from below 5 m to over 70 m. The average water levels were 20.14 m and 14.26 m in dry and wet period respectively (Table 8).

TABLE 8

Fluctuation in static water level between dry and wet seasons

LOCATION ID	STATIC WATER LEVEL WITH RESPECT TO GROUND SURFACE (M)		
	DRY SEASON	WET SEASON	CHANGE IN STATIC WATER LEVEL
MW1 (3BH)	12.80	12.68	0.12
MW2 (4BH)	15.85	15.80	0.05
MW3 (5BH)	11.50	11.22	0.28
MW4 (6BH)	-	3.78	-
MW4A	10.96	10.65	0.31
MW4B	-	6.50	-
MW5 (7BH)	0	0	0
MW6 (8BH)	-	3.73	-
MW6A	-	3.20	-
MW6B	3.50	3.20	0.30
MW7 (9BH)	44.50	-	-
MW8 (11BH)	25.30	-	-
MW9 (12BH)	25.85	25.80	0.05
MW10 (13BH)	23.2	22.76	0.44
MW11 (14BH)	15.60	15.25	0.35
MW12 (15BH)	32.50	32.30	0.20
MW12B	-	28.41	-
MW13 (20BH)	-	18.60	-
Average	20.142	14.258	

Higher level in the wet season is an indication of higher recharge from precipitation and nearby Great Kwa River, in the wet period. The change in static water level between the wet and dry seasons ranged from 0.05 to 0.44 m.

4.1.4 Groundwater movement

4.1.4.1 Flow pattern

Water table contour did not show any definite flow pattern in the dry and wet season (FIGS. 8 & 9), this is an indication of the heterogeneous nature of the aquifer system. This may arise majorly from the physiography of the area, and the presence of aquitard systems as their presence commonly increases the complexity of flow paths, and are capable of deflecting flows, and control boundaries between flow systems at local, intermediate and regional scales (Cherry *et al.*, 2006). The contours were closely spaced in some parts than others indicative of groundwater inflow from such areas. The flow pattern suggest that they are many water divide in the area. The general flow pattern is northward but tends towards the north-eastern direction during the wet period.

4.1.4.2 Hydraulic gradient

The hydraulic gradient was derived from the water table contour generated for the dry and wet season. This was done by drawing a line perpendicular to the equipotential line along the flow direction, on the contoured map and determining the change in head and the distance base on the scale of the map (FIGS. 8 & 9). The results (Table 9) shows that the hydraulic gradient varies between 1.30×10^{-2} and 1.38×10^{-1} with mean value of 4.50×10^{-2} in the dry season and 1.00×10^{-2} and 5.20×10^{-2} with mean value of 2.80×10^{-2} in the wet season, indicating that there was a wider range of hydraulic gradient distribution in dry period compared with that of the wet period. High hydraulic gradient affects the average velocity of groundwater and contaminants movement in an area.

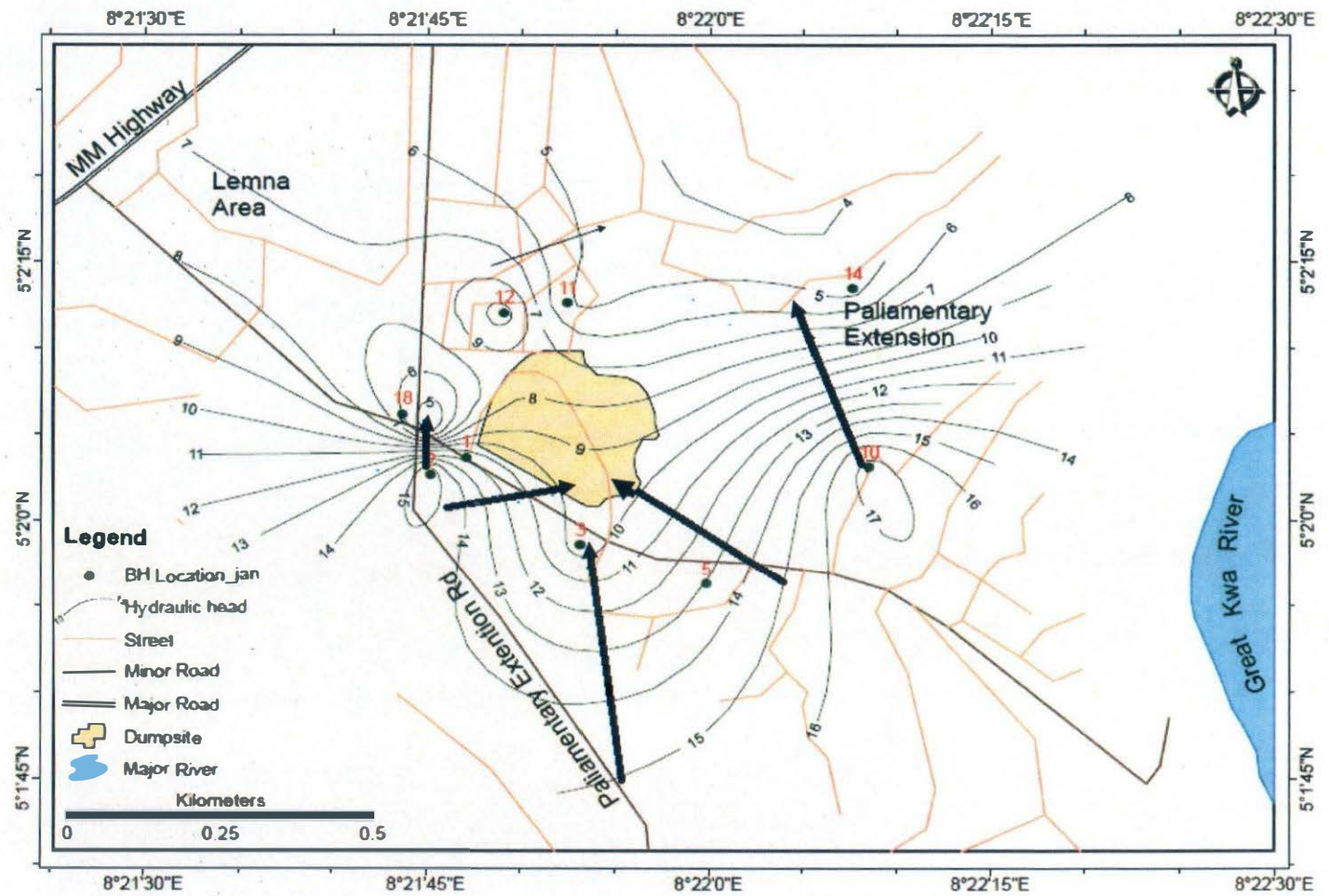


FIG. 8. The study area with equipotential lines and flow direction in the dry period

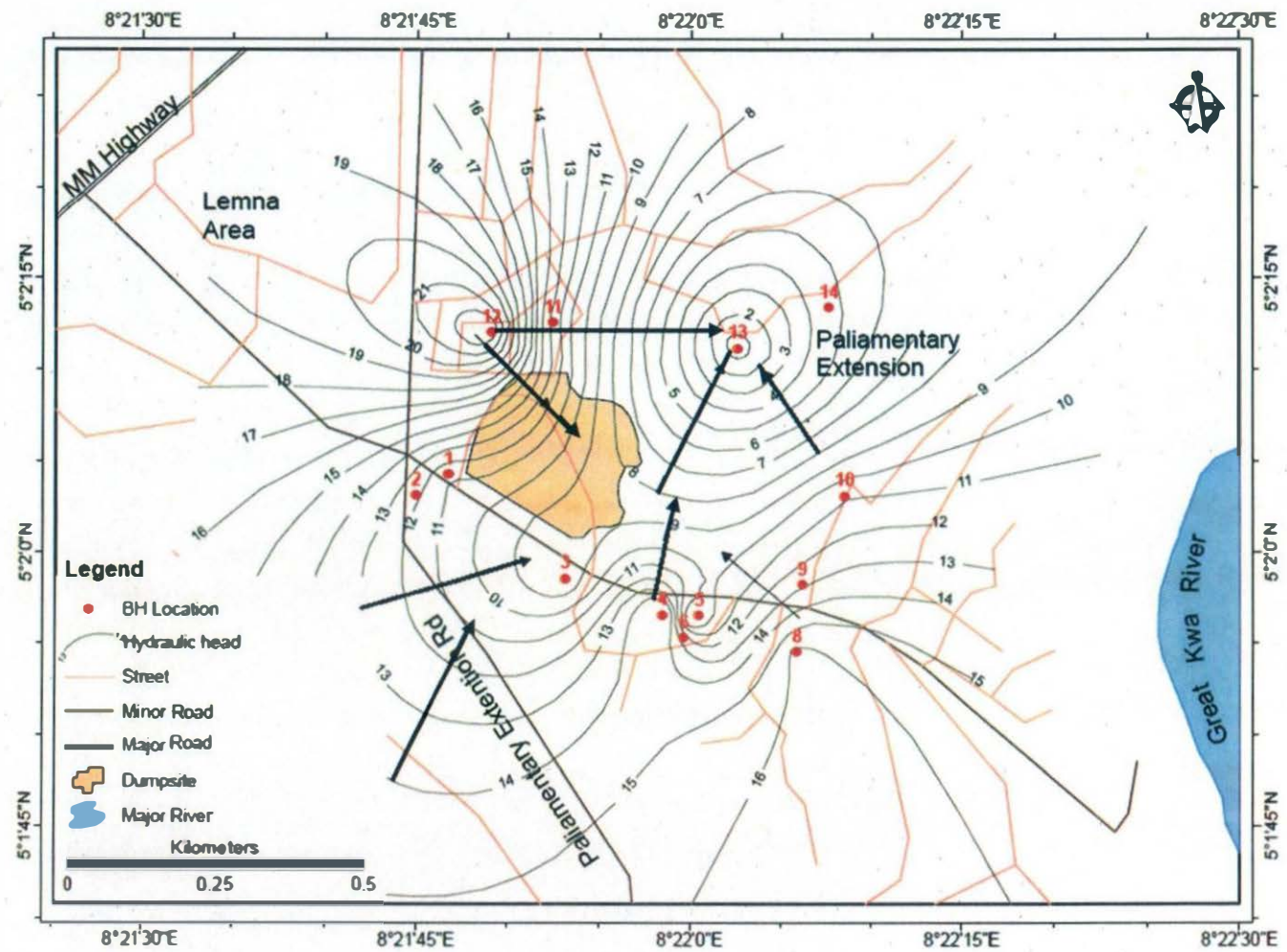


FIG. 9. The study area with equipotential lines and flow direction in the wet period

Table 9
Estimated hydraulic gradient

	Length of flow line (m)	Change in equipotential line (m)	Estimated hydraulic gradient x 10⁻²
Dry season			
1	65	9	13.8
2	171	4	2.30
3	381	5	1.30
4	302	5	1.70
5	289	10	3.50
Dry season average			4.50
Wet season			
1	296	3	1.00
2	276	4	1.40
3	368	19	5.20
4	263	7	2.70
5	171	6	3.50
Wet season average			2.80

4.1.4.3 Average flow velocity and residence time

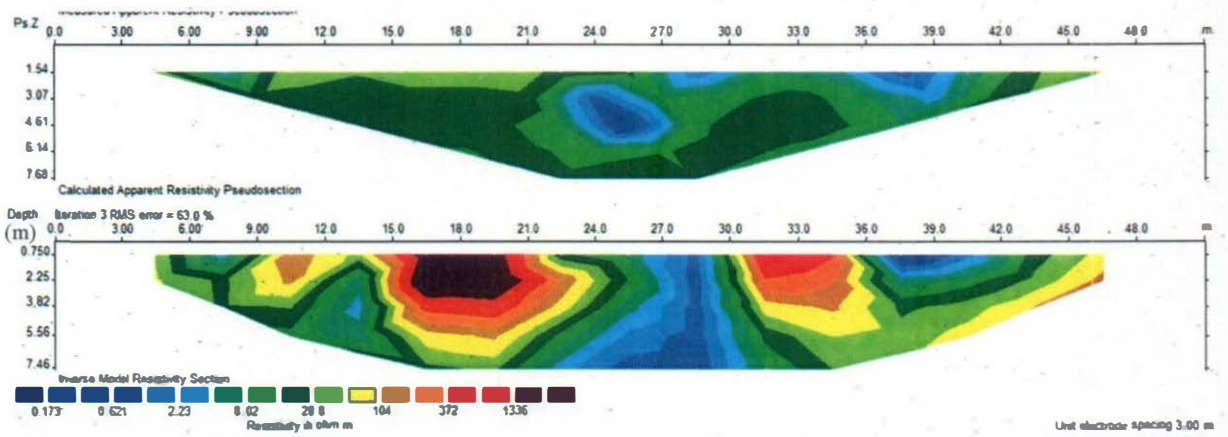
The groundwater flow velocity was estimated based on the average K value estimated from the grain size analysis, and hydraulic gradient (Table 9) from groundwater contour map (FIGS. 8 & 9) using the Darcy equation.

$$V = Ki \quad 21$$

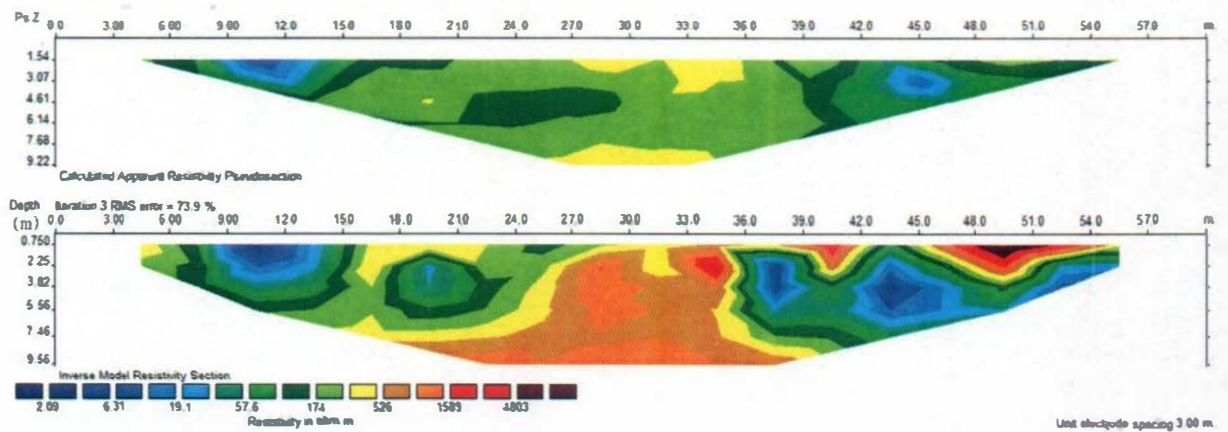
And V is the average flow velocity and i is the hydraulic gradient. From equation 21 using the mean K of 53.14 m/day and maximum and minimum i of 1.38×10^{-1} and 1.30×10^{-2} , the maximum and minimum average groundwater flow velocity was 7.33 m/day and 0.69 m/day respectively for the dry period. While in the wet period the maximum and minimum hydraulic gradient of 5.20×10^{-2} and 1.00×10^{-2} gave the maximum and minimum average groundwater flow velocity of 2.76 m/day and 0.53 m/day respectively. These results indicate that the area experience higher flow regime in the dry period compared to the wet period. Geometric mean of the flow velocity of 2.6 m/day (949 m/year) is an indication of short residence time of groundwater in the area, using an estimated flow distance of 2000m beginning from the upper flow boundary to the lower boundary, then the projected residence time is 2.11 years (2000/949 years). The implication of this is that, all things being equal, it will take a conservative contaminant one year to travel a distance of 949 m within the study area. FIGS 8 and 9 shows the equipotential lines and flow pattern during the dry and wet season respectively.

4.2 Leachate migration

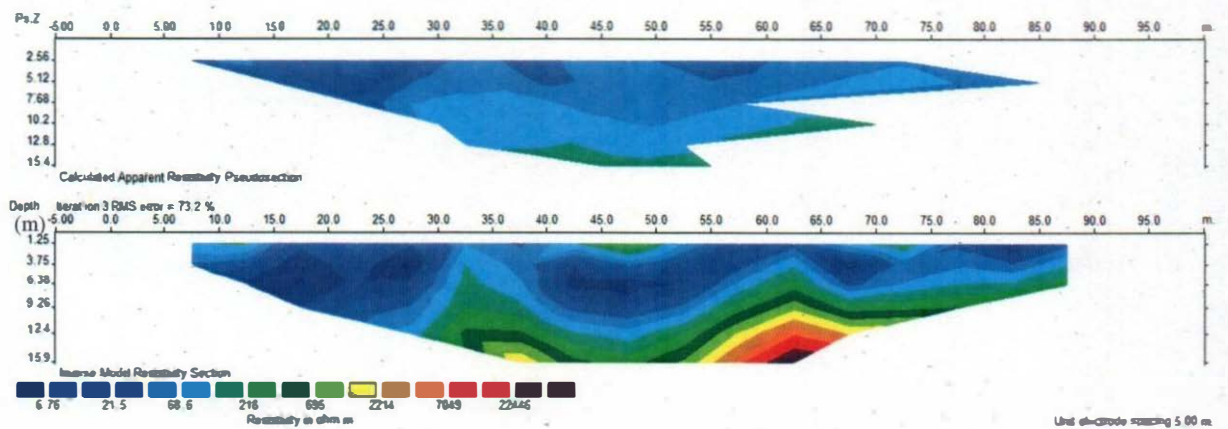
The results of the sub-surface distribution of resistivity is presented in Appendix 5, while the results from the interpretation of the 2-D model are presented in FIGS 10, 11 and 12. In profile one (FIG. 10a)), the low resistivity ($<100 \Omega\text{m}$) was interpreted as leachate migration into the sandy formation, while the areas with high resistivity



(a)

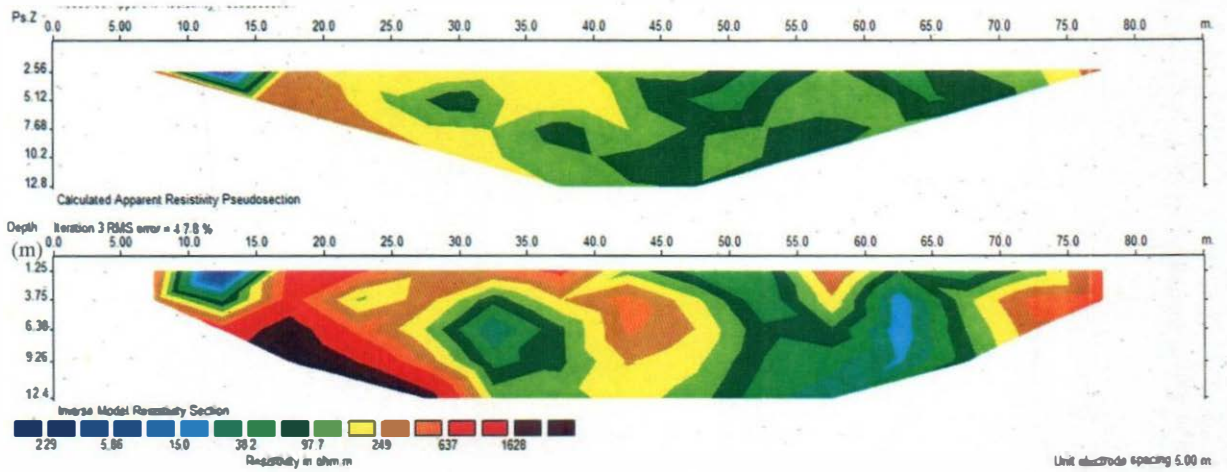


(b)

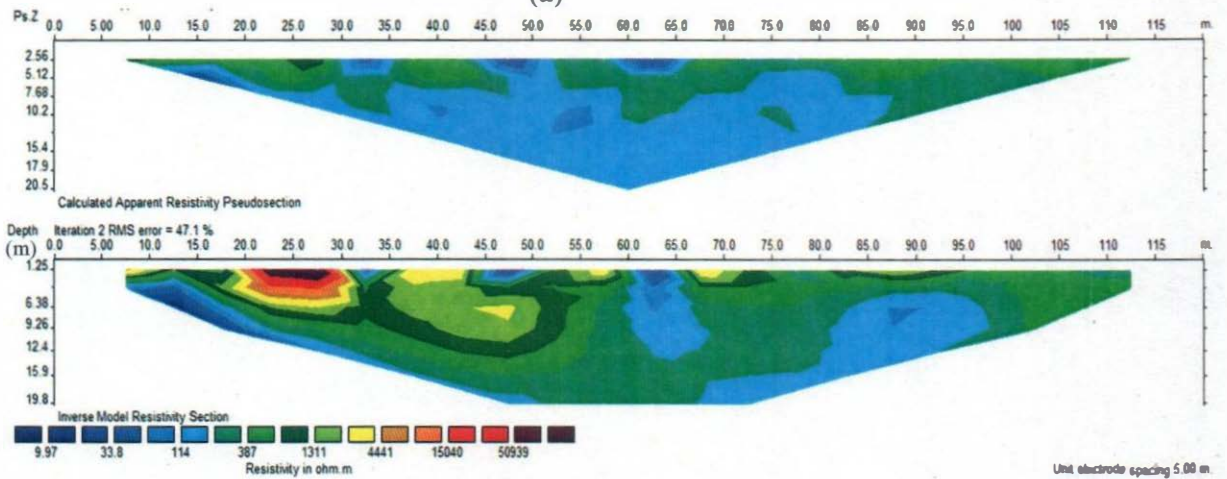


(c)

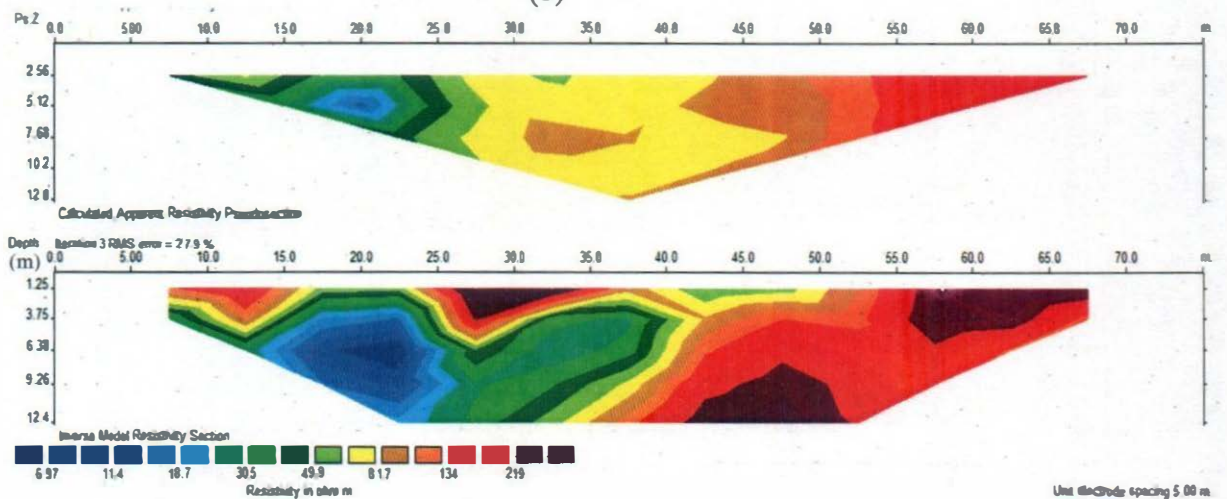
FIG. 10: Apparent resistivity pseudo section and inverse model resistivity section of profile (a) one (b) two and (c) three



(a)

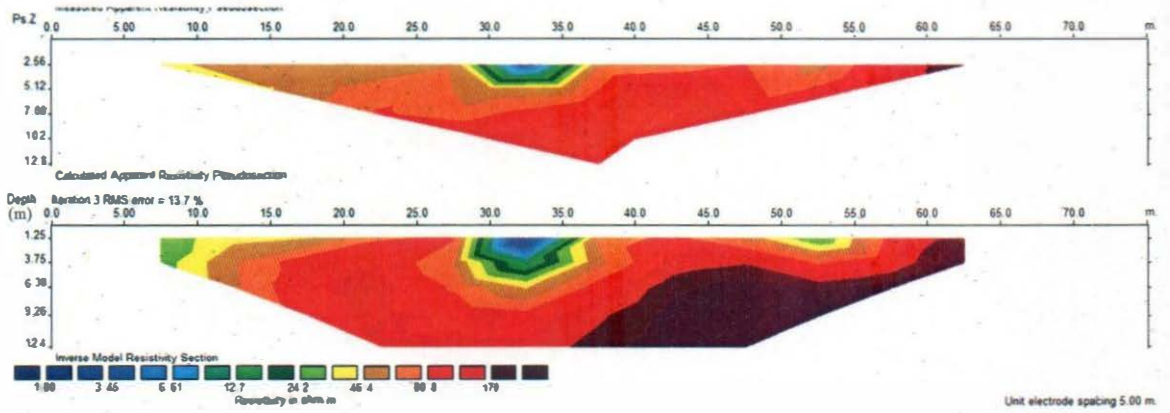


(b)

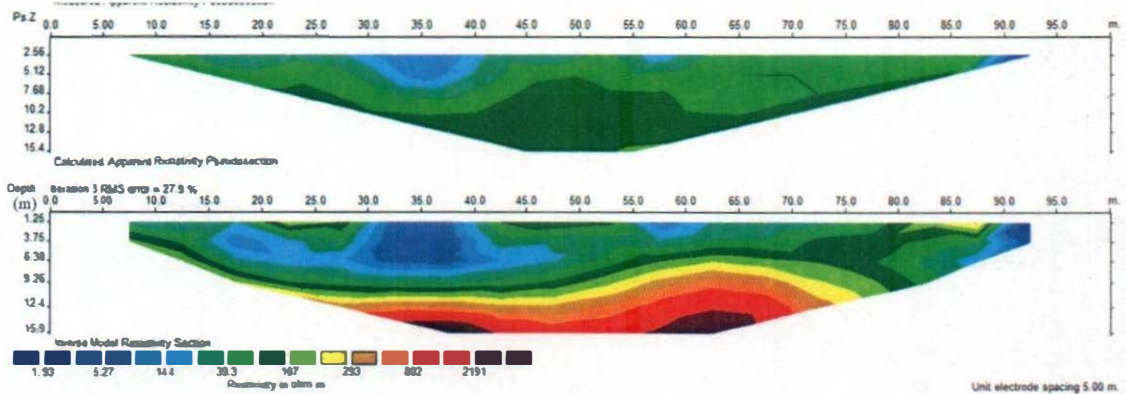


(c)

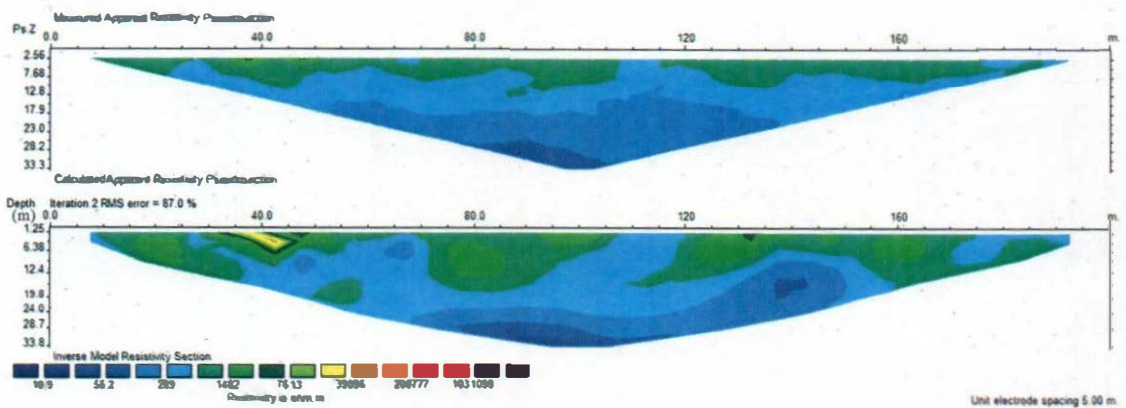
FIG. 11: Apparent resistivity pseudo section and inverse model resistivity section of profile (a) four (b) five and (c) six



(a)



(b)



(c)

FIG. 12: Apparent resistivity pseudo section and inverse model resistivity section of profile (a) seven (b) eight and (c) nine

(>100 Ωm) were interpreted as lateritic sand unaffected by the leachate migration. The results of profile one is dominated by low resistivity areas with pockets of high resistivity areas within the pseudo section. The low resistivity area tends to extend beneath the surface to form conductive flow path which indicate an area of leachate migration, which can be seen to extend beyond the depth of investigation. The area with high resistivity in the section is an indication that the zone is free or save where there is little or no movement of leachate.

The section of profile two (FIG. 10b) indicates a block of resistive zone at the middle flanked by low resistivity zones. The profile suggests a conductive structure on the left and right flank indicated by blue to green coloration. The very conductive area with resistivity value ranging from 2-400 Ωm is surrounded by less conductive zone, which implies that the leachate could have migrated into that area to form a block of plume. The less conductive area with resistivity values of > 526 Ωm indicated by brown to orange colour may represent compacted lateritic sand. Profile two was taken 18 m away from profile one, the section shows that the low resistivity zones are reducing as you move away from the dumpsite, indicating that the area of influence is diminishing horizontally and vertically away.

The section of profile three, four and five shows similar pattern. These profiles were taken parallel to each other, on the south-eastern part of the dumpsite (FIG. 3), with a distance of 20m apart, away from the dump, with profile three closest and five farthest from the dump. From the sections (FIGS. 10c, 11a & 11b) the high conductive zone reduces from profile three towards five, which is an indication that the leachate is migrating. The plume seems to be seeping downwards as the depth to zone of influence is increasing away from the dumpsite towards the water table.

Profile six, seven and eight (FIGS. 11c, 12a & 12b) were taken down slope, to the south of the dump, with profile six and seven parallel to each other and eight cutting across the two in a near perpendicular manner. During the wet season the leachate normally overflow and flow on the surface, the impact of this, has affected this area and is reflected in these three sections. For instance, the low resistivity values of less than $350\Omega\text{m}$ in the entire section six and seven with a clear core of influence in the left flank and centre of section six and seven respectively, is an indication of contaminant migration along that path. Profile eight shows similar pattern but further away from the dump and deeper down the subsurface the effect diminishes as indicated by the higher resistivity values except at the extreme right of the profile which is close to the flow path of the channel. Also an attempt was made to take a control profile not too far away from the dump in the upstream direction for comparison. This profile represented by section nine (FIG. 12c) shows that the upper part of the subsurface is not affected by the leachate compared to the other profiles as indicated by the higher resistivity values in this part of the section, however, the lower section saturated with water displayed very low resistivity values, this could indicate the presence of clay or fine materials within this area. On the whole the presence of low resistivity grounds around the dump is an indication of possible migration of leachate in the subsurface. The presence of indurated sandstone in the area is reflected by the high resistivity values in some sections. The high root mean square error could result from the heterogeneous nature of the sub-surface geology.

4.3 Hydrochemical and biological parameters

4.3.1 Physicochemical parameters

The descriptive statistics of the physicochemical parameters and heavy metals of groundwater, surface water and leachate for study area and control for wet and dry

periods are given in Tables 10 and 11. Details of the analytical results are presented in Appendix 6 and 7.

4.3.1.1 Leachate

In order to access the composition of the leachate three composite samples were collected for analysis, one for wet and two the dry period. The mean temperature in the leachate for the dry season was 26.55 °C and 27.32 °C in the wet period. The pH was 7.3 and 7.8 in dry and wet period respectively. While Electrical conductivity (EC) was 5857.50 µs/cm and 5363 µs/cm in the dry and wet period in that order.

Dissolved oxygen (DO) was 2 mg/l in dry period and 2.75 mg/l in the wet period. The total dissolved solid (TDS) was 10930 mg/l in the dry period and 6300 mg/l in the wet period. The chemical oxygen demand (COD) was 540 mg/l and 840 mg/l for the dry and wet period correspondingly. While the biological oxygen demand (BOD) was 1.63 mg/l and 0.99 mg/l in the dry and wet period correspondingly. The BOD:COD ratio of 0.002 in both season indicate that the leachate is in the stable methanogenic phase, this could be attributed to adequate moisture from rain infiltrating the waste (Kjeldsen *et al.*, 2002). And the hardness was 22.15 mg/l and 14.17 mg/l in dry and wet period respectively.

Apart from EC and TDS all other physical parameters were higher during the wet period compared to the dry period. This indicate that dilution by rain water has impact on the composition of the leachate.

The order of concentration of the main cations in the leachate in the dry season is $\text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+} > \text{NH}_4^+ > \text{Na}^+$ and $\text{NH}_4^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ in the wet period. The variation of this order between the dry and wet season indicate the high mobility of the major cations in the leachate.

TABLE 10

Descriptive statistics of water geochemical data from the study area in wet season

Parameters	Groundwater				Surface water				Leachate	Control
	Maximum	Minimum	Mean	S Dev	Maximum	Minimum	Mean	S Dev	Mean	Mean
Temp ^o C	27.40	26.10	26.68	0.45	27.05	26.07	26.47	0.42	27.32	27.44
Ph	5.55	3.85	4.86	0.52	6.75	4.95	6.08	0.81	7.80	5.61
Ec (μs/cm)	85.45	10.10	33.08	19.95	40	11.00	27.00	12.03	5363	35.13
Dissolved Oxygen (DO) mg/L	4.35	2.05	3.14	0.53	3.45	2.00	2.70	0.59	2.75	3.05
Total Dissolved (TDS) mg/L	93.05	10.00	48.15	22.80	40.5	28.50	33.00	5.34	6300	32.88
Chloride (Cl ⁻) mg/L	184.33	61.45	117.61	35.17	184.32	61.45	122.89	50.16	1228.85	101.81
Carbonate (CO ₃ ²⁻) mg/L	140.00	38.00	74.50	33.22	120	36.00	88.80	37.54	600.00	60.13
Bicarbonate (HCO ₃ ⁻) mg/L	148.15	20.00	67.40	42.77	120.5	50.01	93.87	31.25	73.60	80.32
Nitrate (NO ₃ ⁻) mg/L	10.53	0.98	3.66	2.48	2.14	0.98	1.42	0.51	3.70	2.24
Sulphate (SO ₄ ²⁻) mg/L	5.94	0.81	3.13	1.64	159.52	1.70	54.59	74.20	34.79	2.08
Phosphate (PO ₄ ⁻) mg/L x 10 ⁻²	22	4	8	5	8	3.4	6	2	470	4
Nitrite (NO ₂ ⁻) mg/L	0.15	0.002	0.04	0.04	0.04	0.01	0.02	0.01	0.15	0.02
Salinity (pt)	0.85	0.10	0.49	0.21	0.41	0.28	0.33	0.06	63.10	0.40
Ammonium (NH ₄ ⁺) mg/L	36.01	7.01	14.73	7.43	16.00	11.61	13.54	1.83	380.00	14.43
Chemical Oxygen demand (mg/L)	22.40	5.50	10.26	4.28	10.90	8.85	9.70	0.87	840.00	13.10
Biological Oxygen demand (mg/L)	2.05	0.80	1.17	0.32	1.20	0.83	1.04	0.16	0.99	1.17
Hardness (mg/L)	10.20	2.30	5.36	2.06	7.00	4.00	5.87	1.33	14.17	5.40
Calcium (Ca ²⁺) (mg/L)	128.00	16.00	44.15	40.08	88.00	16.20	53.40	29.37	232.05	43.31
Magnesium (mg ²⁺) mg/L	27.50	3.06	8.01	6.41	16.60	3.20	9.88	5.47	46.20	8.21
Potassium (K ⁺) mg/L	103.48	0.21	9.76	28.18	6.81	1.05	3.02	2.68	30.90	0.49
Sodium (Na ⁺) mg/L	117.11	0.40	10.87	32.05	5.76	0.40	3.01	2.19	21.12	1.92
Copper (Cu) mg/l (x 10 ⁻²)	87.00	0.12	0.35	0.20	0.78	0.03	0.41	0.38	0.83	0.27
Lead (Pb) mg/l (x 10 ⁻²)	76.00	0.10	2.00	1.00	41.00	2.00	22.00	20.00	2.00	1.00
Zinc (Zn) mg/l (x 10 ⁻²)	4.00	24.00	45.00	13.00	64.00	61.00	63.00	2.00	65.00	41.00
Cadmium (Cd) mg/l (x 10 ⁻²)	68.00	1.00	10.00	18.00	5.00	4.00	4.00	0.30	2.00	1.00
Manganese (Mn) mg/l (x 10 ²)	146.00	84.00	104.00	19.00	142.00	115.00	128.00	14.00	111.00	98.00
Chromium (Cr) mg/l (x 10 ⁻²)	17.00	1.00	4.00	5.00	12.00	1.00	7.00	6.00	2.00	1.00
Iron (Fe) mg/l	908	1.82	3.56	2.20	90.09	2.01	46.05	44.00	2.60	2.31

TABLE 11
Descriptive statistics of water geochemical data from the study area in dry season

Parameters	Groundwater				Surface water				Leachate	Control
	Maximum	Minimum	Mean	S Dev	Maximum	Minimum	Mean	S Dev	Mean	Mean
Temp °C	27.75	26.35	26.62	0.39	27.05	26.35	26.61	0.26	26.55	27.75
Ph	5.10	3.35	4.39	0.58	5.45	3.55	4.92	0.97	7.30	5.05
Ec (µS/cm)	130.00	10.00	60.69	34.89	90.00	20.55	42.64	27.62	5857.50	50.00
Dissolved Oxygen (DO) mg/L	5.60	1.35	2.68	1.15	5.05	1.35	2.64	1.44	2.00	1.90
Total Dissolved (TDS) mg/L	78.50	0.02	41.51	23.51	76.00	7.00	32.02	27.78	10930.00	46.00
Chloride (Cl ⁻) mg/L	470.99	36.87	218.17	119.01	331.81	57.15	216.81	100.45	811.10	470.99
Carbonate (CO ₃ ²⁻) mg/L	280.00	24.00	173.05	76.34	240.00	48.05	142.01	80.06	655.00	200.00
Bicarbonate (HCO ₃ ⁻) mg/L	260.00	26.40	160.40	69.90	330.00	19.20	194.30	113.14	1163.00	206.00
Nitrate (NO ₃ ⁻) mg/L	4.04	0.55	2.15	1.14	2.08	0.56	1.21	0.65	69.71	2.08
Sulphate (SO ₄ ²⁻) mg/L	33.92	1.50	22.62	10.62	63.68	0.75	32.33	23.71	74.98	20.24
Phosphate (PO ₄ ⁻) mg/L (x 10 ⁻²)	20.00	1.00	1.00	6.00	18.00	5.00	9.00	5.00	1171.00	20.00
Nitrite (NO ₂ ⁻) mg/L	0.28	0.03	0.17	0.08	0.25	0.06	0.18	0.07	0.92	0.25
Salinity (pt)	0.90	0.23	0.54	0.19	0.81	0.20	0.38	0.25	109.31	0.42
Ammonium (NH ₄ ⁺) mg/L	23.62	6.10	16.39	5.76	22.63	5.95	15.93	6.83	114.68	9.28
Chemical Oxygen demand (mg/L)	21.11	7.15	11.71	4.26	14.69	8.05	12.42	2.57	540.93	12.81
Biological Oxygen demand (mg/L)	4.25	0.60	1.42	0.94	2.65	1.00	1.49	0.68	1.63	0.80
Hardness (mg/L)	22.45	4.39	15.63	5.26	22.05	5.95	12.99	5.92	22.15	14.07
Calcium (Ca ²⁺) (mg/L)	191.00	16.35	82.11	44.99	82.60	24.00	67.18	24.94	644.08	191.00
Magnesium (Mg ²⁺) mg/L	38.20	3.25	16.75	9.01	18.30	4.80	14.18	5.45	127.99	38.20
Potassium (K ⁺) mg/L	11.29	0.36	2.51	2.68	6.93	0.60	2.82	2.43	703.57	0.83
Sodium (Na ⁺) mg/L	9.10	1.21	2.62	1.93	4.45	2.02	3.19	1.16	71.83	1.61
Copper (Cu) mg/l (x 10 ⁻²)	42.00	7.00	29.00	12.00	37.00	14.00	25.00	10.00	343.00	28.00
Lead (Pb) mg/l (x 10 ⁻²)	31.00	0.10	4.00	8.00	9.00	1.00	5.00	3.00	22.00	0.20
Zinc (Zn) mg/l (x 10 ⁻²)	49.00	27.00	37.00	7.00	35.00	7.00	27.00	12.00	327.00	36.00
Cadmium (Cd) mg/l (x 10 ⁻²)	5.00	1.00	3.00	2.00	68.00	2.00	20.00	28.00	23.00	5.00
Manganese (Mn) (x 10 ⁻²) mg/l	143.00	38.00	98.00	29.00	146.00	76.00	97.00	28.00	813.00	78.00
Chromium (Cr) mg/l (x 10 ⁻²)	18.00	0.20	9.20	7.00	14.00	1.00	8.00	5.00	15.00	12.00
Iron (Fe) mg/l (x 10 ⁻²)	559.00	42.00	178.00	124.00	361.00	53.00	158.00	125.00	4959.00	210.00

The concentration of NH_4^+ in dry period was 114.64 mg/l and 380 mg/l in wet period. Wherea concentration of Ca^{2+} was 644.08 mg/l in the dry period and 232.05 mg/l in the wet period.

Concentration of Mg^{2+} was 127.99 mg/l and 46.2 mg/l during dry and wet period correspondingly. K^+ concentration was 703.57 mg/l and 30.9 mg/l in dry and wet period respectively, and Na^{2+} concentration was 71.83 mg/l and 21.12 mg/l in dry and wet period correspondingly. The major cations concentrations were meaningfully greater in the dry period compared to the wet, this can be attributed to dilution of the leachate in the wet season by rain water. Apart from K^+ and Na^+ concentration in wet season composite sample, the concentration of all the main cations fell within the range recorded by Kjeldesen *et al.* (2002). Also the concentration of Ca^{2+} and Mg^{2+} is within the range (Ca^{2+} :20-600 mg/l and Mg^{2+} :40-350 mg/l) recorded by Ehrig (1988) for leachate in the methanogenic phase.

The order of concentration of the major anions in the leachate in the dry season composite sample is $\text{Cl} > \text{CO}_3^{2-} > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^- > \text{NO}_2^-$, the same order is maintained in the wet season sample, this is an indication of more stability in the anions compared to cations. The concentration of Cl^- in the dry season was 811.1 mg/l and 1228.85 mg/l in wet period, and CO_3^{2-} concentration was 655 mg/l and 600 mg/l in dry and wet periods correspondingly.

The concentration of HCO_3^- in the dry period composite sample was 1163 mg/l and that of the wet season sample was 73.60 mg/l. The concentration of SO_4^{2-} in dry period was 74.98 mg/l and 34.79 mg/l in wet period, these values are within the range (10-420 mg/l) observed for leachate in the methanogenic phase by Ehrig (1988). While the concentration of PO_4 was 11.71 mg/l and 4.7 mg/l in dry and wet periods

correspondingly. The concentration of NO_3^- was 69.71 mg/l and 3.70 mg/l in the dry and wet period correspondingly and that of NO_2^- was 0.92 mg/l in the dry season and 0.15 mg/l in the wet period. Apart from Cl^- all other major anions had higher concentration in dry season compared to wet period composite sample, again an indication of the effect of dilution on the leachate.

4.3.1.2 Groundwater

The measured temperature in groundwater ranged from 26.10 °C at location 11BH to 27.40 °C at location 21BH with mean value of 26.68 ± 0.45 °C in the wet season and from 26.35 °C at location 3BH to 27.75 °C at location 15BH with mean value of 26.62 ± 0.39 °C in dry season, the average value of temperature for the wet and dry season at the control locations were 27.44 °C and 27.75 °C respectively (Tables 9 & 10). The groundwater temperature around the dumpsite and control points are within the range of the atmospheric temperature (wet; 23.4 – 29.0 °C and dry; 23.4 – 33.4 °C) (Appendix 1) during the period.

The pH varied from 3.85 in location 11HB to 5.55 at location 9BH with mean value of 4.86 ± 0.52 in the wet season and from 3.35 at location 11BH to 5.10 at location 9BH with mean value of 4.39 ± 0.58 in dry period. The average value of pH in the control points were 5.61 and 5.01 in wet and dry periods correspondingly. The mean pH of the control points samples is more than those of the samples around the dumpsite, these values are lower than the WHO (2008) recommended guideline limit of 6.5 – 8.5. It has been reported that lower pH values are attributed to humic acid from decaying vegetative materials that infiltrate into the underground water from the soil zone (Edet, 2018). Lower pH in groundwater around the dumpsite suggest the presence of other processes that is reducing the acid buffering capacity.

The Electrical conductivity (EC) ranged from 10.10 $\mu\text{S}/\text{cm}$ at location 12BH and 14BH to 85.45 $\mu\text{S}/\text{cm}$ at location 11BH with mean value of 33.08 ± 19.95 $\mu\text{S}/\text{cm}$ in the wet period and from 10 $\mu\text{S}/\text{cm}$ at location (BH11 and BH14) to 130 $\mu\text{S}/\text{cm}$ at location 12BH with mean value of 60.69 ± 34.89 $\mu\text{S}/\text{cm}$ during the dry period. The mean value of electrical conductivity at the control points for the wet and dry season were 35.13 $\mu\text{S}/\text{cm}$ and 50 $\mu\text{S}/\text{cm}$ respectively. The mean EC of the control points are lower than those around the dumpsite in both season. Total dissolved solids (TDS) ranged between 10 mg/l at location 9BH and 93.05 mg/l at location 15BH with mean value of 48.15 ± 22.8 mg/l in the wet period and between 0.02 mg/l at location 19BH and 78.5 mg/l at location 9BH with average value of 41.51 ± 23.51 mg/l in dry period. The mean value of TDS in the control points were 32.88 mg/l and 46.00 mg/l in wet and dry period correspondingly. The mean value of TDS is higher around the dumpsite in the wet season compared to the control point but the reverse is the case in the dry period, TDS point to the level of ion or solute in the water (Appelo & Postma, 2005). However, the groundwater samples had TDS and EC values lower than WHO (2008) maximum admissible values of 1000 mg/l and 1400 $\mu\text{S}/\text{cm}$ respectively.

Dissolved oxygen (DO) varied from 2.05 mg/l at location 9BH to 4.35 mg/l at location 12BH with average value of 3.14 ± 0.53 mg/l during the wet period and from 1.35 mg/l at location 7BH to 5.6 mg/l at 19BH with average of 2.68 ± 1.15 mg/l in the dry period. The average value of DO at the control points in wet and dry periods were 3.05 mg/l and 1.15 mg/l respectively. The mean value of dissolve oxygen in the groundwater around the dumpsite and control points are below the WHO limit of 5 mg/l. Low value of DO is an indication of high microbial activity (Pitt *et al.*, 1994) and poor waste management (Edet, 2017).

Chemical oxygen demand (COD) varied from 5.5 mg/l at location 8BH to 22.40 mg/l at location 9BH with mean value of 10.26 ± 4.28 mg/l in wet period and from 7.15 mg/l at location 20BH to 19.10 mg/l at location 5BH with average value of 11.71 ± 4.26 mg/l during the dry period. The mean value of COD in the wet and dry period were 14.43 mg/l and 12.81 mg/l respectively at the control points. Biological oxygen demand (BOD) ranged from 0.8mg/l at location 9BH to 2.05 mg/l at location 12BH with mean value of 1.17 ± 0.32 mg/l in wet period and from 0.6 mg/l at location 11BH to 4.25 mg/l at location 19BH with average of 1.42 ± 0.94 mg/l during the dry period, with mean value of 13.10 mg/l and 0.80 mg/l at the control points in the wet and dry periods respectively.

Total hardness (H_T) ranged from 2.30 mg/l at location 6BH to 10.2 mg/l at location 15BH with mean value of 5.36 ± 2.06 mg/l and between 4.93 mg/l at location 20BH and 22.45 mg/l at location 3BH with mean value of 15.63 ± 5.26 mg/l in wet and dry period in that order. The mean hardness at the control points in wet and dry periods were 5.40 mg/l and 22.15 mg/l correspondingly, suggesting that the groundwater in the area is soft (Edet, 2018).

The main cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) accounted for 21 percent and 15 percent of the main ions in the wet and dry period correspondingly. The order of concentration of the major cations was $Ca^{2+} > Na^+ > K^+ > Mg^{2+}$ in the wet period and $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ in the dry period. For the control points the order were $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ in both wet and dry periods. The consistency in the order at the control points in both seasons similar to the dry season groundwater around the dumpsite could indicate the influence of precipitation on the distribution of these ions around the dumpsite.

Calcium (Ca^{2+}) is the dominant cation accounting for 13 percent and 12 percent of the major ions in wet and dry season respectively. Its concentration ranged from 16.00 mg/l

at location 11BH to 128.00 mg/l at location 15BHB with mean concentration of 44.15 ± 40.08 mg/l in wet period and between 16.35 mg/l at location 19BH and 191.00 mg/l at location 15BH with average value of 82.11 ± 4.99 mg/l in the dry period. The mean concentration of Ca^{2+} in both seasons were within the same range with that of the control points average values, however, some locations down slope of the dumpsite had concentration far above average indicating that they could have been influenced by the dumpsite leachate with high concentration of Ca^{2+} in both seasons. The concentration of Ca^{2+} are all within the WHO maximum admissible limit of 200mg/l.

Magnesium (Mg^{2+}) is next to calcium in concentration accounting for 2 percent and 3 percent in wet and dry season correspondingly. The Mg^{2+} content varied from 3.06 mg/l at location 11BH to 27.50 mg/l at location 15BH with mean value of 8.01 ± 6.41 mg/l in wet period and between 3.25 mg/l at location 19BH and 38.20 mg/l at location 15BH with average concentration of 16.75 ± 9.01 mg/l in dry period. The Mg^{2+} content in all the locations were higher than the Nigerian standard for drinking water quality of 0.2mg/l, and excess Mg^{2+} in drinking water can cause neurological disorder in Man according to Standard Organization of Nigeria (2015).

Concentration of potassium (K^+) accounted for 3 percent and less than 1 percent of the major ions in the wet and dry period correspondingly. The value of K^+ varied between 0.21 mg/l at location 14BH and 103.18 mg/l at location 9BH with average value of 9.76 ± 28.18 mg/l in wet period and between 0.36 mg/l at location 14BH and 11.29 mg/l at location 9BH with average value of 2.51 ± 2.68 mg/l in dry period. The concentration of K^+ in both seasons were far above the control points mean values of 0.49 mg/l and 0.83 mg/l in wet and dry period correspondingly, this could be an indication of the influence of the dumpsite leachate which has high concentration of K^+ in both seasons.

The concentration of K^+ in the dry season sample of location 9BH is above the WHO standard value of 12 mg/l.

While Na^+ accounted for 3 percent and less than 1 percent of the total ion concentration in the wet and dry period respectively, with its concentration ranging from 0.40 mg/l at location 5BH to 117.11 mg/l at location 9BH with average concentration of 10.87 ± 32.05 mg/l in the wet period and from 1.21 mg/l at location 12BH to 9.10 mg/l at location 9BH with average value of 2.62 ± 1.93 mg/l in dry period. The Na^+ content in most locations around the dumpsite in both season seasons were above the control points average values of 1.92 mg/l and 1.61 mg/l in the wet and dry season, indicating an additional source of Na^+ in the underground water around the dumpsite, which could be linked to the dumpsite leachate with high concentration of Na^+ . However, all the sample had concentrations that are below the Standard Organisation of Nigeria (2015) maximum permitted limit of 200 mg/l.

The minor ions comprising ammonium (NH_4^+), phosphate (PO_4^{3-}), and nitrite (NO_2^-) contributed little to the total dissolve ions. The order of concentration of the minor ions in the wet period was $NH_4^+ > PO_4^{3-} > NO_2^-$ and $NH_4^+ > NO_2^- > PO_4^{3-}$ in the dry season, the same order was maintained at the control points.

The concentration of NH_4^+ ranged from 7.01 mg/l at location 5BH to 36.01 mg/l at location 9BH with mean value of 14.73 ± 7.43 mg/l in the wet period and between 6.10 mg/l at location 19BH and 23.62 mg/l at location 4BH with average concentration of 16.39 ± 5.76 mg/l in dry period. The NH_4^+ content in most locations around the dumpsite are a little above the control points, with average values of 14.43 mg/l and 9.28 mg/l in the wet and dry periods respectively. The PO_4^{3-} content varied between 0.04 mg/l at location 21BH and 0.22 mg/l at location 9BH with average value of 0.08 ± 0.05 mg/l in

wet period and between 0.01 mg/l at location 8BH and 0.20mg/l at location 15BH with average concentration of 0.01 ± 0.06 mg/l in the dry season, while that of NO_2^- varied between 0.002 mg/l at location 21BH and 0.15 mg/l at location 9BH with mean concentration of 0.04 ± 0.04 mg/l in wet period and between 0.03 mg/l at location 8BH and 0.28 mg/l at location 12BH with average concentration of 0.17 ± 0.08 mg/l in the dry period. NO_2^- concentration of in some dry season samples (locations; 3BH, 9BH, 11BH, 12BH, 14BH & 15BH) located around the dumpsite is slightly above the Standard Organisation of Nigeria (2015) threshold value of 0.2 mg/l, and NO_2^- contaminated water is said to cause cyanosis and asphyxia ('blue baby syndrome') in babies below three months.

The major anions (Cl^- , CO_3^{2-} , HCO_3^- , NO_3^- and SO_4^{2-}) constitute more than 79 percent of the major ion in the groundwater during wet season and 85 percent in the dry season, this is comparable with the control points value of 82 percent and 80 percent in the wet and dry season respectively. The order of concentration of the major anions in the wet season is $\text{Cl}^- > \text{CO}_3^{2-} > \text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{2-}$ and $\text{Cl}^- > \text{CO}_3^{2-} > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$ in the dry period, the order in the control areas were $\text{Cl}^- > \text{HCO}_3^- > \text{CO}_3^{2-} > \text{NO}_3^- > \text{SO}_4^{2-}$ in the wet season and $\text{Cl}^- > \text{CO}_3^{2-} > \text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{2-}$ in the dry season. The position of bicarbonate in these ordering could be responsible for the lower pH values in the samples around the dumpsites compared to those of the control points. Chloride (Cl^-) is the dominant ion accounting for 35 percent and 32 percent in the wet and dry period respectively, its concentration ranges from 61.45 mg/l at locations 21BH to 184.33 mg/l at location 15BH with a mean value of 117.61 ± 35.17 mg/l in wet period and varied between 36.87 mg/l at location 20BH and 470.99 mg/l at location 15BH with average concentration of 218.17 ± 119.01 mg/l in the dry period. Mean concentration of Cl^- in wet period was more than the average control points value of 107.81 mg/l in wet period,

however, the reverse was the case in dry period. In general, Cl^- concentration was greater in the dry period compared to wet period. The Cl^- concentration in all the samples were below the WHO standard value of 600 mg/l.

Carbonate (CO_3^{2-}) is next to Cl^- accounting for 22 percent of the major ions during the wet season and 26 percent in the dry season. The concentration of CO_3^{2-} ranged from 38.00 mg/l at location 15BH to 140.00 mg/l at location 9BH with average concentration of 74.50 ± 33.22 mg/l in the wet period and varied from 24.00 mg/l at location 20BH to 280.00 mg/l at location 6BH with average value of 173.05 ± 76.34 mg/l in the dry period. The mean concentration of CO_3^{2-} in the groundwater around the dumpsite were higher compared to the mean control point values in both season, indicating an additional source of CO_3^{2-} in the groundwater within the vicinity of the dumpsite, this could be linked to the dumpsite leachate with very high concentration of CO_3^{2-} in both seasons.

Carbonate (CO_3^{2-}) is closely followed by bicarbonate (HCO_3^-) which accounted for 20 percent of the major ions in the wet season but constituted 24 percent of the major ions in the dry season. The concentration of HCO_3^- varied from 20.00 mg/l at location 7BH to 148.15 mg/l at location 9BH with mean value of 67.40 ± 42.77 mg/l in wet period and between 26.40 mg/l at location 19BH and 260.00 mg/l at location 14BH with average concentration of 160.40 ± 69.90 mg/l in the dry period. The mean concentration of HCO_3^- at the control points were 80.32 mg/l and 200 mg/l in the wet and dry season correspondingly, higher than the average value of the samples around the dumpsite, the higher values of HCO_3^- at the control points samples could be responsible for the higher pH values at these points, as elevated pH are related to HCO_3^- (Edet, 2018). The concentration of HCO_3^- in the groundwater were within the WHO (2008) threshold value of 500 mg/l.

Sulphate constitute 1 percent and 3 percent of the major ions in the wet and dry period respectively and it varied between 0.81 mg/l at location 14BH and 5.94 mg/l at location 6BH with average concentration of 3.13 ± 1.64 mg/l during the wet period and between 1.50 mg/l at location 20BH and 33.92 mg/l at location 3BH with average value of 22.65 ± 10.62 mg/l in dry period. The SO_4^{2-} content in most locations around the dumpsite were higher compared to the average control points values of 2.08 mg/l and 20.24 mg/l in wet and dry periods respectively. This also is an indication that the groundwater around the dumpsite could have been affected by the dumpsite leachate which has a high concentration of SO_4^{2-} in both seasons. However, the concentration of SO_4^{2-} in all the groundwater samples were all below the Nigerian standard for drinking water quality value of 100 mg/l (Standard Organisation of Nigeria, 2015)

Nitrate (NO_3^-) is the least of the major anions, accounting for 1 percent and less than 1 percent of the major ions in the wet and dry period respectively. Nitrate concentration varied between 0.98 mg/l at location 21BH and 10.53 mg/l at location 9BH with mean value of 3.66 ± 2.48 mg/l in wet period and between 0.55 mg/l at location 19BH and 4.04 mg/l at location 6BH with average concentration of 2.15 ± 1.14 mg/l in dry period. There was no substantial variance between the concentration of nitrate in the groundwater around the dumpsite compared to the control points values in both seasons, however, the nitrate concentration in the leachate samples were high, this is an indication that there is a process controlling the distribution of nitrate in the area. Also the NO_3^- concentration in all the groundwater samples were below the Standard Organisation of Nigeria (2015) standard value of 50 mg/l.

4.3.1.3 Surface water

The measured temperature in the surface water ranged from 26.07 °C at location 2SW to 27.05 °C at location 1SW with mean value of 26.47 ± 0.42 °C and from 26.35 °C at

location 10SW to 27.05 °C at location 18 SW with mean value of 26.61 ± 0.26 °C in the wet and dry season respectively. The pH ranged from 4.95 at location 10SW to 6.75 at location 1SW with mean value of 6.08 ± 0.81 in the wet season and from 3.55 at location 10SW to 5.45 at location 2SW with mean value of 4.29 ± 0.79 in the dry period.

The EC varied from 11.00 $\mu\text{s/cm}$ at location 10SW to 40.00 $\mu\text{s/cm}$ at location 2SW with average value of 27.00 ± 12.03 $\mu\text{s/cm}$ in the wet period and from 20.55 $\mu\text{s/cm}$ at location 18SW to 90.00 $\mu\text{s/cm}$ at location 2SW with mean value of 42.64 ± 27.62 $\mu\text{s/cm}$ in the dry period.

The DO varied from 2.00 mg/l at location 2SW to 3.54 mg/l at location 1SW with mean value of 2.70 ± 0.59 mg/l in wet period and from 1.35 mg/l at location 10SW to 5.05 mg/l at location 18SW with average value of 2.64 ± 1.44 mg/l in dry period.

The TDS varied from 28.50 mg/l at location 10SW to 40.50 mg/l at location 2Sw with average value of 33.00 ± 5.30 mg/l in wet period and from 7.00 mg/l at location 18SW to 76.00 mg/l at location 2SW with average value of 32.02 ± 27.78 mg/l in dry period.

The COD varied from 8.85 mg/l at location 1SW to 10.90 mg/l at location 10SW with mean value of 9.70 ± 0.87 mg/l in the wet period and from 8.05 mg/l at location 18SW to 14.69 mg/l at location 10SW with average value of 12.42 ± 2.57 mg/l in dry period.

The BOD ranged from 0.83 mg/l at location 10SW to 1.20 mg/l at location 1SW with mean value of 1.04 ± 0.16 mg/l in wet period and between 1.00 mg/l at location 1SW and 2.65 mg/l at location 18SW with average value of 1.49 ± 0.68 mg/l in the dry period.

The total hardness varied from 4.00 mg/l at location 10SW to 7.00 mg/l at location 1SW with average concentration of 5.87 ± 1.33 mg/l in wet period and from 5.95 mg/l at location 18SW to 22.05 mg/l at location 10SW with average value of 12.99 ± 5.92 mg/l in the dry period.

The major cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) accounted for 16 percent and 5 percent of the major ions during wet and dry periods correspondingly. The order of concentration of the major cations in the wet season was $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ and $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^+ > \text{K}^+$ in the dry period.

The concentration of Ca^{2+} varied from 16.20 mg/l at location 10SW to 88.00 mg/l at location 2SW with mean value of 53.40 ± 29.37 mg/l in the wet period and from 24.00 mg/l at location 18SW to 82.60 mg/l at location 1SW with average value of 67.18 ± 24.94 mg/l in the dry period. The distribution of Ca^{2+} in the water of the area is influenced by the dumpsite leachate and other anthropogenic sources as indicated by its high concentration in locations close to and far away from the dumpsite. The Ca^{2+} content in all surface water sampled are less than the WHO standard value of 200 mg/l.

The concentration of Mg^{2+} in the wet period ranged between 3.20 mg/l at location 10SW and 16.60 mg/l at location 2SW with average of 9.88 ± 5.47 mg/l and between 4.80 mg/l at location 18SW and 18.30 mg/l at location 10SW with mean value of 14.18 ± 5.45 mg/l in the dry period. The distribution of Mg^{2+} in the waters could have been influenced by the dumpsite leachate, as indicated by the higher concentration of the ion in water bodies around the dumpsite compared to those further away. The concentration of Mg^{2+} in all surface water are above the Standard Organisation of Nigeria permitted value of 0.2 mg/l.

The concentration of K^+ range from 1.05 mg/l at location 10SW to 6.80 mg/l at location 2SW with average value of 3.02 ± 2.68 mg/l in the wet period and from 0.60 mg/l at location 18SW to 6.93 mg/l at location 2SW with average value of 2.82 ± 2.43 mg/l in dry period. The distribution of K^+ is influenced by the dumpsite leachate as suggested by the higher concentration at areas closer to the dumpsite compared to those further

away, and the concentration of K^+ in the leachates is high. However, the concentration of K^+ in all surface water were less than the WHO standard value of 12 mg/l.

For Na^+ during the wet period, the lowest concentration of 0.40 mg/l was recorded at location 10SW and the maximum value of 5.76 mg/l at location 2SW with average of 3.01 ± 2.19 mg/l while in the dry period the lowest level of 2.02 mg/l was recorded at location 10SW and the highest level of 4.45 mg/l was at location 1SW. The concentration of Na^+ was generally low in the area, and falls below the WHO standard value of 200 mg/l.

The major anions (Cl^- , CO_3^{2-} , HCO_3^- , NO_3^- and SO_4^{2-}) constituted more than 84 percent of the major ion in the groundwater during wet season and 95 percent in the dry season, this is relatively higher than the concentration in the groundwater. The order of concentration of the major anions was $Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2-} > NO_3^-$ in both season.

The concentration of Cl^- is dominant accounting for 28 percent and 35 percent of the ions in the wet and dry period respectively, ranging from 61.42 mg/l at location 10SW to 184.32 mg/l at location 2SW with a mean value of 122.89 ± 50.16 mg/l in wet period and between 57.15 mg/l at location 18SW and 331.81 mg/l at location 2SW with an average value of 218.17 ± 119.01 mg/l in dry period. The high content of Cl^- in location 2SW in both seasons is attributed to its link with the dumpsite leachate which has a very high concentration of Cl^- . The concentration of Cl^- in location 2SW in the dry season is above the Standard Organisation of Nigeria permitted maximum value of 250 mg/l.

The HCO_3^- in the surface water accounted for 22 percent and 32 percent of the major ion in the wet and dry period respectively and its concentration ranged from 50.10 mg/l at location 10SW to 120.50 mg/l at location 2SW with mean concentration of 93.87 ± 31.32 mg/l in the wet period and from 19.20 mg/l at location 18SW to 330.00

mg/l at location 2SW with average value of 194.30 ± 113.14 mg/l in the dry period. Higher concentration recorded in location 2SW which is linked to the leachate from the dumpsite through surface flow is an indication that the additional source of HCO_3^- is from the leachate. The concentration of CO_3^{2-} in the surface water accounted for 21 percent in the wet and 23 percent in the dry period, ranging from 36.00 mg/l at location 10SW to 120.00 mg/l at location 2SW with mean value of 88.80 ± 37.54 mg/l in wet period and varied from 48.05 mg/l at location 18SW to 240.00 mg/l at location 10SW with average value of 216.81 ± 100.45 mg/l in dry season. High concentration of CO_3^{2-} in location 2SW and 10SW is an indication of the influence of the effluents from the dumpsite.

The concentration of SO_4^{2-} ranged from 1.70 mg/l at location 1SW to 159.52 mg/l at location 10SW with mean value of 54.59 ± 74.20 mg/l in wet period and varied from 0.75 mg/l at location 18SW to 63.68 mg/l at location 1SW with average value of 32.33 ± 23.71 mg/l during the dry period. The SO_4^{2-} content, though high in the leachate the higher concentration at locations far away from the dumpsite could be an indication that other processes could be contributing to the distribution of SO_4^{2-} in the area. The concentration of SO_4^{2-} in location 10SW is higher than the Standard Organisation of Nigeria maximum permitted value of 100 mg/l.

Nitrate concentration ranged from 0.98 mg/l at location 1SW to 2.14 mg/l at location 2SW with average of 1.42 ± 0.51 mg/l during wet period and from 0.56 mg/l at location 18SW to 2.08 mg/l at location 2SW with mean value of 1.21 ± 0.65 mg/l in dry period. The distribution of nitrate in waters around the dumpsite could be influence by the leachate as indicated by the higher concentration of this ion close to the dumpsite

compared to distant rivers. The concentration of NO_3^- in all the surface water are below the Standard Organisation of Nigeria maximum permitted value of 50 mg/l.

The order of concentration of the minor ions in surface water was $\text{NH}_4^+ > \text{PO}_4^- > \text{NO}_2^-$ in wet season and $\text{NH}_4^+ > \text{NO}_2^- > \text{PO}_4^-$ in dry period. Lowest level of NH_4^+ was 11.6 mg/l at location 10SW and the highest of 16.00 mg/l at location 1SW with mean value of 13.54 ± 1.83 mg/l in the wet period and lowest of 5.95 mg/l at location 18SW and the highest value of 22.63 mg/l at location 1SW with mean value of 15.93 ± 6.83 mg/l during the dry period. For PO_4^- it varied between 0.03 mg/l at location 2SW and 0.08 mg/l at location 1SW with mean value of 0.06 ± 0.02 mg/l in the wet period and between 0.05 mg/l at location 1SW and 0.18 mg/l at location 10SW with average value of 0.09 ± 0.05 mg/l in the wet period. While NO_2^- concentration varied between 0.01 mg/l at location 1SW and 0.04 mg/l at location 10SW with mean value of 0.02 ± 0.01 mg/l in the wet period and between 0.06 mg/l at location 18SW and 0.25 mg/l at location 2SW with mean value of 0.18 ± 0.07 mg/l in the dry period. Concentration NO_2^- in some surface water samples are higher than the Standard Organisation of Nigeria maximum permitted Concentration of 0.2 mg/l. Generally, the concentration of the minor ions in the waters were low and their distribution is influenced by anthropogenic sources as indicated by their spatial distribution across the study area.

4.3.2 Heavy metals

The descriptive statistics of the heavy metals; copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), manganese (Mn), chromium (Cr) and iron (Fe) in the wet and dry periods for groundwater, surface water, leachate for the study area and control areas are given in Table 12. Details of the analytical results are presented in Appendix 6 and 7.

TABLE 12
Descriptive statistics of heavy metals content in wet and dry periods

Wet season										
Parameters	Groundwater				Surface water				Leachate	Control
	Maximum	Minimum	Mean	S Dev	Maximum	Minimum	Mean	S Dev	Mean	Mean
Copper (Cu) mg/l (x 10 ⁻²)	87.00	12.00	35.00	20.00	78.00	3.00	41.00	38.00	83.00	27.00
Lead (Pb) mg/l (x 10 ⁻²)	76.00	0.10	2.00	1.00	41.00	2.00	22.00	2.00	2.00	1.00
Zinc (Zn) mg/l (x 10 ⁻²)	4.00	24.00	45.00	13.00	64.00	61.00	63.00	2.00	65.00	41.00
Cadmium (Cd) mg/l (x 10 ⁻²)	68.00	1.00	10.00	18.00	5.00	4.00	4.00	0.30	2.00	1.00
Manganese(Mn) mg/l (x 10 ⁻²)	146.00	84.00	104.00	19.00	142.00	115.00	128.00	14.00	111.00	98.00
Chromium (Cr) mg/l (x 10 ⁻²)	17.00	1.00	4.00	5.00	12.00	1.00	7.00	6.00	2.00	1.00
Iron (Fe) mg/l (x 10 ⁻²)	908.00	182.00	356.00	220.00	9009.00	201.00	4605.00	4404.0	260.00	231.00
Dry season										
Parameters	Groundwater				Surface water				Leachate	Control
	Maximum	Minimum	Mean	S Dev	Maximum	Minimum	Mean	S Dev	Mean	Mean
Copper (Cu) mg/l (x 10 ⁻²)	42.00	7.00	0.29	12.00	37.00	14.00	25.00	10.00	343.00	28.00
Lead (Pb) mg/l (x 10 ⁻²)	31.00	0.10	4.00	8.00	9.00	1.00	5.00	3.00	22.00	0.20
Zinc (Zn) mg/l (x 10 ⁻²)	49.00	0.27	37.00	7.00	35.00	7.00	27.00	12.00	327.00	36.00
Cadmium (Cd) mg/l (x 10 ⁻²)	5.00	0.001	3.00	2.00	68.00	2.00	20.00	28.00	23.00	5.00
Manganese(Mn) mg/l (x 10 ⁻²)	143.00	0.38	98.00	29.00	146.00	76.00	97.00	28.00	813.00	78.00
Chromium (Cr) mg/l (x 10 ⁻²)	18.00	0.002	9.20	7.00	14.00	1.00	8.00	5.00	15.00	12.00
Iron (Fe) mg/l (x 10 ⁻²)	559.00	0.42	178.00	124.00	361.00	53.00	158.00	125.00	4959.00	210.00

4.3.2.1 Leachate

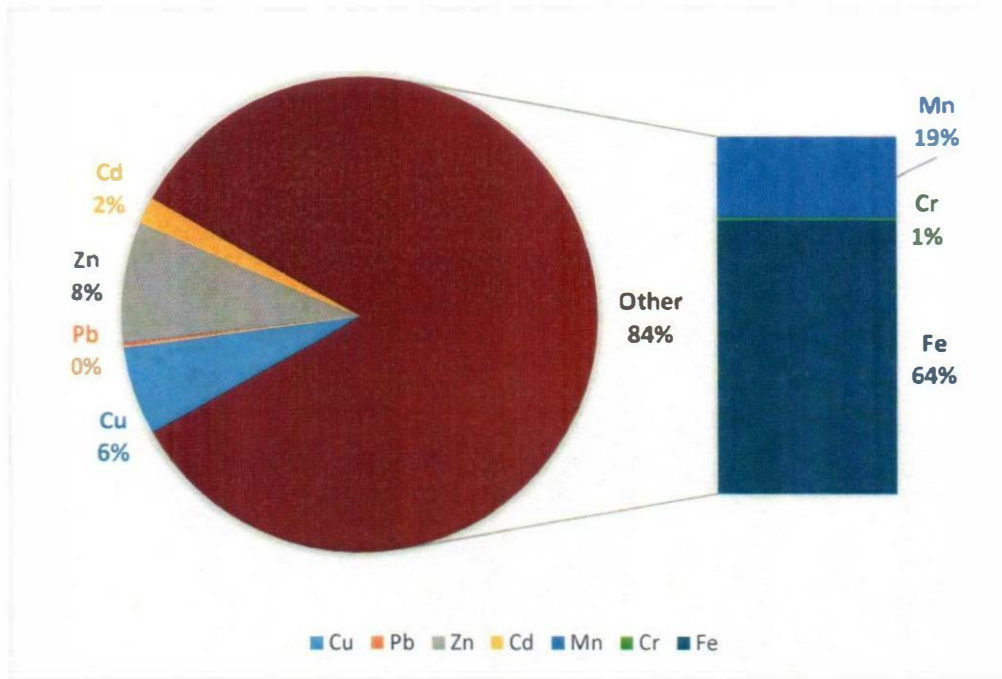
The summary heavy metals content of the composite leachate samples during the wet and dry periods are shown in Table 12. The average concentration of Cu was 0.83 mg/l and 3.43 mg/l in wet and dry period respectively. The average concentration of Pb was 0.02 mg/l and 0.22 mg/l in wet and dry period correspondingly. While that of Zn was 0.65 mg/l in the wet period and 3.27 mg/l in the dry period. Cadmium concentration was 0.02 mg/l in the wet period and 0.05 mg/l in the dry period. The concentration of Mn in the leachate sample is 1.11 mg/l in wet period and 8.13 mg/l in the dry period, and Cr concentration was 0.02 mg/l in the wet period and 0.15 mg/l in the dry period. While Fe was 2.60 mg/l and 49.59 mg/l in wet and dry season correspondingly.

The concentration of the heavy metals in the composite leachate were considerably greater in the dry period samples compared to the wet period samples. This is an indication that the leachate is influenced by the dilution effect of rain water in the wet season.

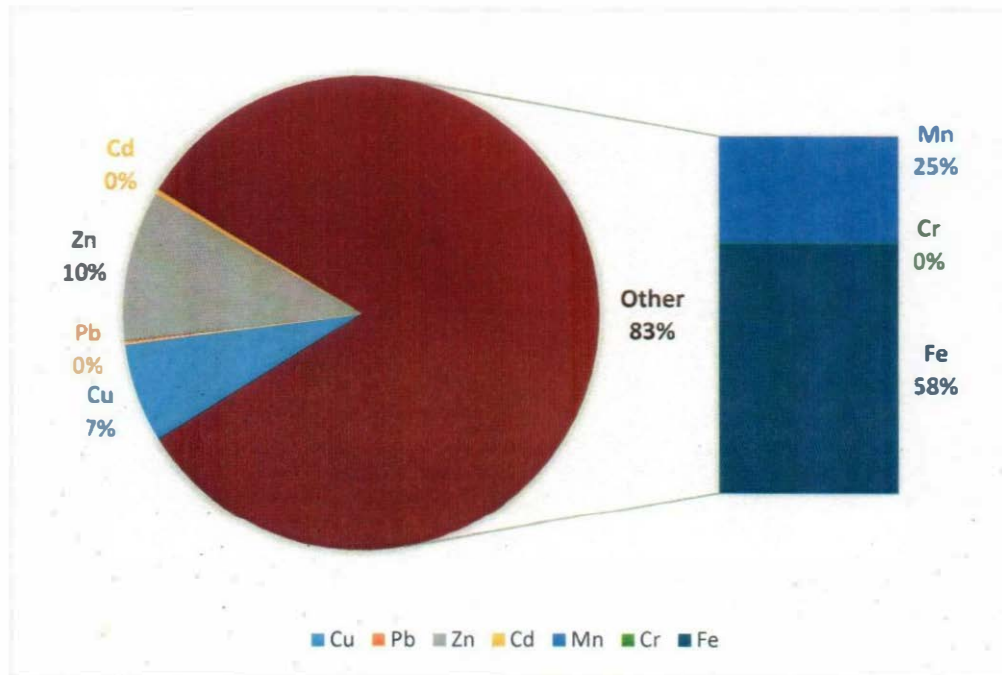
4.3.2.2 Groundwater

The results of heavy metals concentration in the wet and dry periods in the groundwater (Table 12; FIGS. 13, 14, 15 & 16) shows that Fe is the dominant heavy metal in both wet and dry season, the order of concentration of the heavy metals in the wet season was Fe>Mn>Zn>Cu>Cd>Cr>Pb for all groundwater around dumpsite and control points, while in the dry season the order was Fe>Mn>Zn>Cu>Cr>Pb>Cd for groundwater around the dumpsite and Fe>Mn>Zn>Cu>Cr>Cd>Pb for groundwater at the control points (FIGS. 13 & 14).

The mean concentration of Cu is 0.35 ± 0.2 mg/l in wet period and 0.29 ± 0.12 mg/l in the dry period (FIG. 15a), and that of Pb is 0.02 ± 0.01 mg/l and 0.04 ± 0.08 mg/l for wet and dry periods correspondingly. The concentration of Pb is higher in most locations

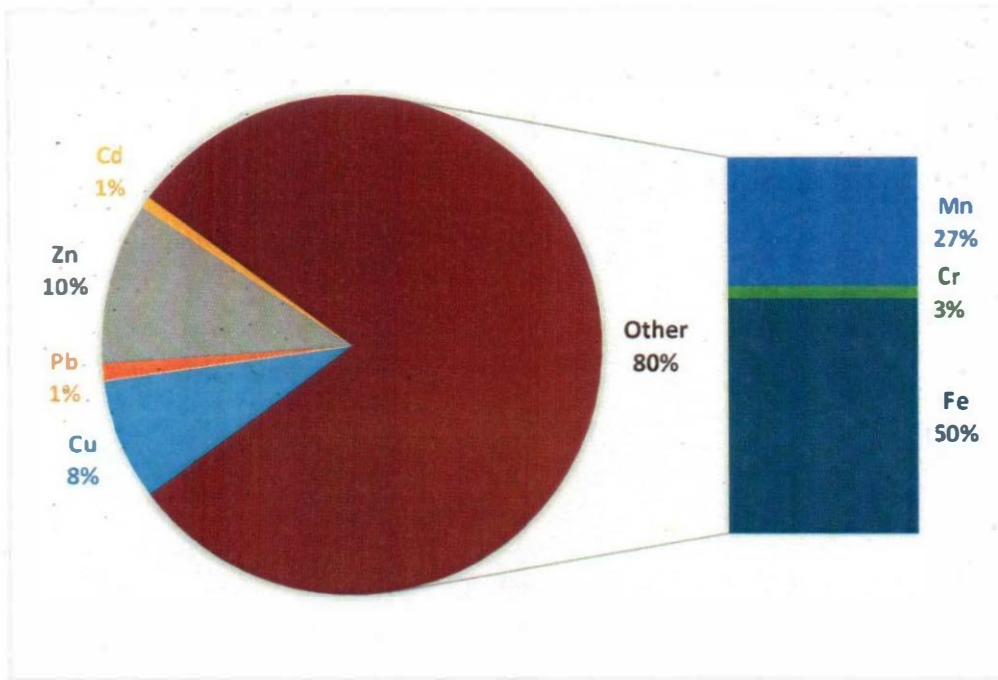


(a)

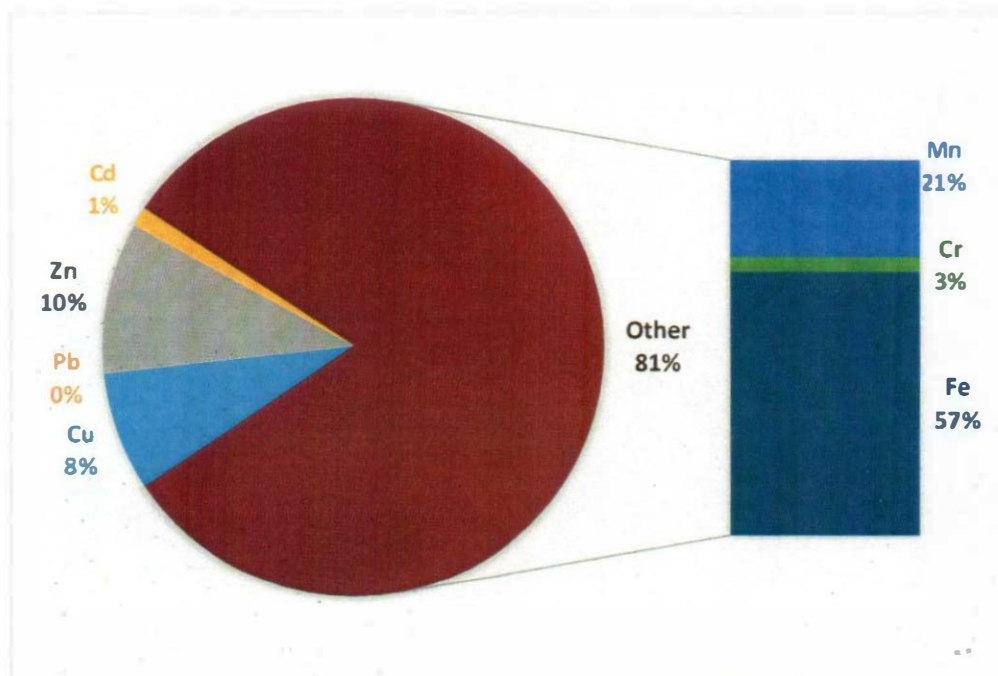


(b)

FIG. 13: Relative composition of heavy metals in groundwater (a) around dumpsite and (b) control points during the wet season

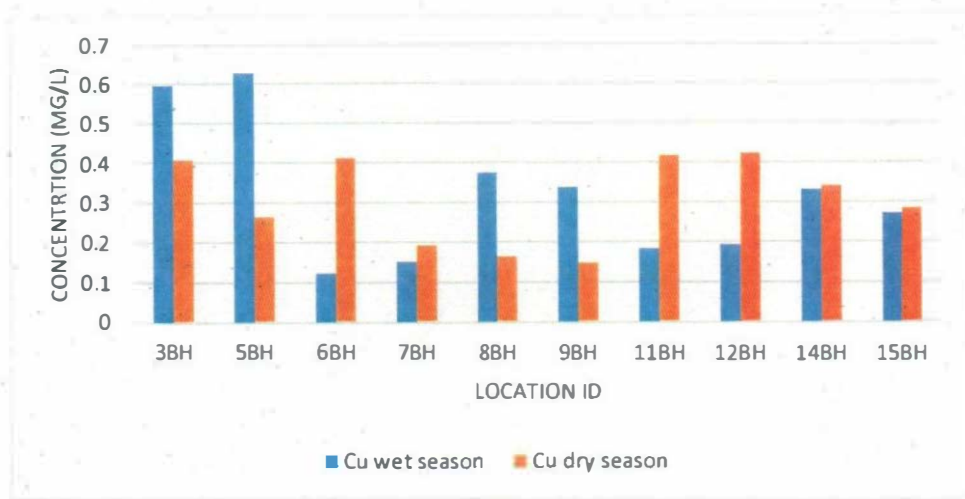


(a)

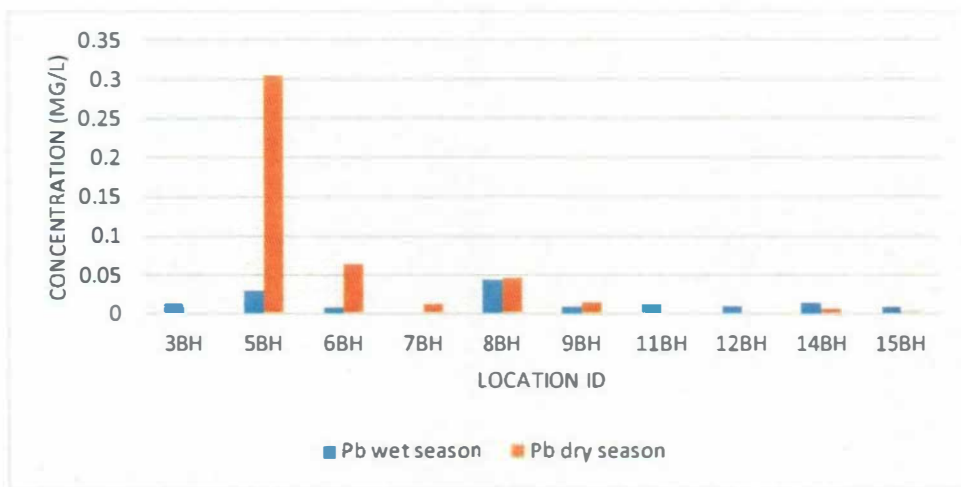


(b)

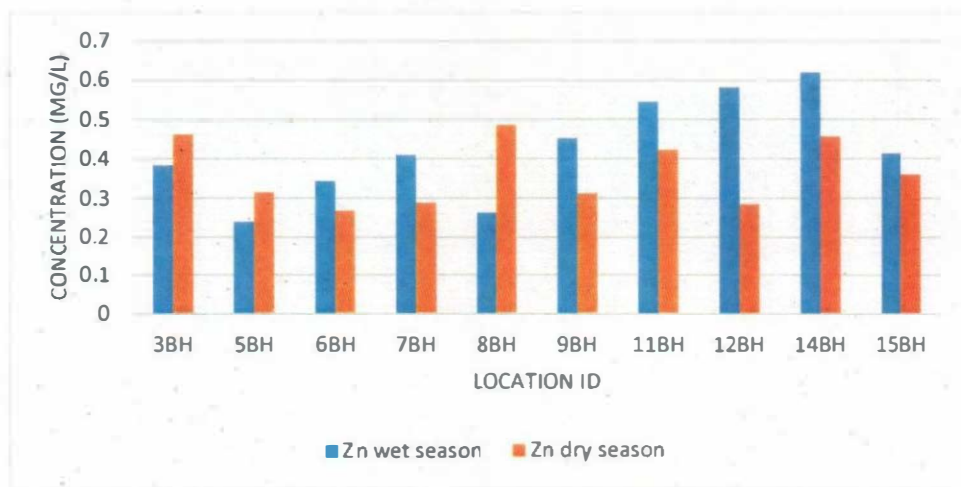
FIG. 14: Relative composition of heavy metals in groundwater (a) around dumpsite and (b) control points during the dry season



(a)

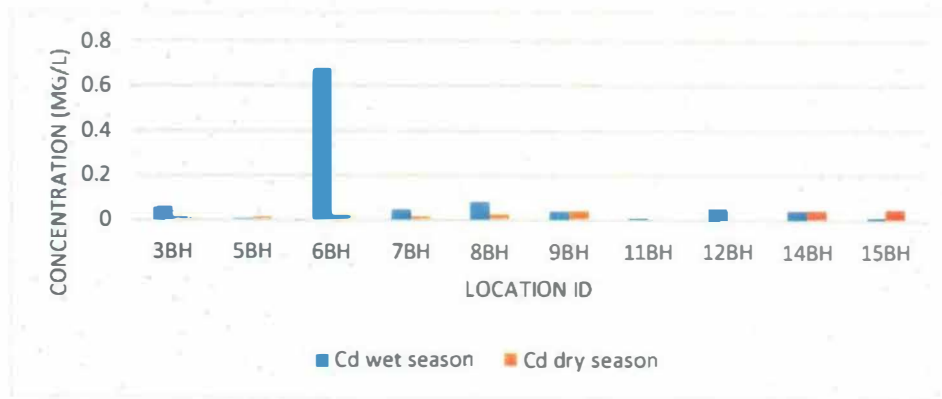


(b)

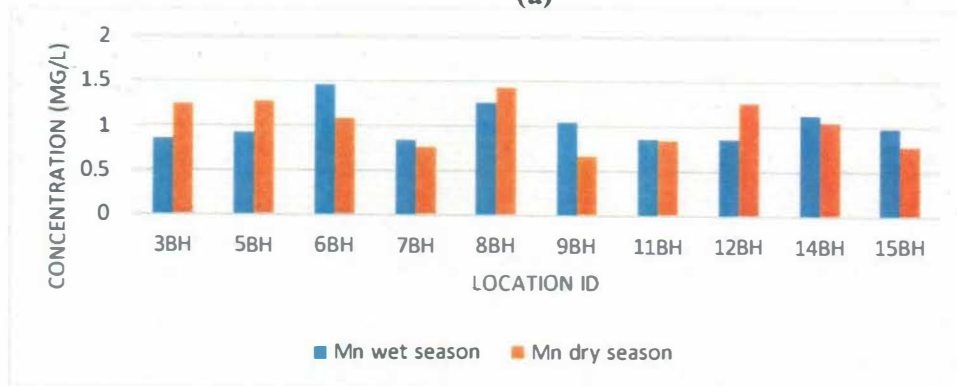


(c)

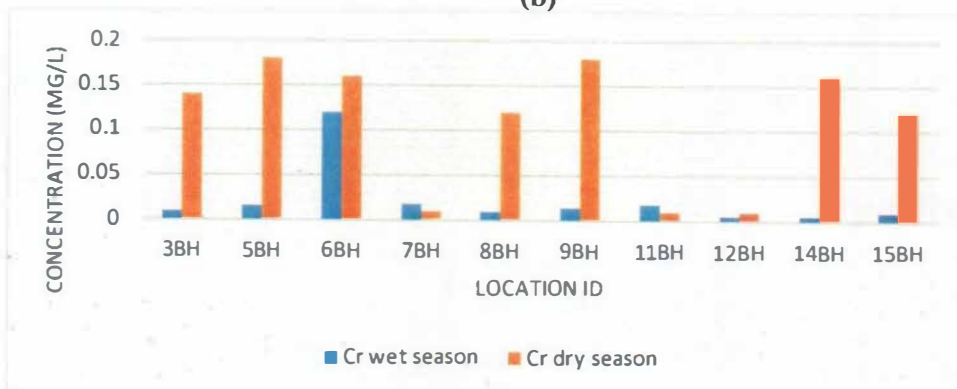
FIG. 15: Comparative concentration of the heavy metal in the groundwater during the wet and dry periods (a) Cu, (b) Pb and (c) Zn



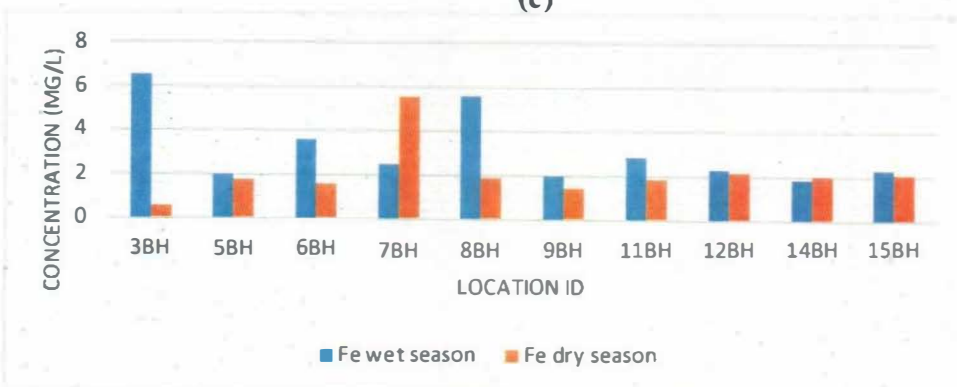
(a)



(b)



(c)



(d)

FIG. 16: Comparative concentration of the heavy metal in the groundwater during the wet and dry periods (a) Cd, (b) Mn, (c) Cr and (d) Fe

around the dumpsite compared to the average value at the control points of 0.01 mg/l and 0.002 mg/l for wet and dry period respectively (FIG. 15b). This is an indication that the dumpsite leachate could be an additional source of Pb to the groundwater. The content of Pb in the groundwater is higher than the Nigerian Standard for drinking water quality of 0.01 mg/l, and Standard Organisation of Nigeria (2015) reported some health impact of the consumption of Pb contaminated water to include; interfering with vitamin D uptake, effects on infants' mental growth, poisonous to the central and peripheral nervous systems and carcinogenic.

The average concentration of Zn is 0.45 ± 0.13 mg/l and 7 ± 0.07 mg/l in wet and dry period correspondingly (FIG. 15c). Concentration of Zn in most location around the dumpsite is higher compared to the mean concentration at the control points of 0.41 mg/l and 0.36 mg/l in wet and dry period correspondingly. The Zn is content below the Nigerian standard for drinking water quality, Zn is an essential element needed for our normal growth and development. While the mean concentration of Cd is 0.10 ± 0.18 mg/l and 0.03 ± 0.02 mg/l in wet and dry period respectively (FIG. 16a). Concentration of Cd in most locations within the vicinity of the dumpsite is higher than the control point average values of 0.01 mg/l and 0.05 mg/l during wet and dry periods respectively, this is an indication that the dumpsite leachate could be another source of Cd in the underground water in this area. Concentration of Cd in most areas is higher than the Nigerian standard value for drinking water quality of 0.003 mg/l, the health implication of elevated concentration of Cd in drinking water is its toxicity to the kidney.

The mean concentration of Mn is 1.04 ± 0.18 mg/l in the wet period and 8 ± 0.29 mg/l in the dry period, the average content of Mn around the dumpsite in both seasons are higher than the mean concentration at the control points of 0.98 mg/l and 0.78 mg/l in

the wet and dry periods respectively (FIG. 16b), indicating that they could be coming from the dumpsite leachate. Also the average concentration of Mn is higher than the Nigerian standard value of drinking water quality of 0.002 mg/l, which calls for concern as the intake of Mn contaminated water is linked with neurological disorder.

Cr which was least in terms of its concentration in the groundwater, had the mean value of 0.04 ± 0.05 mg/l in wet period and 0.09 ± 0.07 mg/l in the dry period, the concentration of Cr in groundwater around the dumpsite is higher than the control points mean value of 0.001 mg/l and 0.12 mg/l during wet and dry periods respectively. Nevertheless, the variation in their distribution between the control point and groundwater around the dumpsite during the dry season was not much. This could be an indication of seasonal effect on the distribution of Cr in the area (FIG. 16c). The concentration of Cr in most locations around the dumpsite are higher than the Nigerian standard value of drinking water quality of 0.05 mg/l, and consumption of water with high concentration of a specie of Cr (Cr^{+6}), is known to cause cancer (Standard Organisation of Nigeria, 2015).

The concentration of Fe was highest in both seasons, with mean concentration of 3.56 ± 2.20 mg/l in the wet period and 1.78 ± 1.24 mg/l during the dry period (FIG. 16d). The mean concentration of Fe in all location are higher than the SON permitted value of 0.3 mg/l, though there is no health implication of consuming water contaminated with Fe.

4.3.2.3 Surface water

The order of concentration of heavy metals in the surface water in the wet and dry seasons were $\text{Fe} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Pb} > \text{Cr} > \text{Cd}$ and $\text{Fe} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Cd} > \text{Cr} > \text{Pb}$ respectively. The concentration of Cu varied between 0.03 mg/l at location 1SW and 0.78 mg/l at location 2SW with mean value of 0.41 ± 0.38 mg/l in the wet period and

between 0.13 mg/l at location 10SW and 0.37 mg/l at location 2SW with average value of 0.25 ± 0.10 mg/l in the dry period. Concentration of Pb varied between 0.02 mg/l at location 1SW and 0.41 mg/l at location 2SW with average value of 0.22 ± 0.20 mg/l in wet period and from <0.01 mg/l at location 10SW to 0.09 mg/l at location 2SW with average value of 0.05 ± 0.03 mg/l in the dry period. Concentration of Zn ranged from 0.61 mg/l at location 2SW to 0.64 mg/l at location 10SW with mean value of 0.63 ± 0.02 mg/l in the wet period and 0.07 mg/l at location 18SW to 0.35 mg/l at location 10SW with average value of 0.27 ± 0.12 mg/l in dry period. Cd concentration varied from 0.04 mg/l at location 2SW to 0.05 mg/l at location 10SW with mean value of 0.04 ± 0.01 mg/l in the wet period and 0.02 mg/l at location 18SW to 0.68 mg/l at location 10SW with average value of 0.20 ± 0.28 mg/l in the dry period. While that of Mn varied between 1.15 mg/l at location 10SW and 1.42 mg/l at location 2SW with mean value of 1.28 ± 0.14 mg/l in wet period and 0.76 mg/l at location 1SW to 1.46 mg/l at location 10SW with mean concentration of 0.97 ± 0.28 mg/l in the dry period. Cr concentration ranged between 0.01 mg/l at location 10SW and 0.12 mg/l at location 2SW with mean value of 0.07 ± 0.06 mg/l in wet period and 0.01 mg/l at location 2SW to 0.14 mg/l at location 10SW with average value of 0.08 ± 0.05 mg/l in dry period. Fe concentration varied between 2.01 mg/l at location 10SW and 90.01 mg/l at location 2SW with average value of 46.05 ± 44.04 mg/l in wet period and between 0.53 mg/l at location 18SW and 3.61 mg/l at location 10SW with average value of 1.58 ± 1.25 mg/l in dry period.

The relative composition of all the metals unlike in the groundwater, were greater in the wet period compared to the dry period except for Cd and Cr which was slightly greater in the dry period likened to the wet period. Also the distribution of the metals was higher in water bodies which had link with the dumpsite, such as location 2SW and

10SW, compared to others far off, this is an indication that precipitation and dumpsite leachate influenced the distribution of the metals in the area. The mean concentration of Fe, Pb, Cd, Mn and Cr in the surface water were all above the SON maximum permitted value of 0.3 mg/l, 0.01 mg/l, 0.003 mg/l, 0.2 mg/l and 0.05 mg/l respectively.

4.3.3 Microbiological parameters

Results of the microbiological analysis of the leachate, underground and surface water in this work are given in Tables 13 and 14 for the dry and wet season respectively.

4.3.3.1 Leachate

The total bacterial count in the composite leachate samples were high in both seasons. The dry season sample had an average value of 7.6×10^5 cfu/100ml while the wet season sample had 1.7×10^4 cfu/100ml. The mean total coliform bacterial count in the leachate was 1.01×10^5 cfu/100ml in the dry season and 3.3×10^3 cfu/100ml. The total *salmonella/shigella* count in the dry season sample was 2.0×10^2 cfu/100ml and 3.7×10^3 cfu/100ml in the dry and wet season respectively.

The average total faecal coliform count in the dry season composite sample was 3.5×10^2 cfu/100ml and 6.0×10^2 cfu/100ml in the wet season sample. The total vibrio cholera count was 1.0×10^2 cfu/100ml and 5.0×10^2 cfu/100ml in dry and wet periods respectively. No *Escherichia coli* was recorded in dry season leachate sample but 3.0×10^2 cfu/100ml was recorded in the wet season composite sample.

4.3.3.2 Groundwater

The total bacterial count for all samples were quite high in groundwater, ranging from 7.0×10^1 cfu/100ml in location 14BH to 6.3×10^4 cfu/100ml in location 20BH and from 1.5×10^3 cfu/100ml in location 25BH to 2.1×10^4 Cfu/100ml in location 22BH in dry

TABLE 13
Results of microbial densities in water samples in the dry season

Sample ID	Total bacterial count (cfu/100ml)	Total Coliform bacterial count (cfu/100ml)	Total Salmonella /shigella count (cfu/100ml)	Total faecal coliform count (cfu/100ml)	Total Vibrio cholera count (cfu/100ml)	Total Escherichia coli count (cfu/100ml)
Groundwater						
3BH	3.0×10^2	-	5.0×10^1	-	-	-
4BH	2.6×10^2	3.0×10^1	-	-	-	-
5BH	5.5×10^2	1.0×10^2	1.0×10^2	1.0×10^2	-	-
6BH	4.1×10^2	-	-	2.6×10^2	-	-
7BH	2.5×10^2	1.0×10^2	1.0×10^1	1.2×10^2	-	-
8BH	1.0×10^2	-	-	-	-	-
9BH	1.1×10^2	-	-	5.0×10^1	-	-
11BH	3.0×10^2	-	-	-	-	-
12BH	7.1×10^2	-	-	-	-	-
14BH	7.0×10^1	-	-	-	-	-
15BH	5.0×10^2	1.0×10^2	-	-	-	-
19BH	1.1×10^3	6.0×10^1	3.5×10^2	8.0×10^1	*	-
20BH	6.3×10^4	6.0×10^2	2.2×10^2	8.0×10^1	*	-
Surface water						
1SW	7.0×10^2	2.1×10^2	-	5.0×10^1	-	-
2SW	3.4×10^2	1.2×10^2	1.0×10^2	-	-	-
10SW	2.5×10^2	-	1.0×10^2	-	-	1.0×10^1
18SW	3.7×10^2	8.0×10^1	5.0×10^1	-	*	-
Leachate						
16L	5.2×10^5	2.0×10^5	-	5.0×10^2	-	-
17L	1.0×10^6	1.0×10^3	2.0×10^2	2.0×10^2	1.0×10^2	-

*Sample not analyzed for Vibrio cholera

TABLE 14

Results of Microbial densities in water samples in wet Season

Sample ID	Total bacterial count (cfu/100ml)	Total Coliform bacterial count (cfu/100ml)	Total Salmonella /shigella count (cfu/100ml)	Total faecal coliform count (cfu/100ml)	Total Vibrio cholera count (cfu/100ml)	Total Escherichia coli count (cfu/100ml)
Groundwater						
3BH	1.7 X 10 ⁴	5.6 X 10 ²	2.4 X 10 ³	1.0 X 10 ¹	7.0 X 10 ¹	-
5BH	8.4 X 10 ³	2.1 X 10 ²	1.5 X 10 ²	-	-	-
6BH	5.4 X 10 ³	2.4 X 10 ²	5.0 X 10 ¹	1.2 X 10 ¹	-	6.0 X 10 ¹
7BH	7.0 X 10 ³	1.6 X 10 ²	8.0 X 10 ¹	2.0 X 10 ¹	1.0 X 10 ²	3.0 X 10 ¹
8BH	7.9 X 10 ³	8.0 X 10 ²	1.2 X 10 ²	-	4.0 X 10 ²	-
9BH	1.6 X 10 ⁴	1.8 X 10 ²	2.0 X 10 ³	3.4 X 10 ²	7.0 X 10 ²	3.0 X 10 ²
11BH	2.0 X 10 ⁴	4.2 X 10 ²	1.7 X 10 ³	-	-	-
12BH	1.0 X 10 ⁴	7.2 X 10 ²	5.0 X 10 ³	-	5.0 X 10 ³	-
14BH	9.2 X 10 ³	1.1 X 10 ²	3.0 X 10 ²	-	-	-
15BH	1.1 X 10 ⁴	2.2 X 10 ³	1.2 X 10 ³	2.0 X 10 ¹	-	5.0 X 10 ¹
21BH	1.4 X 10 ⁴	5.5 X 10 ²	1.5 X 10 ³	3.0 X 10 ¹	7.0 X 10 ¹	6.0 X 10 ¹
22BH	2.1 X 10 ⁴	1.1 X 10 ³	1.4 X 10 ³	1.06 X 10 ¹	3.0 X 10 ²	2.1 X 10 ¹
23BH	6.0 X 10 ³	1.4 X 10 ²	-	-	2.8 X 10 ²	-
24BH	7.3 X 10 ³	8.0 X 10 ¹	2.9 X 10 ²	-	-	-
25BH	1.5 X 10 ³	-	1.1 X 10 ¹	-	-	-
26BH	4.0 X 10 ³	1.0 X 10 ¹	1.0 X 10 ¹	-	-	-
Surface water						
1SW	2.5 X 10 ⁴	5.1 X 10 ²	1.3 X 10 ²	1.0 X 10 ¹	4.0 X 10 ¹	3.0 X 10 ¹
2SW	2.0 X 10 ³	6.0 X 10 ²	2.8 X 10 ²	-	4.0 X 10 ²	-
10SW	1.0 X 10 ⁴	9.0 X 10 ²	1.6 X 10 ³	-	1.0 X 10 ²	-
Leachate						
16L	1.7 X 10 ⁴	3.3 X 10 ³	3.7 X 10 ³	6.0 X 10 ²	5.0 X 10 ²	3.0 X 10 ²

and wet period respectively. The total Coliform bacterial count ranged from 0 cfu/100ml in locations (3BH, 6BH, 8BH, 9BH, 11BH, 12BH and 14BH) to 6.0×10^2 cfu/100ml in location 20BH and from 0 cfu/100ml in location 25BH to 2.2×10^3 in location 15BH in the dry and wet period respectively. While the total *salmonella/shigella* count in dry period ranged between 0 cfu/100ml (in locations 4BH, 6BH, 8BH, 9BH, 11BH, 12BH, 14BH, and 15BH) and 3.5×10^2 cfu/100ml at location 19BH and from 0 cfu/100ml at location 23BH to 5.0×10^3 cfu/100ml at location 12BH in the wet season.

The total faecal *coliform* count ranged from 0 cfu/100ml (in locations 3BH, 4BH, 8BH, 11BH, 12BH, 14BH and 15BH) to 2.6×10^2 cfu/100ml at location 6BH in the dry season and from 0 cfu/100ml (in locations 5BH, 8BH, 11BH, 12BH, 14BH, 23BH, 24BH, 25BH and 26BH) to 3.4×10^2 cfu/100ml at location 9BH in the wet season. The total *vibrio cholera* was not recorded in dry period but ranged between 0 cfu/100ml (in locations 5BH, 6BH, 11BH, 14BH, 15BH, 24BH, 25BH and 26BH) and 5.0×10^3 cfu/100ml in location 12BH in the wet season. Also the total *Escherichia coli* (*E. coli*) was not recorded in the dry period groundwater samples but ranged between 0 cfu/100ml (in locations 3BH, 5BH, 8BH, 11BH, 12BH, 14BH, 23BH, 24BH, 25BH and 26BH) and 3.0×10^2 cfu/100ml at location 9BH in the wet season.

The result of the microbial profile in the groundwater shows the isolation of the following genera from the sample; *Shigella spp.*, *Corynebacterium spp.*, *Listeria greyii*, *Streptococcus faecium*, *Streptococcus pyogenes*, *Micrococcus Luteus*, *Aerococcus viridians*, *E. coli*, *Salmonella typhi*, *Salmonella paratyphi*, *Microsporium canis*, *Penicillium notatum*, *Bacillus subtilis*, *Bacillus cereus*, *Micrococcus varians*, *Staphilococcus luteus*, *Staphilococcus epidemidis*, *Staphilococcus aureus*, *Botrytis spp.*, *Klebsiella spp.*, and *Pseudomonas cepacia*.

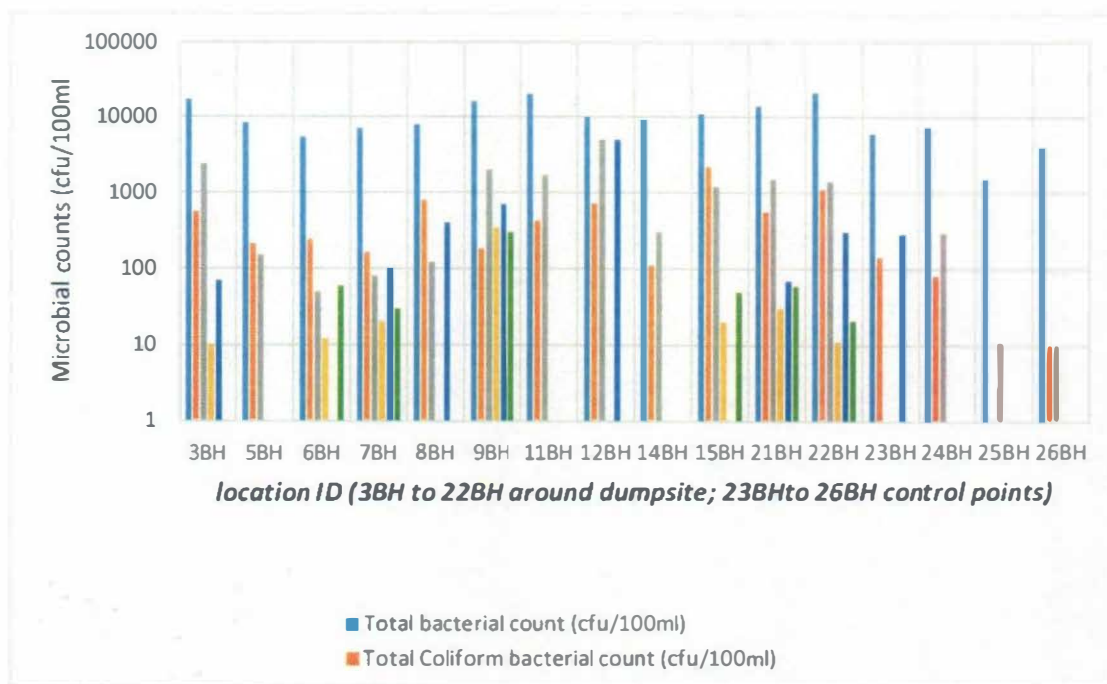
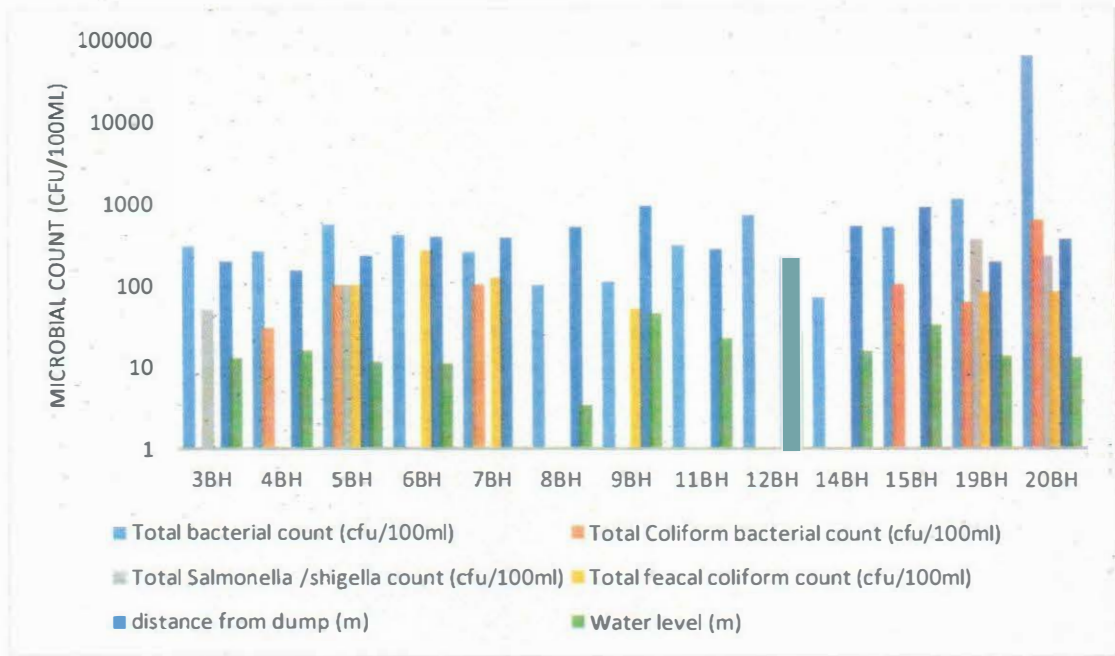


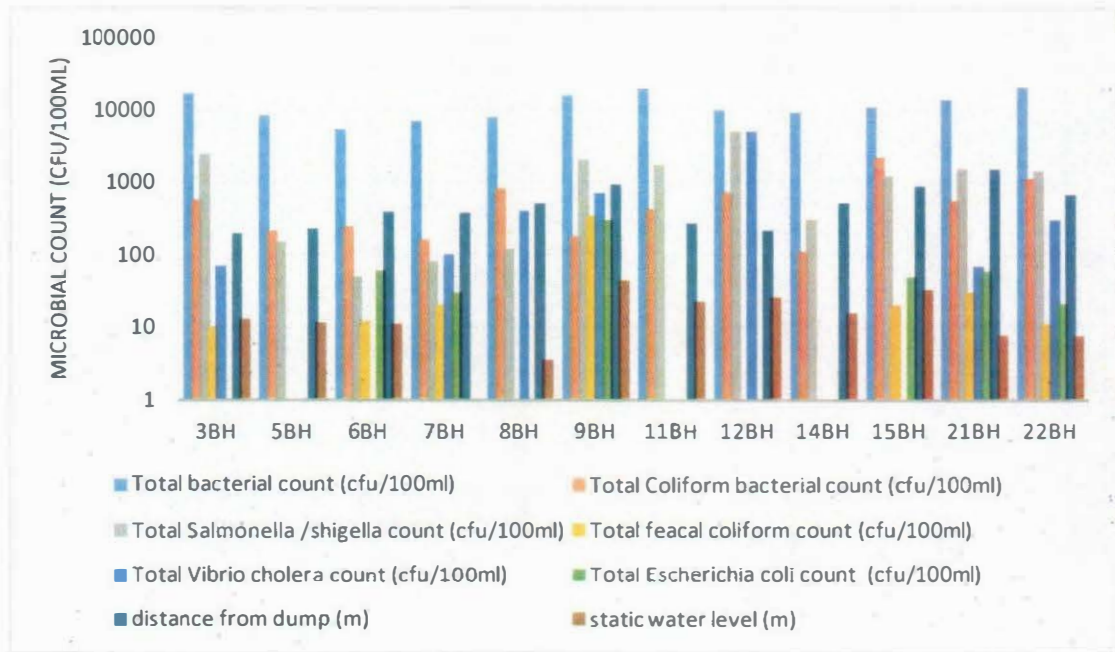
FIG. 17: Distribution of the microbial indicators around the dumpsite and control points in wet season.

water levels were made (FIG. 18). The result was compared with other factors such as the activities around the well head and location of the well in relation to the dumpsite and groundwater flow direction. There was no observable pattern in terms of static water level and distance from the dumpsite. However, the wells located downstream of the dumpsite (22BH, 20BH, 19BH and 7BH) had higher diversity and concentration of the indicator organisms compared to those closer to the dumpsite but upstream. While boreholes with poorly protected well head (21BH, 15BH, 9BH and 5BH) also, had high concentration and diversity of the indicator organisms. This suggest that the organisms are distributed along with the groundwater flow (Sen, 2010). Wells with poorly protected well heads are more vulnerable to microbial contaminations compared to wells with well protected well head.

Also the result shows that unlike inorganic contaminants, the microbial indicators were higher in concentration and diversity in the wet period compared to the dry period. This suggest that recharge of high volume rain water could have caused the release of formally attached organisms to travel along with the flowing groundwater and contaminate the wells. Pathogens are capable of travelling hundreds of meters within the subsurface depending on the nature of aquifer materials (Steffen & Christian, 2011), so the higher count of these organisms in the groundwater within the vicinity of the dumpsite is an indication that dumpsite leachate could be an additional source of the organisms into the water system. Pathogenic organisms such as *E. coli*, *Salmonella* *Staphylococci* etc. that were isolated causes a wide range of diseases ranging from typhoid fever, paratyphoid fever, food poisoning and related illnesses.



(a)



(a)

FIG. 18: comparison of the microbial concentration with distance from the centre of the dumpsite and static water level in the (a) dry and (b) wet season.

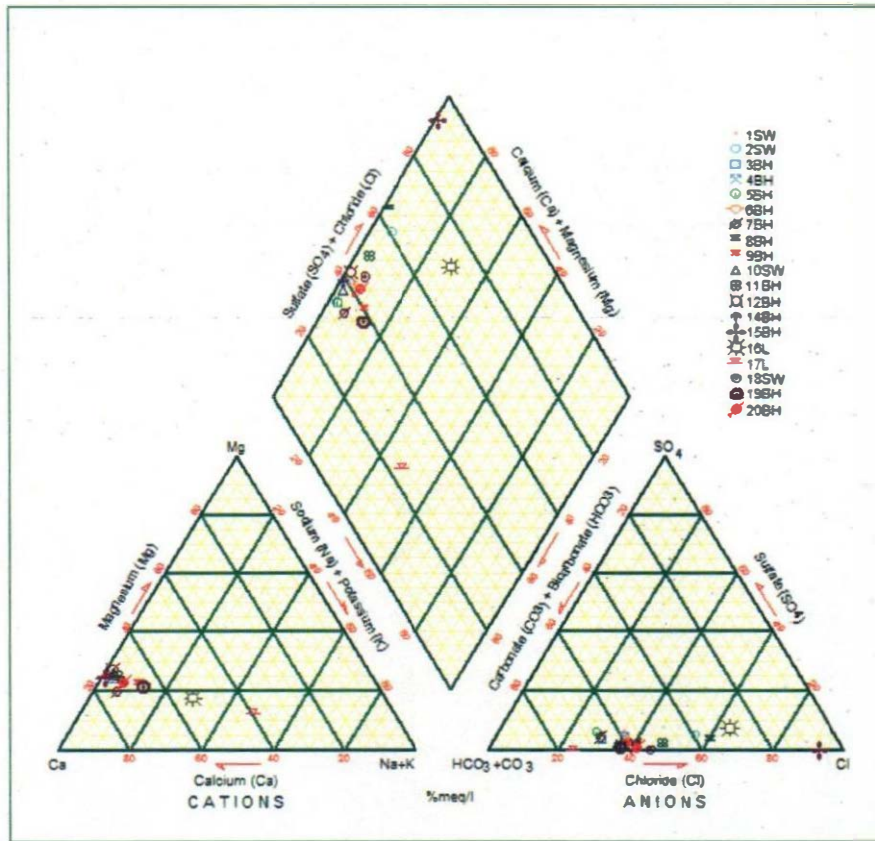
4.3.3.3 Surface water

The total bacteria count in the surface water ranged from 3.4×10^2 cfu/100ml at location 2SW to 7.0×10^2 cfu/100ml at location 1SW in the dry season, and from 2.0×10^3 cfu/100ml at location 2SW to 2.5×10^4 cfu/100ml at location 1SW in the wet season. The total coliform bacterial count ranged from 0 cfu/100ml at location 10 SW to 2.1×10^2 cfu/100ml at location 2SW in the dry season, and from 5.1×10^2 cfu/100ml at location 1SW to 9.0×10^2 cfu/100ml at location 10SW in the wet season. The total salmonella/shigella count ranged from 0 cfu/100ml at location 1SW to 1.0×10^2 cfu/100ml at locations 2SW and 10SW in the dry season and from 1.3×10^2 cfu/100ml at location 1SW to 1.6×10^3 cfu/100ml at location 10SW in the wet season. The total faecal coliform count ranged from 0 cfu/100ml at locations 2SW and 10SW to 5.0×10^1 cfu/100ml at location 1SW in the dry season and from 0 cfu/100ml at locations 2SW and 10SW in the wet season. The total vibrio cholera was not recorded in the dry season but ranged from 4.0×10^1 cfu/100ml at location 1SW to 4.0×10^2 cfu/100ml at location 2SW, and the total *E. coli* count of 1.0×10^1 cfu/100ml was recorded only at location 10SW in the dry period and ranged between 0 cfu/100ml at locations 10SW and 2SW and 3.0×10^1 cfu/100ml at location 1SW in the wet season.

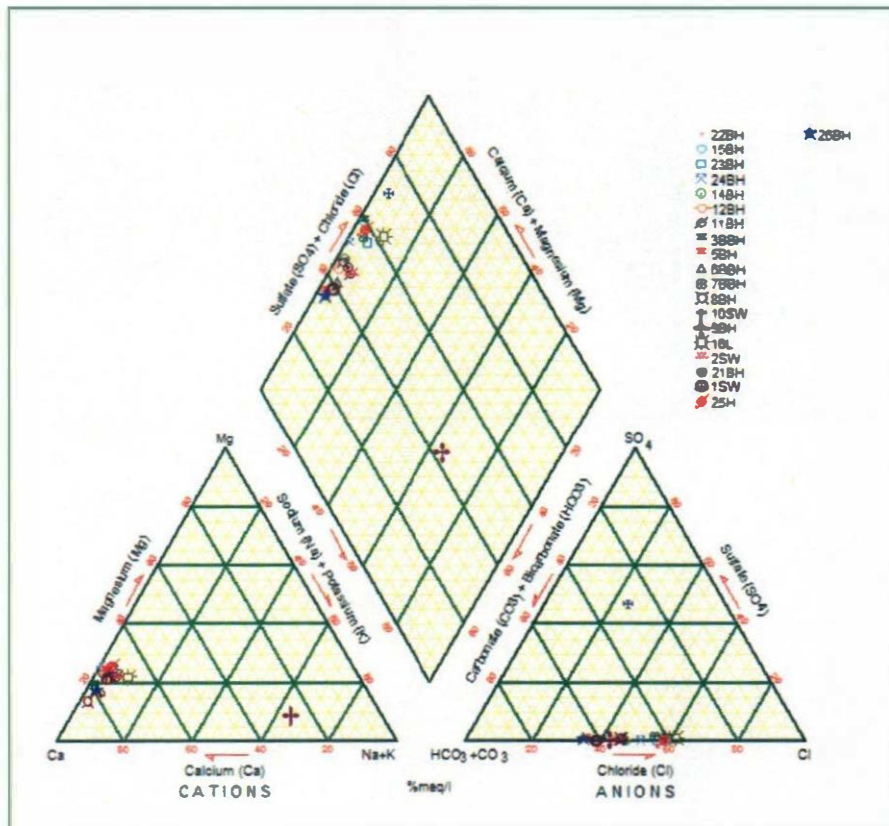
4.4 Hydrochemical processes

4.4.1 Hydrochemical facies and water classification

The result of Piper-trilinear diagram is presented in FIG. 19. The diagram shows the similarities, dissimilarities and different water types in the study area. The waters were categorised into hydrochemical facies representing water types based on the divisions of the Piper-trilinear diagram recommended by Back and Hanshaw (Hiscock, 2005). Using this classification scheme, the waters were classified into the Ca-HCO₃ type which made up 53 percent and 82 percent of the water in the wet and dry period



(a)



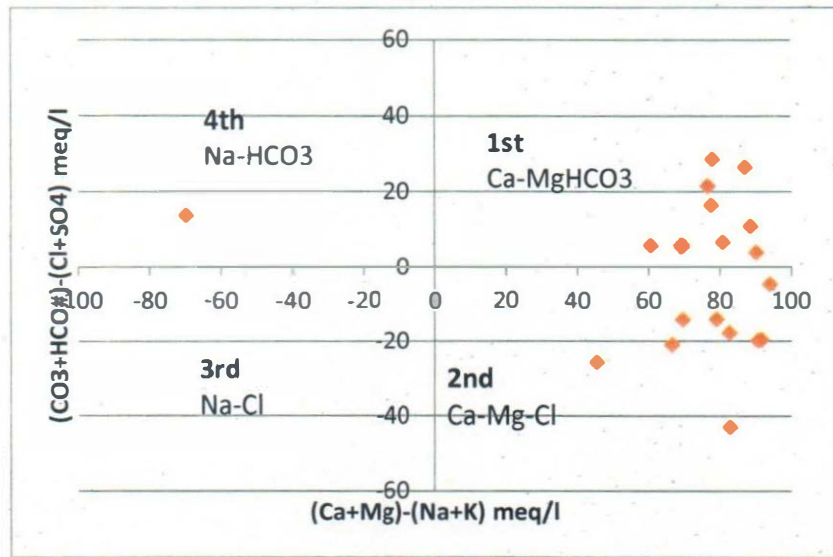
(b)

FIG. 19: Piper plot of hydrochemical data for (a) dry and (b) wet season

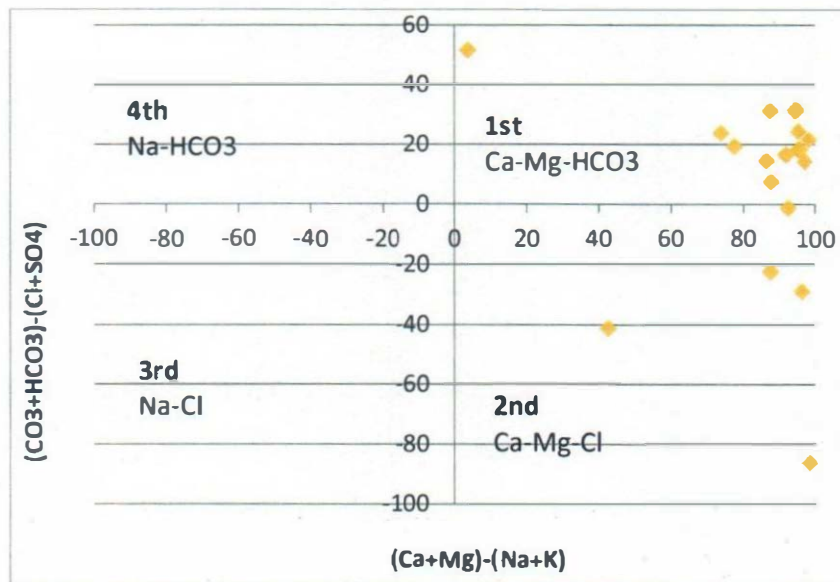
respectively, indicating carbonate dissolution (Edet, 2018). The mixed Ca-Mg-Cl type which made up 26 percent and 5 percent of the samples in the wet and dry period respectively, the mixed Ca-Na-HCO₃ type making up 21 percent of the wet season sample and the Ca-Cl type which constituted 13 percent of the dry season samples all these indicates mixing of water and/or ion exchange (Nwankwoala & Udom, 2011).

Also, the plot of the modified Piper diagram and the hydrochemical processes and chemical facies recommended by Chadha are given in FIG. 20, and Table 15 present the features of the underground water in the different regions resulting from the Chadha's diagram. Majority of the samples (60 percent in wet and 79 percent in dry season) plotted in the 1st field signifying Ca-Mg-HCO₃ water type, the 2nd field representing the Ca-Mg-Cl type had 35 percent of the wet period and 21 percent of the dry period samples, which is an indication of water with temporal hardness. Also 5 percent of the wet season samples plotted in the 4th field representing the Na-HCO₃. The analysis of the chemical facies shows that the hydrochemical features of the water in the area shows significant variations within and out of season, which could be an indication that several dynamics such as composition of aquifer materials, soil types and even pollution of recharge water is responsible for the evolution of the groundwater. Also the dominance Ca- Mg-HCO₃ water type in both seasons is an indication of carbonate dissolution and recharge from precipitation while the presence of Ca-Mg-Cl water is indicative of some level of reverse ion exchange.

The Stuyfzand classification (Stuyfzand, 2012) was also considered since it takes into account unusual water types such as FeCO₃ and NH₄CO₃ which were encountered in the area. Table 16 shows the result of the subdivision of the samples into main type, type, sub type and class according to the Stuyfzand classification. Four main water types were identified based on the chloride content; this was dominated by fresh (F)



(a)



(b)

FIG. 20: water sample from the area plotted on the modified piper diagram (a) wet and (b) dry season and their characteristics (After Chadha, 1999)

TABLE 15

Characteristics of groundwater samples in different zones derived from Chadha's diagram.

Fields	Chemical facie	Characteristics	Wet	Dry
1 st	Ca.Mg.HCO ₃ type of recharge waters	Water type with temporal hardness	60 percent	79 percent
2 nd	Ca-Mg-Cl type of reverse ion exchange waters	Water type with temporary hardness	35 percent	21 percent
3 rd	Na-Cl type of end member water (sea water)	Water type with permanent hardness	0 percent	0 percent
4 th	Na-HCO ₃	Water type which causes foaming	5 percent	0 percent

TABLE 16
Subdivision of the water samples according to Styfzand classification scheme

Subdivision	Classification code	Samples within subdivision		percent of samples within subdivision	
		Dry	Wet	Dry	Wet
Main type	Fb	1SW, 3BH, 4BH, 6BH, 9BH, 10SW, 11BH, 12BH, 14BH,	2SWB, 9BHB and 15BHB	47%	15%
	F	2BH, 5BH, 7BH, 18SW and 19BH	1SWB, 3BHB, 5BHB, 6BHB, 7BHB, 8BHB, 10SWB, 11BHB, 12BHB, 14BHB, 21BHB, 22BHB, 23BHB, 24BHB, 25BHB and 26BHB	26%	80%
	B Bs	2SW, 8BH, 16L and 17L 15BH	NIL 16LB	21% 5%	0% 5%
Type	X	20BH	5BHB, 6BHB, 7BHB, 10SWB, 11BHB, 14BHB and 26BHB	5%	35%
	0	18SW and 19BH	1SWB, 2SWB, 3BHB, 8BHB, 9BHB, 12BHB, 21BHB, 22BHB, 23BHB, 24BHB and 25BHB	10%	55%
	1	1SW, 2SW, 6BH, 7BH, 8BH, 9BH, 11BH, 12BH, 14BH and 15BH	15BHB and 16LBB	53%	10%
	2	3BH, 4BH, 5BH, 10SW, 16L and 17L	NIL	32%	0%
Sub type	CaCO ₃	1SW, 3BH, 4BH, 5BH, 6BH, 7BH, 9BH, 10SW, 12BH, 14BH, 17L, 18SW, 19BH and 20BH	NIL	74%	0%
	CaCl	2SW, 8BH, 15BH and 16L	NIL	21%	0%
	CaMix	11BH	NIL	5%	0%
	MgCl	NIL	1SWB, 3BHB, 7BHB, 15BHB, 16LB, 23BHB, 24BHB and 25BHB	0%	40%
	FeCO ₃	NIL	2SWB	0%	5%
	MgCO ₃	NIL	5BHB, 8BHB, 11BHB, 21BHB and 26BHB	0%	25%
	NH ₄ CO ₃	NIL	6BHB and 14BHB	0%	10%
	NaCO ₃	NIL	9BHB	0%	5%
	NH ₄ MIX	NIL	10SWB	0%	5%
	NH ₄ HCO ₃	NIL	12BHB	0%	5%
NH ₄ Cl	NIL	22BHB	0%	5%	
Class	+	NIL	9BHB	0%	5%
	-	All samples	All except 9BHB	100%	95%

water which constituted 26 percent and 80 percent of the dry and wet season samples respectively, followed by fresh-brakish (F_b) water that formed 47 percent and 15 percent of the dry and wet period's samples respectively. 21 percent of the dry season samples were classified as brakish (B) no wet season sample fall within this category. 5 percent of the dry and wet season samples were classified as brakish-salt (B_s) water. The wet season samples were dominated by fresh water constituting 80 percent of the total samples, indicating freshening by precipitation. The only brakish-salt water recorded in this season was the leachate sample (16L). The other three samples classified as Fresh-brakish were deeper ground water samples (9BH and 15BH) and the surface water (2SW) which have a link with the overflowing leachate during the rains.

Also four types of water were identified, based on total hardness, this was dominated by soft (0) water which constituted 10 percent and 55 percent of the dry and wet period samples respectively. 53 percent and 10 percent of the dry and wet period water samples respectively were moderately hard water (1). 5 percent and 35 percent of the dry and wet period samples were classified as very soft (X) respectively. And 32 percent of the dry season samples were hard, no hard water was recorded in the wet season again indicating dilution by precipitation.

On the basis of the major cations and anions three sub types were identified in the dry season; $CaCO_3$ (74 percent), $CaCl$ (21 percent) and $CaMIX$ (5 percent). And eight sub types were identified in the wet season; $MgCl$ (40 percent), $MgCO_3$ (25 percent), NH_4CO_3 (10 percent), $FeCO_3$ (5 percent), $NaCO_3$ (5 percent), NH_4MIX (5 percent), NH_4HCO_3 (5 percent) and NH_4Cl (5 percent). The distinct categorization of the dry and wet period samples is an indication of the influence of seasonal variation on the hydrochemistry of the water which could be due to recharge by precipitation water. The

high precipitation introduces additional ions from anthropogenic sources which lead to the alteration of the groundwater chemistry.

Base on the correction for (Na+K+Mg) all the water samples except one (9BHB) were (Na+K+Mg)-deficit (-) indicating a former salt water intrusion and marine cations deficit.

Table 17 presents the final coding and description of the water sample according to Stuyfzand. The outcome of the Stuyfzand classification suggest that carbonate dissolution is a significant process in most of the groundwater. HCO_3^- is perhaps an intermediate type between fresh and salt water, resulting from cation exchange with the soil adsorption complex. A bulk of the waters shows a composition that indicates fresh water intrusion based on the Stuyfzand classification, which again is in line with other interpretation implicating the influence of high precipitation on the groundwater chemistry.

4.4.2 Sources of ions

4.4.2.1 Inferences from cross plots, ionic ratios and indices

As groundwater flows from the recharge points towards the discharge points it undergoes chemical alterations as a result of the minerals in the aquifer, entrapped solutes and clay layers in a sedimentary rock. Cross plots and ionic ratio analysis were used to deduce information on some of these reactions. Some samples with high ionic concentration were excluded and the concentration of the ions were converted to milliequivalent per liter (meq/l) in order to combine the various ions in a chemically meaningful way (Nwankwoala & Udom, 2011).

4.4.2.1.1 Cross plots

The evaluation of the governing mechanism of the water chemistry in terms of dissolve

TABLE 17

Coding and description of the water samples according to Styfzand classification

Code	Description	Sample ID		percent of samples	
		Dry	Wet	Dry	Wet
F _b 1-CaCO ₃ -	Fresh-brakish, moderately hard calcium carbonate water with (Na +K+Mg)- deficit	1SW, 6BH, 9BH, 12BH and 14BH	NIL	26%	0%
F _b 2-CaCO ₃ -	Fresh-Brakish, hard calcium carbonate water with (Na +K+Mg) – deficit	3BH, 4BH and 10SW	NIL	16%	0%
F2-CaCO ₃ -	Fresh, hard calcium carbonate water with (Na+K+Mg) – deficit	5BH	NIL	5%	0%
F1-CaCO ₃ -	Fresh, moderately hard calcium carbonate water with (Na +K+Mg) – deficit	7BH	NIL	5%	0%
FX-CaCO ₃ -	Fresh, very soft calcium carbonate water with (Na +K+Mg) – deficit	2BH	NIL	5%	0%
9FO-CaCO ₃ -	Fresh, soft calcium carbonate water with (Na+K+Mg) – deficit	18SW and 19BH	NIL	10%	0%
F _b 1-CaMIX-	Fresh-Brakish, moderately hard calcium mix water with (Na+K+Mg) – deficit	11BH	NIL	5%	0%
B ₁ 1-CaCl-	Brakish-salty, moderately hard calcium chloride water with (Na +K+Mg) – deficit	15BH	NIL	5%	0%
B2-CaCl-	Brakish, hard calcium chloride water with (Na+K+Mg) – deficit	16L	NIL	5%	0%
B2-CaCO ₃ -	Brakish, hard calcium carbonate water with (Na +K+Mg) – deficit	17L	NIL	5%	0%
B1-CaCl-	Brakish, moderately hard calcium chloride water with (Na +K+Mg) – deficit	2SW and 8BH	NIL	10%	0%
FO-MgCl-	Fresh, soft magnesium chloride water with (Na +K+Mg) – deficit	NIL	1SW, 3BH, 23BHB, 24BH and 25BH	0%	25%
F _b 0-FeCO ₃ -	Fresh-brakish, soft iron carbonate water with (Na +K+Mg) – deficit	NIL	2SW	0%	5%
FX-MgCO ₃ -	Fresh, very soft magnesium water with (Na+K+Mg) – deficit	NIL	5BH, 11BH, 26BH	0%	15%
FX-NH ₄ CO ₃ -	Fresh, very soft ammonium carbonate water with (Na +K+Mg) – deficit	NIL	6BH and 14BH	0%	10%
FX-MgCl-	Fresh, very soft magnesium chloride water with (Na +K+Mg) – deficit	NIL	7BH	0%	5%
FO-MgCO ₃ -	Fresh, soft magnsium carbonate water with (Na +K+Mg) – deficit	NIL	8BH and 21BH	0%	10%
F _b 0-NaCO ₃ +	Fresh-brakish, sodium carbonate water with (Na +K+Mg) – surplus	NIL	9BH	0%	5%
FX-NH ₄ MIX-	Fresh, very soft ammonium mix water with (Na +K+Mg) – deficit	NIL	10SW	0%	5%
FO-NH ₄ HCO ₃ -	Fresh, soft ammonium bicarbonate water with (Na +K+Mg) – deficit	NIL	12BH	0%	5%
F _b 1-MgCl-	Fresh-brakish, magnesium chloride water with (Na +K+Mg) – deficit	NIL	15BH	0%	5%
FO-NH ₄ Cl-	Fresh, soft ammonium chloride water with (Na +K+Mg) – deficit	NIL	22BH	0%	5%
B ₁ 1-MgCl-	Brakish-salt, magnesium chloride water with (Na+K+Mg) – deficit	NIL	16L	0%	5%

ion existing in the water as evaporation-crystallization dominance, rock weathering dominance and/or atmospheric precipitation dominance, was assessed through a plot of the hydrochemical information based on the variation in the ratio of $\text{Cl}/(\text{Cl}+\text{HCO}_3^-)$ and TDS was done according to Gibbs (1970) recommendation. The Gibbs diagram (FIG. 21) of the chemical information were mostly around the atmospheric precipitation and rock-water interaction control field, indicating that chemical evolution of the water was majorly controlled by atmospheric precipitation and water-rocks interaction.

The plot of $\text{SO}_4^{2+}+\text{HCO}_3^-$ against $\text{Ca}^{2+}+\text{Mg}^{2+}$ proposed by Datta and Tyagi (1996) was plotted for the wet and dry seasons (FIG. 22). This plot will be close to the 1:1 line if carbonate dissolutions are main reactions in a system (Fisher and Mulcan, 1996; Thilagarathi, Chidambaram, Prasanna, Thirya & Singaraja, 2012) ion exchange tend to move the points below the 1:1 line as a result of excess (Ca+Mg) govern by the equation

$$\text{Na}^+\text{-water} + \text{Ca}^{2+}(\text{Mg}^{2+})\text{-clay} \leftrightarrow \text{Na}^+\text{-clay} + \text{Ca}^{2+}(\text{Mg}^{2+})\text{-water} \quad 22$$

The points will shift to the left, above the 1:1 line, due to an excess of $(\text{SO}_4^{2+}+\text{HCO}_3^-)$ over $(\text{Ca}^{2+}+\text{Mg}^{2+})$ resulting from reverse cation exchange process. FIG. 22 shows that over 90 percent of the water samples crowded around and below the 1:1 line in both season. Suggesting surplus Ca+Mg in the system, suggesting that ion exchange is the dominant process. The points that plotted above the line, one surface water (1SW) and one groundwater (7BH) in the dry season and one surface water (10SW) and one groundwater (6BH) in the wet season suggest that reverse ion exchange dominate the process here. Few samples such as 12BH, 14BH, 26BH and 2SW fall within the 1:1 line indicating carbonate dissolution.

Also, the plot of $\text{Ca}^{2+}+\text{Mg}^{2+}$ against HCO_3^- (FIG. 23) shows that $\text{Ca}^{2+}+\text{Mg}^{2+}$ is in surplus compared to HCO_3^- in almost all the samples in both season. The excess $\text{Ca}^{2+}+\text{Mg}^{2+}$ suggest some additional source of Ca^{2+} and Mg^{2+} , requiring that part of the

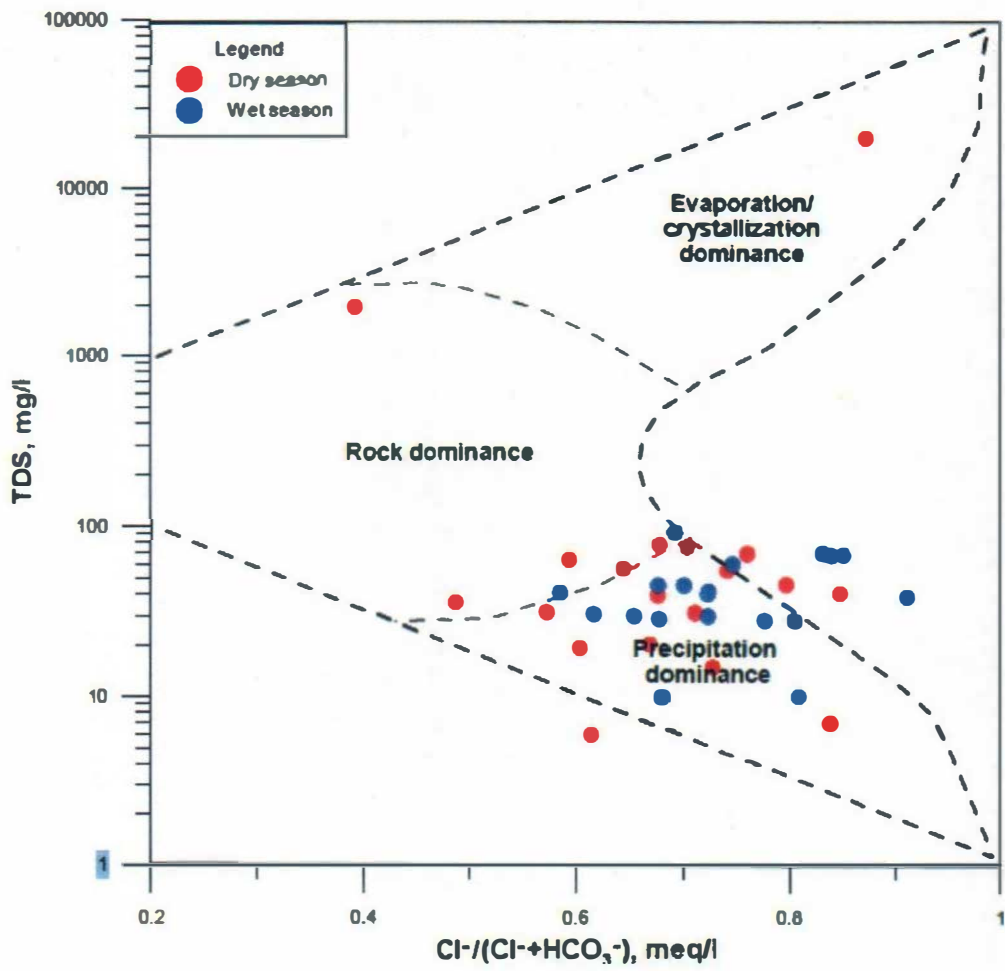


FIG. 21: Gibb's plot of Log TDS against Cl/(Cl+HCO₃)

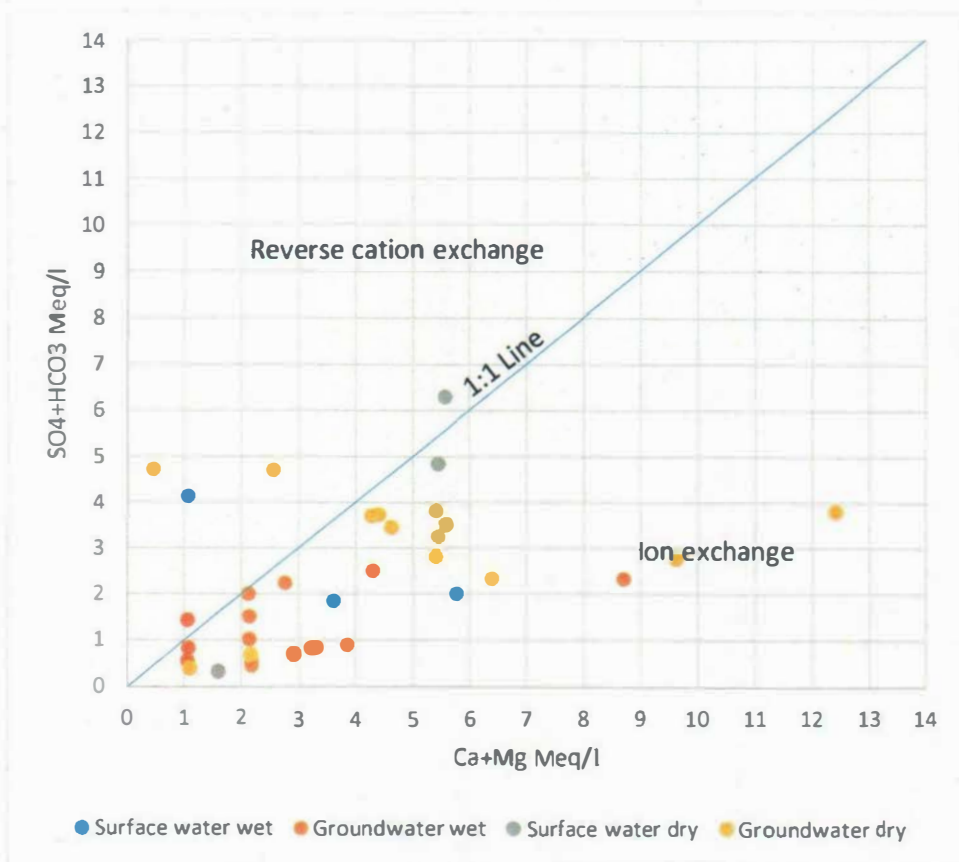


FIG. 22: Plot of SO_4+HCO_3 against $\text{Ca}+\text{Mg}$ in the wet and dry season

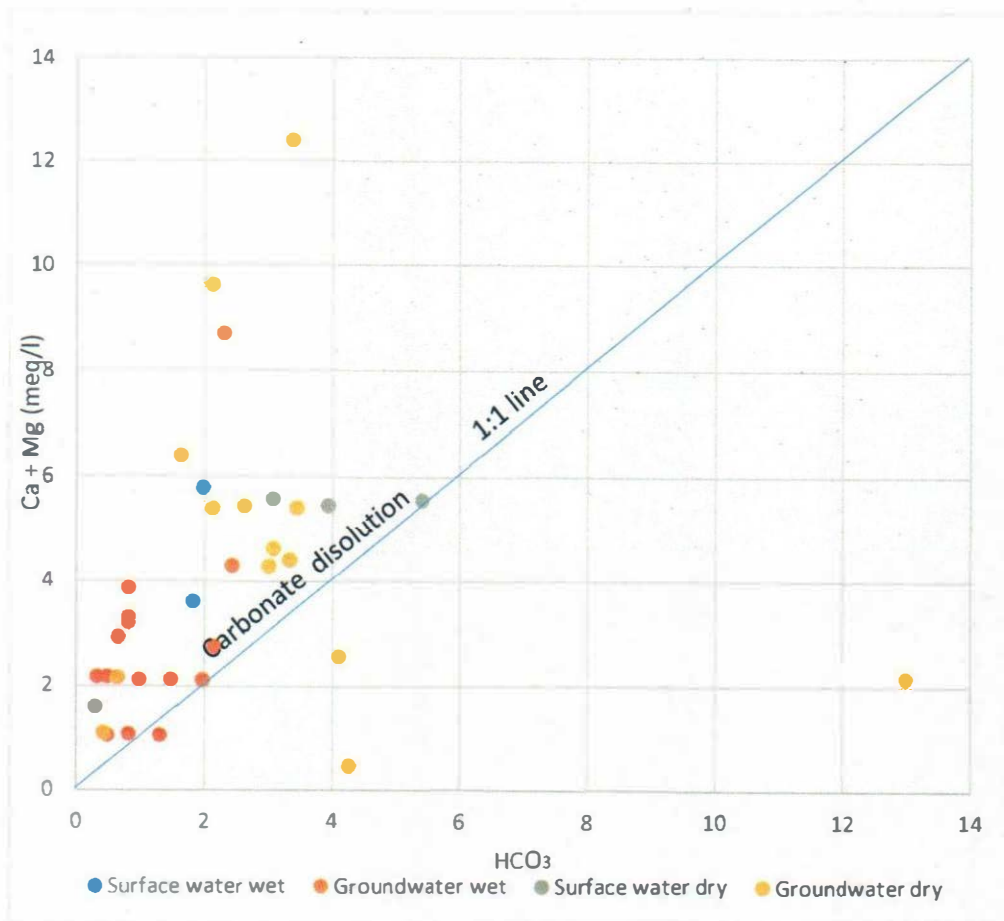


FIG. 23. Plot of Ca²⁺+Mg²⁺ against HCO₃⁻ in the Dry and Wet season

surplus positive charge be balanced by other anions such as SO_4^{2-} and/or Cl^- . Nevertheless, some of the wet season samples plotted close to the 1:1 line, indicative of carbonate dissolution. While one sample (7BH) had excess HCO_3^- over $\text{Ca}^{2+}+\text{Mg}^{2+}$ in the dry season. Suggesting that a portion of the HCO_3^- ought to be balanced by other cations like Na^+ and/or K^+ (Edet, 2018).

The relationship between Na^+ and HCO_3^- (FIG. 24) support carbonate dissolution, due to the enrichment of HCO_3^- in almost all the samples in both seasons. However, the enrichment of Na^+ in one sample (9BH) in the wet season, indicate that other process, such as ion exchange or saline water intrusion, could be responsible for the enrichment of Na^+ .

Cross plot of Na^+ against Cl^- (FIG. 25) indicate enrichment of Cl^- with respect to Na^+ in all the samples, except location 9BH which fell on the 1:1 line indicating halite dissolution. The result of this plot suggest an additional source of Cl^- . This also could be due to ion exchange resulting to the depletion of Na^+ from the waters.

4.4.2.1.2 Ionic ratios

Ionic ratios were also used to further understand the sources of ions in the water. The mole ratio of $(\text{Ca}+\text{Mg})/\text{HCO}_3^-$ was used to deduce the origin of Ca and Mg ion in the aquifer. The ratio of $(\text{Ca}+\text{Mg})/\text{HCO}_3^-$ less than 1 and around 0.5 implies that Ca and Mg are released into the solution at lower rate than the HCO_3^- , ratio around 0.5 is an indication that they originate from dissolution of carbonates and other accessory minerals (Rajmohan & Elango, 2004; Nganje *et al.*, 2010). The ratio for the groundwater samples varied between 0.22 and 1.91 with mean ratio of 0.81 ± 0.47 and from 0.62 to 4.52 with mean ratio of 2.38 ± 1.14 in wet and dry period respectively (Tables 18 & 19), the ratio is greater during dry period compared to wet period.

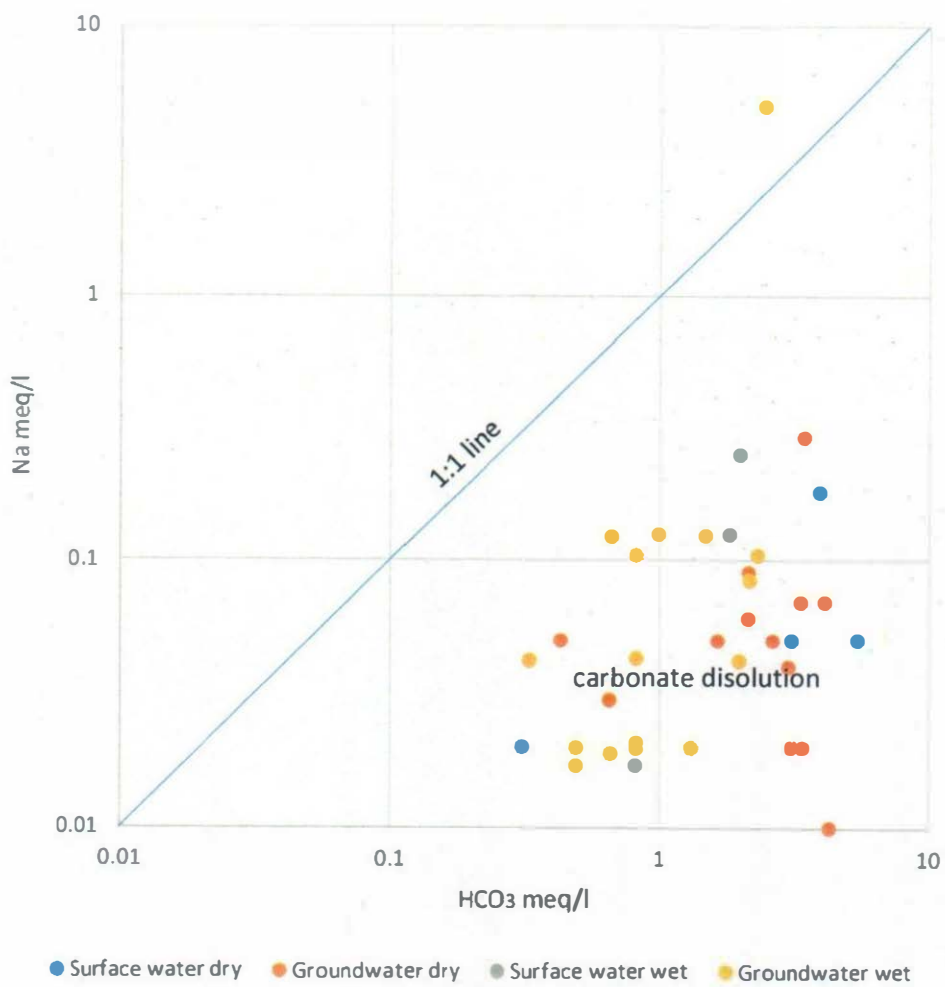


FIG. 24. Plot of Na^+ against HCO_3^- in the Dry and Wet period

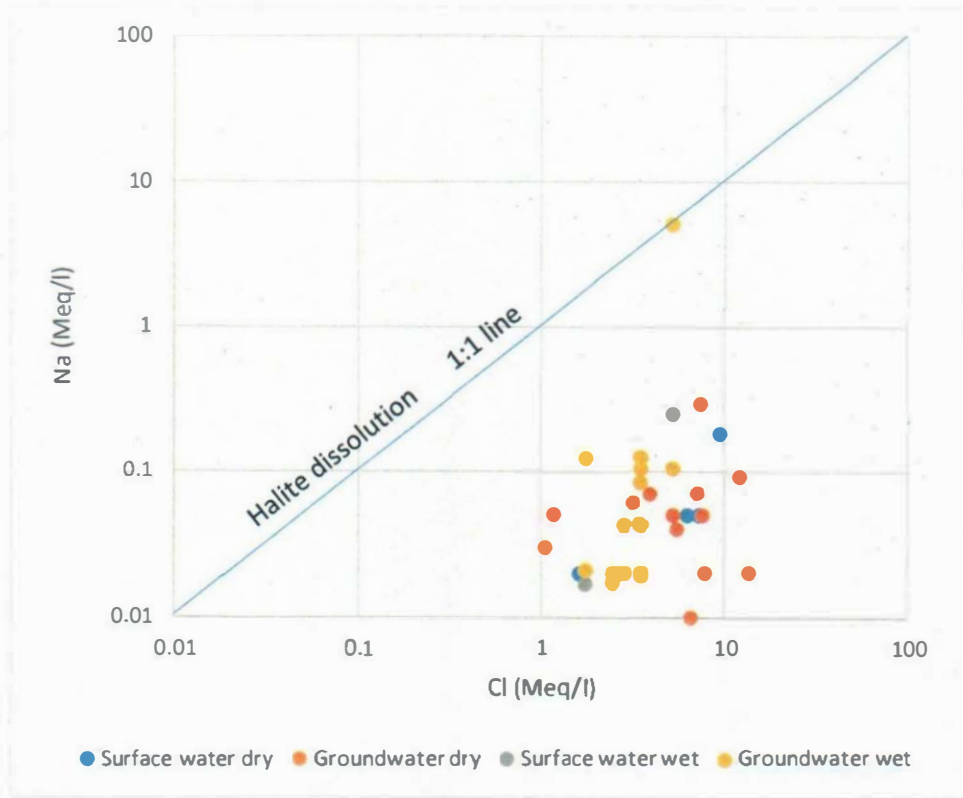


FIG. 25. Plot of Na⁺ against Cl⁻ in the Dry and Wet period

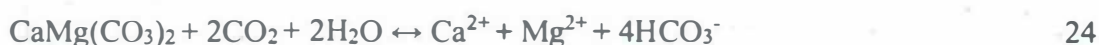
TABLE 18
Ionic ratios and indices of the water samples in the wet season

Sample ID	Na/Cl	Mg/Na	Ca/Na	HCO ₃ /Na	HCO ₃ /Ca	Mg/Ca	Cl/HCO ₃	Na+K/ Ca+Mg	Ca+Mg/ Na+K	Ca/Mg	CAI-1	CAI-2	(Ca+Mg)/ HCO ₃
Groundwater													
3BH	0.006	30.526	124.210	34.737	0.280	0.250	5.279	0.015	66.818	4.000	0.990	0.700	0.92
5BH	0.007	32.941	95.294	28.824	0.302	0.340	4.911	0.023	42.745	2.940	0.980	0.680	1.21
6BH	0.006	13.000	40.000	65.500	1.638	0.331	2.632	0.045	22.083	3.020	0.990	0.610	0.22
7BH	0.012	13.810	38.095	7.857	0.206	0.365	10.525	0.043	23.441	2.7400	0.970	0.730	1.91
8BH	0.013	13.023	76.744	19.070	0.248	0.169	4.127	0.025	39.794	5.910	0.970	0.670	0.75
9BH	0.981	0.216	0.628	0.477	0.759	0.344	2.138	1.800	0.556	2.910	-0.490	-0.290	1.54
11BH	0.007	13.000	40.000	24.500	0.613	0.319	5.687	0.071	14.133	3.140	0.970	0.690	0.64
12BH	0.015	12.381	38.095	46.905	1.231	0.320	1.412	0.024	42.400	3.120	0.980	0.510	0.27
14BH	0.008	13.000	41.000	41.000	1.000	0.315	2.957	0.023	43.200	3.170	0.990	0.640	0.32
15BH	0.020	22.115	61.538	22.115	0.359	0.358	2.260	0.015	68.504	2.790	0.980	0.590	1.01
21BH	0.071	4.228	19.512	5.366	0.275	0.214	2.640	0.049	20.420	4.680	0.920	0.580	0.82
22BH	0.036	4.320	12.800	7.920	0.619	0.334	3.513	0.084	11.955	3.000	0.950	0.640	0.6
23BH	0.036	4.355	12.903	11.935	0.925	0.336	2.359	0.069	14.965	2.980	0.960	0.590	0.38
24BH	0.012	38.095	114.286	39.048	0.342	0.333	2.109	0.011	91.429	3.000	0.980	0.580	0.99
25BH	0.030	8.654	23.077	7.885	0.342	0.372	4.221	0.035	28.696	2.690	0.970	0.670	1.11
26BH	0.024	5.952	26.905	25.595	0.951	0.225	1.612	0.033	30.667	4.450	0.970	0.530	0.24
Mean	0.080	14.351	47.818	24.296	0.631	0.308	3.649	0.148	35.113	3.409	0.880	0.570	0.808
Max	0.981	38.095	124.211	65.500	1.638	0.372	10.525	1.800	91.429	5.910	0.990	0.730	1.910
Min	0.006	0.216	0.628	0.477	0.206	0.169	1.412	0.011	0.556	2.690	-0.490	-0.290	0.220
Std. Dev.	0.233	10.749	35.719	17.239	0.406	0.058	2.182	0.427	23.251	0.866	0.354	0.230	0.471
Surface water													
1SW	0.036	6.560	22.400	14.560	0.650	0.293	1.901	0.043	23.205	3.410	0.950	0.550	0.47
2SW	0.048	5.520	17.600	7.920	0.450	0.314	2.628	0.074	13.600	3.180	0.920	0.580	0.79
10SW	0.010	15.294	48.235	48.235	1.000	0.329	2.111	0.041	24.545	3.040	0.970	0.270	0.35
Mean	0.031	9.125	29.412	23.572	0.700	0.312	2.213	0.052	20.450	3.210	0.947	0.467	0.537
Max	0.048	15.294	48.235	48.235	1.000	0.329	2.628	0.074	24.545	3.410	0.970	0.580	0.790
Min	0.010	5.520	17.600	7.920	0.450	0.293	1.901	0.041	13.600	3.040	0.920	0.270	0.350
Std. Dev	0.016	4.383	13.454	17.649	0.227	0.015	0.305	0.015	4.875	0.153	0.021	0.140	0.186

TABLE 19
Ionic ratios and indices of the water samples in the dry season

Sample ID	Na/Cl	Mg/Na	Ca/Na	HCO ₃ /Na	HCO ₃ /Ca	Mg/Ca	Cl/HCO ₃	Na+K/Ca+Mg	Ca+Mg/Na+K	Ca/Mg	CAI-1	CAI-2	(Ca+Mg)/HCO ₃ ⁻
Groundwater													
3BH	0.007	27.000	80.000	75.000	0.938	0.340	1.820	0.030	32.923	2.940	0.980	0.420	1.43
4BH	0.010	32.000	96.000	32.800	0.342	0.330	3.170	0.022	45.714	3.020	0.970	0.540	3.9
5BH	0.019	23.333	66.667	35.500	0.533	0.350	1.460	0.028	36.000	2.840	0.950	0.360	2.53
6BH	0.007	28.400	80.400	52.400	0.652	0.350	2.870	0.026	38.857	2.830	0.980	0.580	2.08
7BH	0.018	8.000	28.571	58.571	2.050	0.280	0.950	0.066	15.059	3.640	0.960	0.390	0.62
8BH	0.008	26.660	80.222	23.667	0.295	0.330	5.120	0.020	50.632	3.010	0.980	1.510	4.52
9BH	0.040	4.759	13.862	11.862	0.856	0.340	2.110	0.128	7.826	2.900	0.910	0.560	1.57
11BH	0.010	16.857	46.000	47.571	1.034	0.370	2.110	0.039	25.882	2.740	0.980	0.880	1.32
12BH	0.003	65.000	166.000	153.500	0.925	0.390	2.470	0.015	66.000	2.560	0.990	0.670	1.5
14BH	0.002	186.000	560.000	426.000	0.761	0.330	1.520	0.008	124.333	3.020	0.990	0.560	1.75
15BH	0.002	159.000	478.000	169.000	0.354	0.330	3.930	0.007	141.556	3.000	0.990	1.250	3.77
19BH	0.044	5.600	16.400	8.600	0.524	0.330	2.650	0.145	6.875	3.020	0.860	0.490	2.56
20BH	0.029	18.000	54.000	21.667	0.401	0.330	1.590	0.074	13.500	3.020	0.850	0.590	3.32
Mean	0.015	46.201	135.856	85.857	0.743	0.338	2.444	0.047	46.551	2.965	0.953	0.677	2.375
Max	0.043	186.000	560.000	426.000	2.050	0.390	5.120	0.145	141.556	3.640	0.990	1.510	4.520
Min	0.002	4.759	13.862	8.600	0.295	0.280	0.950	0.007	6.875	2.560	0.850	0.360	0.620
Std. Dev	0.014	56.087	168.471	109.339	0.448	0.024	1.093	0.043	40.585	0.236	0.047	0.24	1.137
Surface water													
1SW	0.007	28.400	82.800	108.200	1.3068	0.350	1.340	0.043	23.167	0.240	0.970	0.520	1.030
2SW	0.019	7.667	22.556	21.833	0.968	0.340	2.380	0.066	15.111	0.362	0.960	1.190	1.380
10SW	0.008	30.400	81.200	61.600	0.759	0.380	2.020	0.025	39.857	0.137	0.980	0.530	1.810
18SW	0.012	20.000	60.000	15.500	0.258	0.330	5.110	0.069	14.545	0.105	0.940	0.780	5.160
Mean	0.012	21.617	61.639	51.783	0.823	0.350	2.713	0.051	23.170	0.211	0.963	0.755	2.345
Max	0.019	30.400	82.800	108.200	1.307	0.380	5.110	0.069	39.857	0.362	0.980	1.190	5.160
Min	0.007	7.667	22.556	15.500	0.258	0.330	1.340	0.025	14.545	0.105	0.940	0.520	1.030
Std. Dev	0.005	8.950	24.293	37.056	0.380	0.019	1.434	0.018	10.220	0.100	0.015	0.272	1.649

The increase in dry period suggests that Ca and Mg are released into the solution at a higher rate than HCO₃. While in most locations, the reverse was the case in the wet period. If Mg and Ca are mostly product of carbonate minerals the ratio ought to be around 0.5 (Rajmohan & Elango, 2004). The prevailing equations for the dissolution of calcite and dolomite in the aquifer will be.



All the samples fell above the ratios 0.5, except some samples in the wet season, this could be ascribed to addition of Ca and Mg or reduction of HCO₃ in the aquifer. Increase in the ratio could be an indication that Ca and Mg addition to the water is from sources such as reverse ion exchange or Ca-Mg silicate.

Also the Ca/Mg ratios of underground water samples portray the dissolution of calcite and dolomite existing in the aquifer, if the Ca/Mg ratio = 1, dissolution of dolomite ought to occur, while the ratio > 1 indicates dissolution of calcite (Li, Wu, Qian & Gao, 2018). The Ca/Mg ratio is greater than 2 in the entire sample (Tables 18 & 19), indicating that calcite is the major carbonate mineral in the aquifer.

Also Mg/Ca and Cl/HCO₃ ratios were used to assess the salinity and source of the groundwater in the area. The Mg/Ca values were all less than 2.0 (Tables 18 & 19), ranging from 0.17 to 0.37 with mean ratio of 0.31±0.06 and 0.28 to 0.39 with average ratio of 0.34±0.02 in the wet and dry season respectively. This is an indication that the groundwater of the area is not under marine influence, as water under marine influence would have ratio of about 5.0 (Amajor, 1986). The Cl/HCO₃ values ranged from 1.41 to 10.53 with average ratio of 3.65±2.18 and from 0.95 to 5.12 with average ratio of 2.44±1.09 in the wet and dry period respectively (Tables 18 & 19), which is also an indication of inland origin of the groundwater as the value of this ratio given for inland

waters are between 0.1 and 5 and between 20 and 50 for seawater (Custodio, 1987; Nwankwoala & Udom, 2011). The higher Cl/HCO₃ ratio in location 7BH in the wet season indicates additional source of Cl in this location.

In addition, the ratios of Mg/Na, Ca/Na and HCO₃/Na were applied to compute the relative fraction of Mg, Ca and HCO₃ in the groundwater in relation to Na. The Mg/Na ranged from 0.22 to 38.10 with average ratio of 14.35±10.75 in the wet period and from 4.76 to 186.00 with average ratio of 46.20±56.09 in dry period. The Ca/Na ratio ranged from 0.63 to 124.21 with mean ratio of 47.82±35.72 in the wet season and from 13.86 to 560.00 with mean ratio of 135.86±168.47 in the dry season. while that of HCO₃/Na ranged between 0.48 and 65.50 with average ratio of 24.30±17.24 in the wet season and from 8.60 to 426.00 with average of 85.86±109.34 in the dry season (Tables 18 & 19). These ratios correspond to dominance of Mg and Ca indicating weathering of carbonate minerals. Mg/Na molar ratio around 10, Ca/Na ratio around 50 and HCO₃/Na ratio around 120 are typical of water draining carbonate rocks, while the ratios assigned to silicate end members are; Mg/Na=0.24, Ca/Na=0.35 and HCO₃/Na=2.00 approximately (Edet, 2018). The molar ratios in this study (Tables 18 & 19) are much higher than those draining silicate rocks, indicating the dominance of carbonate weathering in the area. However, some locations (11BH, 12BH and 15BH) have values far above the typical molar ratios for water draining carbonate rocks indicating that there is an additional source of Ca, Mg and HCO₃ in these locations.

4.4.2.1.3 Indices

Changes in chemical composition of water was also assessed by the use of chloro-alkali indices (CAI-1 and CAI-2) as proposed by Schoeller, for the interpretation of ion exchange amongst groundwater and host environment. The CAI's are calculated from the following relations.

$$\text{CAI-1} = (\text{Cl}^- - (\text{Na} + \text{K})) / \text{Cl} \quad 25$$

$$\text{CAI-2} = (\text{Cl}^- - \text{Na} + \text{K}) / (\text{SO}_4 + \text{HCO}_3 + \text{CO}_3 + \text{NO}_3) \quad 26$$

All ionic concentrations are in meq/l.

The value of CAI can either be positive or negative. If the exchange of Na^+ and K^+ from water with Mg^{+2} and Ca^{+2} in the aquifer materials, the indices are positive suggesting ion exchange. On the other hand, if the exchange of Ca^{+2} and Mg^{+2} of the water is by Na^+ and K^+ of the aquifer materials then the indices will be less than zero which confirms reverse ion exchange. The values of CAI-1 and CAI-2 calculated for all groundwater samples based on the above formulas as given in Tables 18 and 19 are all positive, indicating reverse ion exchange reaction is predominant, except for one wet season sample (location 9BHB) (Rajmohan & Elango, 2004).

4.4.2.2 Multivariate statistical analyses

4.4.2.2.1 Correlation analysis

The correlation matrix amongst the several parameters investigated is presented in Appendix 8. Some of the variables were found to have significant correlation with each other, suggesting close association between these parameters. The major anions Cl^- , CO_3^{-2} , HCO_3^- and SO_4^{-2} shows positive correlation with Ca^{+2} , Mg^{+2} and hardness indicating the main water type in the area. The correlation between Cl^- with Ca^{+2} , Mg^{+2} , CO_3^{-2} , HCO_3^- , SO_4^{-2} and NO_2^- indicates that these ions are probably derived from the same source such as the dumpsite leachate owing to the high concentration of these ions in the leachate sample. This is corroborated by the negative correlation of the same ions (Ca^{+2} , Mg^{+2} , CO_3^{-2} , HCO_3^- , SO_4^{-2} and NO_2^-) with DO, which is a probable link to their anthropogenic sources. Also the correlation of K^+ , Na^+ with NO_3^- , PO_4^{-3} and NH_4^- suggest that these ions could be coming from anthropogenic sources.

4.4.2.2 Principal components analysis

The Principal components analysis (PCA) technique was applied to twenty-eight (28) variables (Temperature, pH, Electrical conductivity, DO, TDS, Cl^- , CO_3^{2-} , HCO_3^- , NO_3^- , SO_4^{2-} , PO_4^- , NO_2^- , Salinity, NH_4^+ , COD, BOD, Hardness, Ca^{+2} , Mg^{+2} , K^+ , Na^+ , Cu, Pb, Zn, Cd, Mn and Fe) of groundwater samples around the dumpsite, which produced eight components with eigen values more than 1, accounting for 82 percent of the total variance in the data. The individual variances are 28.71, 16.20, 8.46, 7.55, 6.90, 5.72, 5.10 and 3.93 percent for components 1, 2, 3, 4, 5, 6, 7 and 8 respectively (Table 20).

The percentage variance explained components after the fourth reduced drastically and such factors are problematic to understand and so the information content of the components is ascribed more to noise in the data than to a hydrochemical process. From table 20 the first PC described up to 28 percent of the variance and was characterised by positive loadings of EC, Cl^- , CO_3^{2-} , HCO_3^- , SO_4^{2-} , PO_4^- , NO_2^- , NH_4^+ , COD, Hardness, Ca^{+2} , Mg^{+2} and Cr with negative PCA loadings of DO and BOD. Component 2 has positive loadings of pH, NO_3^- , PO_4^- , NH_4^- , COD, K^+ and Na^+ with negative loading of EC and salinity. Temperature, pH, Cl^- , Ca^{+2} and Mg^{+2} has positive loadings with Mn having negative loading on principal component 3. Component 4 has positive loadings of BOD and negative loading of Mn and Fe. Temperature, Cd and Cr have negative loading on principal component 5. Component 6 has high positive loading of TDS, Salinity, COD and Pb. Zn had positive loading with Fe having negative loading in component 7, While Principal component 8 had positive loading of Cd and negative loading of Fe.

The existence of CO_3^{2-} , HCO_3^- , SO_4^{2-} , Ca^{+2} , Mg^{+2} in component 1 is an indication of the water type, probably derived from the carbonate weathering.

TABLE 20

Variables	Principal Component							
	1	2	3	4	5	6	7	8
Temperature	-.197	.271	.654	.014	.445	.108	-.217	-.137
pH	-.377	.417	.436	-.048	-.210	.308	.236	.289
EC	.474	-.414	-.247	.208	-.012	.014	-.270	.264
DO	-.742	-.220	.033	.364	.165	.223	.178	.029
TDS	.307	-.359	-.391	-.251	-.311	.448	-.331	.058
CL	.783	.057	.427	-.233	-.159	.082	.039	.123
CO3	.873	-.091	-.063	.149	.060	-.191	-.010	.242
HCO3	.809	.087	.232	.043	-.063	-.323	.039	-.082
NO3	.086	.771	-.315	.171	-.146	.099	-.145	-.008
SO4	.863	-.257	-.109	.115	.172	-.081	.213	-.133
PO4	.452	.478	.175	.233	-.043	-.066	-.394	.102
NO2	.794	-.266	.145	.219	.090	-.331	-.072	.022
Salinity	-.134	-.651	-.118	.369	-.260	.419	-.201	.091
NH4	.503	.618	-.370	.156	.129	-.139	.273	-.044
COD	.510	.450	-.214	.118	.211	.445	-.060	-.178
BOD	-.532	-.246	.250	.636	.155	-.073	.208	-.004
Hardness	.859	-.296	-.055	.176	-.006	-.067	.207	-.165
Ca	.729	.010	.446	-.186	-.154	.362	.077	-.082
Mg	.757	.008	.435	-.121	-.192	.363	.083	-.026
K	.105	.898	-.084	.290	-.036	.072	-.103	.060
Na	.094	.906	-.070	.291	-.032	.072	-.088	.047
Cu	.087	.103	-.383	-.307	-.393	-.134	.033	-.044
Pb	.186	-.182	-.336	.370	.364	.421	.122	-.231
Zn	-.362	.273	.003	-.254	-.151	.086	.523	-.133
Cd	-.180	.060	.012	-.310	.640	-.008	-.185	.539
Mn	.291	.117	-.448	-.438	.374	.133	.377	.290
Cr	.596	-.188	.087	-.073	.518	.259	.079	-.002
Fe	-.220	.079	-.053	-.483	.358	-.053	-.415	-.533
Eigen value	8.039	4.537	2.368	2.115	1.931	1.602	1.428	1.100
percent Variance	28.710	16.204	8.457	7.552	6.895	5.721	5.098	3.929
Cumulative %	28.710	44.914	53.371	60.923	67.818	73.54	78.638	82.567

• The bold and underlined figures are the significant loadings (>0.4)

However, the presence of Cl^- , SO_4^{2-} , PO_4^- , NO_2^- , NH_4^+ , COD, Hardness with DO and BOD in this component is an indication of some anthropogenic influence. The COD concentration varied from 5.5 to 22.4mg/l suggesting the presence of organic contaminant and can be used as organic indicators to assess the groundwater contamination by waste. This is collaborated with decrease in dissolved oxygen which is linked to poor waste management (Edet, 2017). Also the presence of NH_4^+ , Ca^{+2} , Mg^{+2} and hardness is a strong indication of contamination by waste water, due to sorption of ammonium ions (NH_4^+) on soil particles through cation exchange, which could lead to the discharge of exchangeable ions like Ca^{+2} and Mg^{+2} into water, producing additional hardness in water systems. Numerous authors have established that aquifers polluted with waste water holds hard water, which is characterized by elevated levels of Ca^{+2} and Mg^{+2} (Lawrence *et al.*, 2000; Navarro and Carbonell, 2007; Foppen *et al.*, 2008). Component 2, which has positive loading of NO_3^- , NH_4^+ , K^+ and Na^+ which were high in the leachate sample is an indication of anthropogenic contamination. Component 3 designated as manganese reduction suggests that pH, Ca^{+2} and Mg^{+2} are inversely related to manganese. However, high loading of temperature in this component is an indication that these parameters result from natural processes. Component 4 with negative loading of Mn and Fe with high loading of BOD could be an indication of precipitation of Mn and Fe oxides known for their high surface area which, irrespective of low mineral concentrations, is capable of dominating the specific surface area of their surroundings. They also have a variable amount of hydroxyl groups which are capable of interacting with the surrounding fluid via ligand exchange and adsorption/desorption of protons (Knodel *et al.*, 2007). These properties are likely to play a vital part in the retention of some contaminants in the area, as most metals, for instance, are assimilated into iron oxides as they precipitate. And the high loading of

BOD is an indication of the presence of organic materials. The positive loadings of temperature, cadmium and chromium in component 5 suggest that these elements are controlled by natural processes as their concentration is not high in the leachate sample.

4.4.2.2.3 Hierarchical cluster analysis of groundwater samples

Hierarchical cluster analysis was applied to a total of 25 groundwater samples by means of Ward's technique to categorize groundwater into distinctive hydrochemical groups. Twenty-eight (28) parameters (Temperature, pH, Electrical conductivity, DO, TDS, Cl^- , CO_3^{2-} , HCO_3^- , NO_3^- , SO_4^{2-} , PO_4^{3-} , NO_2^- , Salinity, NH_4^+ , COD, BOD, Hardness, Ca^{+2} , Mg^{+2} , K^+ , Na^+ , Cu, Pb, Zn, Cd, Mn and Fe) were used during the classifications. The dendrogram of the Q-mode cluster analysis built on the groundwater displays two major groups and six sub groups of waters (FIG. 26), at a linkage distance of roughly 7 as shown by the red or phenon line (FIG. 26) indicating a close link in the chemical composition of the samples. These groups are:

Group 1: Comprised of 12 water specimens majorly from the wet season samples around the dumpsite is subdivided into two sub groups with a very short linkage distance of approximately 2, indicating a very close relationship.

Group 2: It comprises 11 samples from the dry season and 2 from wet season. The two wet season samples constitute the outliers in the entire group.

The result of the hierarchical cluster analysis reflects the influence of season and borehole depth on the groundwater composition. As the samples were clustered based on seasons. And the two samples that formed the outliers in group two, the dry season group, from the wet season group were from deep holes whose static water level were very high (samples 9BH and 15BH), this is an indication that the impact of season was not much on the deeper aquifers.

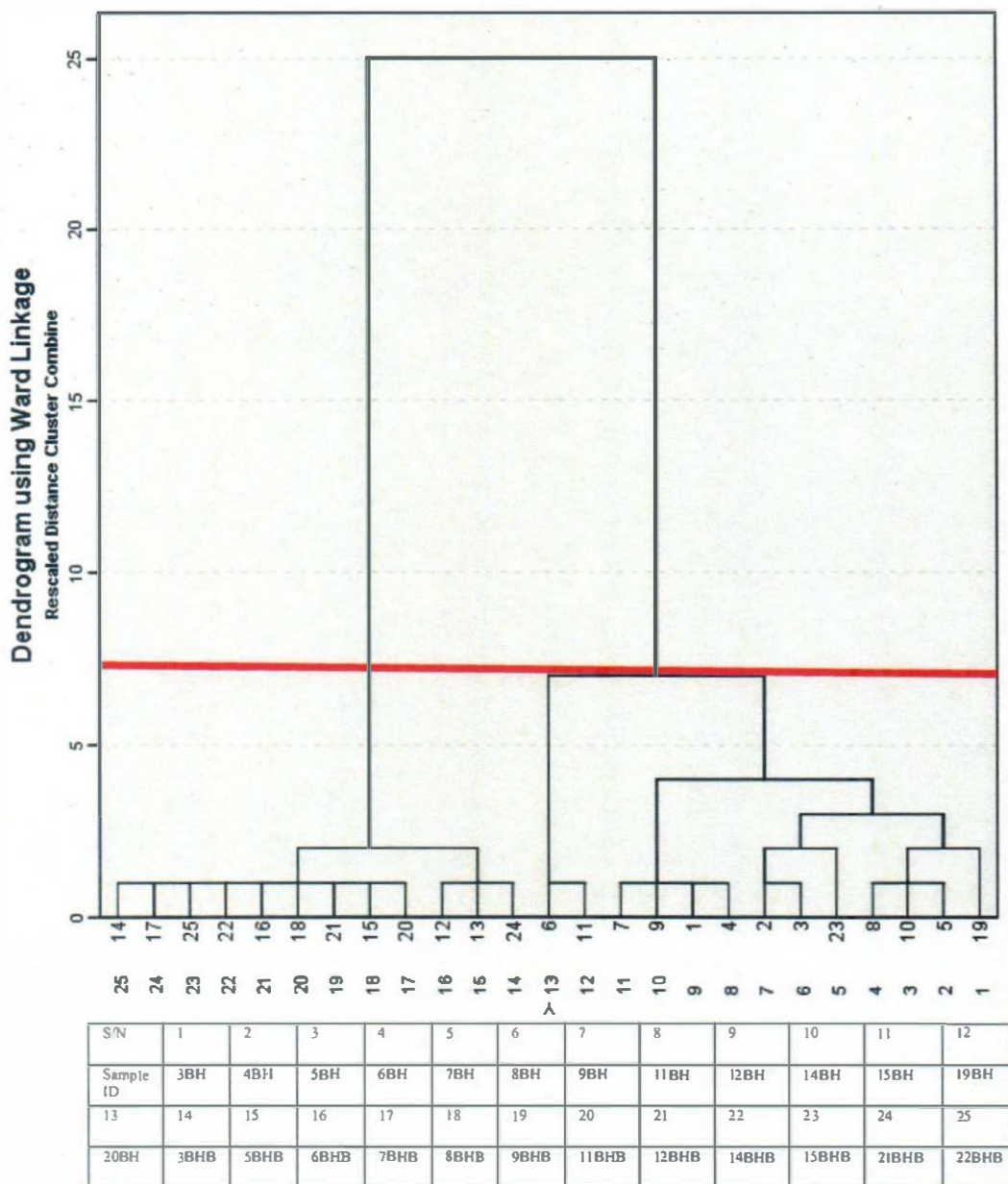
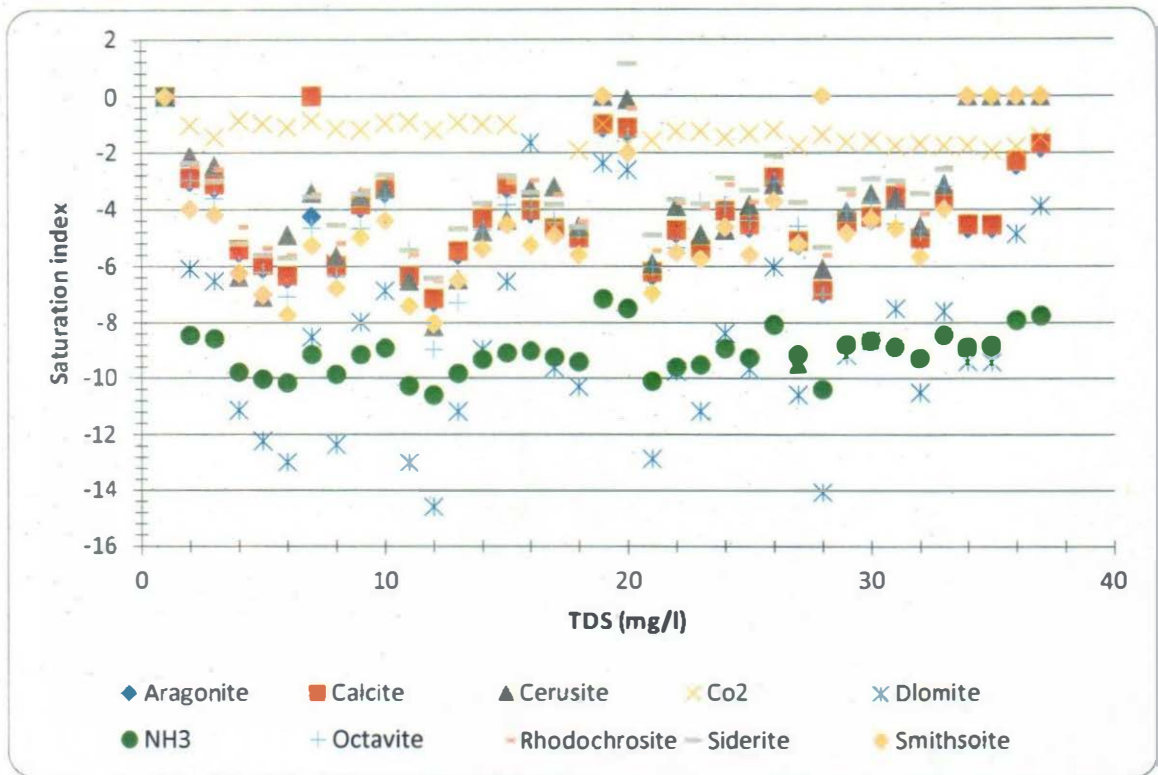


FIG. 26: Dendrogram of Q-mode cluster analysis with samples serial numbers and ID

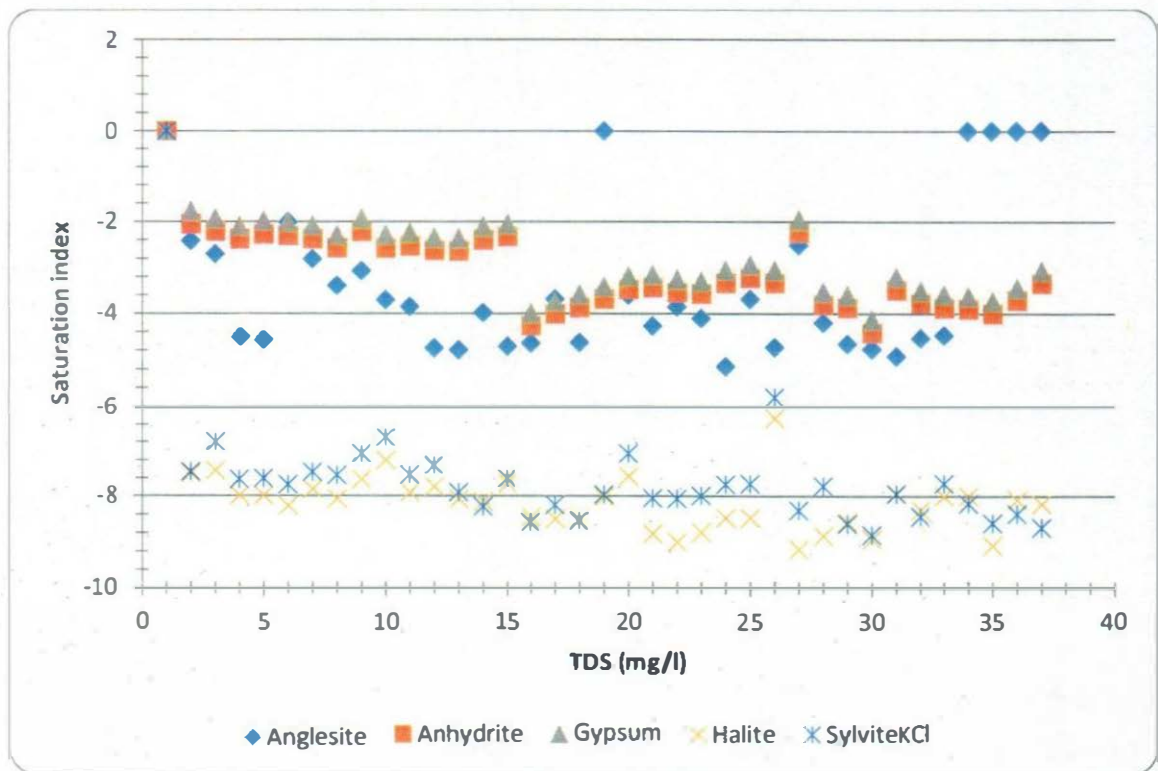
4.5 Geochemical modelling

4.5.1 Speciation modelling

The SI's generated by means of PHREEQC is presented in Appendix 9 and FIG. 27. The saturated indexes for some carbonate, sulphate and chloride minerals were studied as presented in FIG. 25. The carbonate group comprising of Aragonite, calcite, cerusite, dolomite, octavite, rhodochrosite, siderite and smithsonite, the sulphate group comprising of anglesite, anhydrite and gypsum and the chloride group consisting of halite and sylvite. The saturation indices of both the carbonate, sulphate and chloride minerals were all in under saturated state in all the groundwater samples. Some carbonate minerals like aragonite, calcite, cerucite, dolomite and siderite were over saturated in the leachate samples. Octavite and siderite which were over saturated in the dry season sample moved to state of equilibrium in the wet season leachate sample. There was an overall decrease in the saturation index of the sulphate minerals amongst the dry and wet period samples. The SI of the mineral phases bearing the conservative ions (Na^+ , K^+ and Cl^-) halite and sylvite shows thalite SI varies from -9.16 to -5.8 and that of sylvite from -8.85 to -4.39, the largest values are those of the leachate samples indicating that the dissolution of the minerals are high both in the groundwater and leachate samples. The SI values indicate the insufficient amount of the minerals in the solution or short residence time, also the decrease of SI of sulphate minerals (anglesite, anhydrite and gypsum) between dry and wet season is an indication of the effect of dilution on the minerals solubility. The result also shows that iron oxides (goethite and hematite) are oversaturated in most of the samples.



(a)

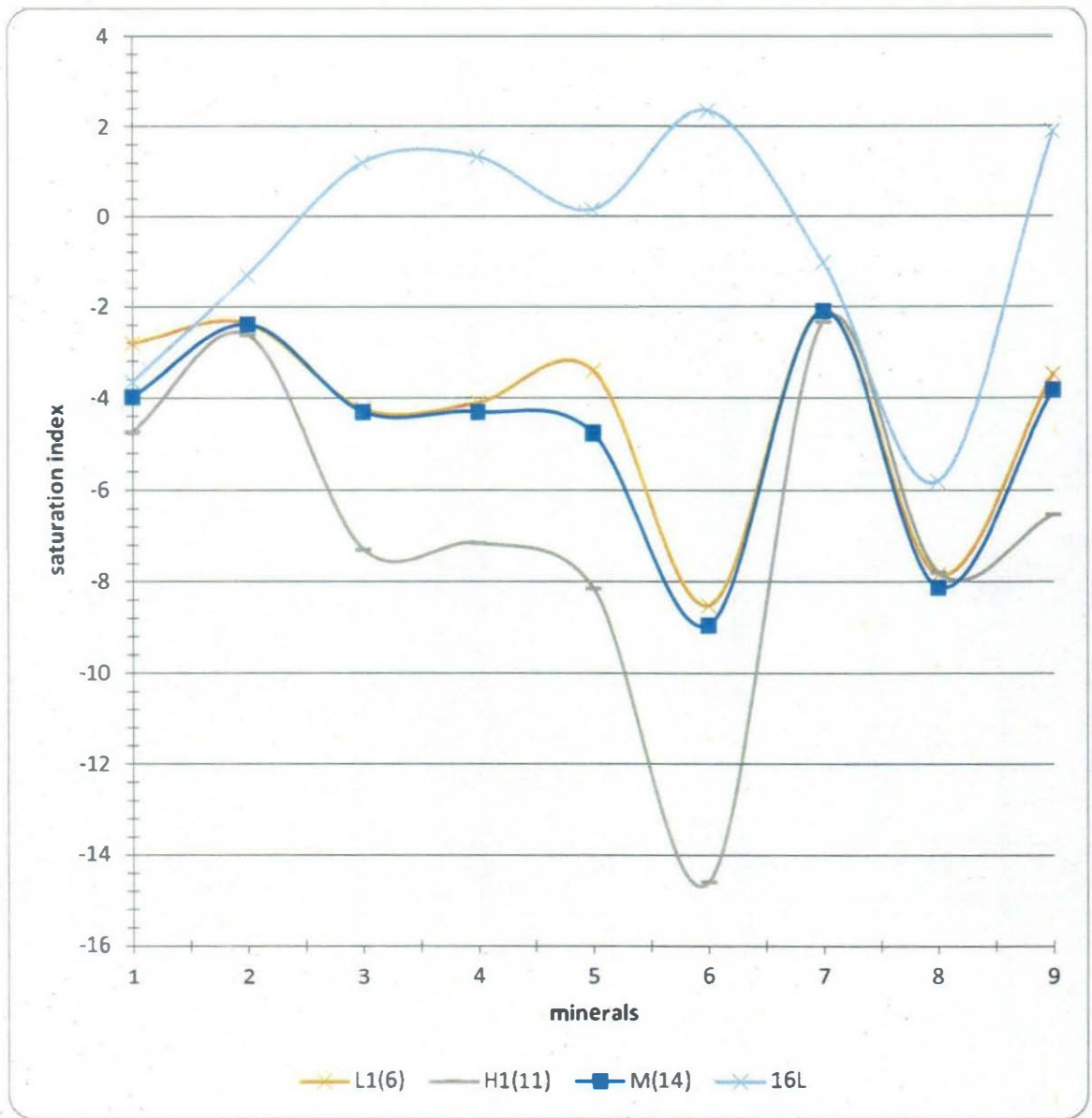


(b)

FIG. 27: Saturation index (SI) of some minerals and gases plotted versus TDS (mg/l)

Comparison of the SI's of some mineral phases (anglesite, aragonite, calcite, cerusite, dolomite, gypsum, halite, rhodochrosite and carbondioxide gas) present in the groundwater located in areas with low, medium and high average flow velocity zones were made, to assess the effect of flow on the mineral SI's. From FIG. 28 it can be observed that the leachate sample from location 16L had the highest saturation index for all the minerals except for anglesite, the saturation indexes of most of the minerals in groundwater located in the high average flow velocity area represented by location 11 (H1) is least compared with others, this is shown by the gray line in FIG. 28. The groundwater in areas of low average flow velocity represented by location 6 (L1) in FIG. 28, has higher saturation index values for most of the minerals considered. While the groundwater located in areas designated as medium average flow velocity represented by 14 (M) in FIG. 28 falls in between. This again is indicative of the effect of flow velocity in relation to residence time and its impact on the saturation index of minerals, as higher average flow velocity implies lower residence time and little time available for the groundwater to interact with the aquifer materials. While lower average flow velocity implies more time for the groundwater to interact with the aquifer materials, to bring some of the minerals phases towards equilibrium (Kumar *et al.*, 2016).

From FIG. 28, it can also be seen that the conservative minerals such as halite, shows high level of convergence, in terms of their saturation index in the entire borehole from high to low average velocity areas. And there is a clear pattern in the distribution of the saturation indexes across the velocity zones, which might be an indication that the same process is responsible for their presence in the groundwater of the area.



1- Anglesite, 2- anhydrite, 3- aragonite, 4- calcite, 5- cerucite, 6- Dolomite, 7- Gypsum, 8- Halite, 9- Rhodochrosite

FIG. 28: Distribution of the saturation indexes of minerals in the leachate and boreholes located in areas of low (L1), medium (M) and high (H1) flow velocity.

4.5.2 Batch reaction modelling

In order to infer the reaction that is likely to take place when the leachate encounters the groundwater, a batch reaction involving a mixture of 2 parts of the leachate solution and 3 parts of solution from location 7BH which is located down slope of the dumpsite was simulated, the modeled outcome is presented in Appendix 10. The outcome shows emergence of some mineral phases that were not present in the initial solution, these include, methane, nitrogen gas, pyrite, sphalerite and sulfur, there was also a further drop in the saturation index of oxygen in the final solution.

The transformation of nitrogen species is indicated by the emergence of nitrogen gas in the final solution, which may result from denitrification process. Generally, ammonium and ammonia are stable under anaerobic conditions, but when conditions become aerobic, ammonium is rapidly oxidized into nitrate via unstable nitrite through the process of nitrification. On the other hand, when a nitrate rich environment (leachate) becomes anaerobic, as it penetrates the subsurface into the groundwater environment, nitrogen gas which is stable is released due to nitrate reduction and ultimately escapes from the aquifer, through denitrification process. Also the restricted removal of ammonium by anaerobic oxidation (anammox) has been described in anaerobic waters impacted by waste water discharge (Robertson *et al.*, 2012). Anammox is a bacteria-mediated process where ammonium is transformed to nitrogen gas, the bacteria are likely to be present in abundance as indicated by the microbial result. Denitrification seems to be the dominant process controlling the distribution of nitrogen species between the leachate plume and groundwater, and the anaerobic condition is indicated by the very low saturation index of oxygen.

The transformation of sulphur species is indicated by the emergence of sulphur, sphalerite, iron sulphide (FeS), pyrite and hydrogen sulphide gas in the final solution. The saturation index of hydrogen sulphide gas and sulphur are -3.11 and -2.84 respectively, indicating that they are under saturated and will dissolve in the solution, while that of pyrite and sphalerite are 10.89 and 2.62 respectively, indicating that they are over saturated in the solution and will precipitate out of the solution, according to Barella *et al.* (2013). Environment with excess organic materials are disposed to to pyrite formation (FeS₂), a process well-known as pyritisation, which occur as a product of elevated sulphide concentrations as well as the redox settings that are favourable to iron solubility, this process is confirmed by the reduced sulphate content. These processes could be accountable for the reduction of sulphate in the groundwater of the area. The emergence of hydrogen sulphide gas could be responsible for the odour of some of the groundwater extracted from some boreholes in the area, as this gas is known for its offensive odour. Precipitation of sphalerite from the solution could also be a controlling process on the distribution of zinc in the groundwater.

The transformation process led to a drastic change in the concentration of the redox sensitive species (nitrogen and sulphur) which ultimately led to the change in the pe of the final solution. From Appendix 10 the pe of the final solution is -3.589 down from 4 of the initial solutions. This drastic change is an indication of the complex process that goes on in the subsurface as the groundwater encounters different geochemical environments.

A plot of the saturation index of some selected mineral phases in the batch reaction is presented in FIG. 29. From the figure it can be seen that the sulphates are becoming more undersaturated compared to the carbonates minerals. This might be an indication

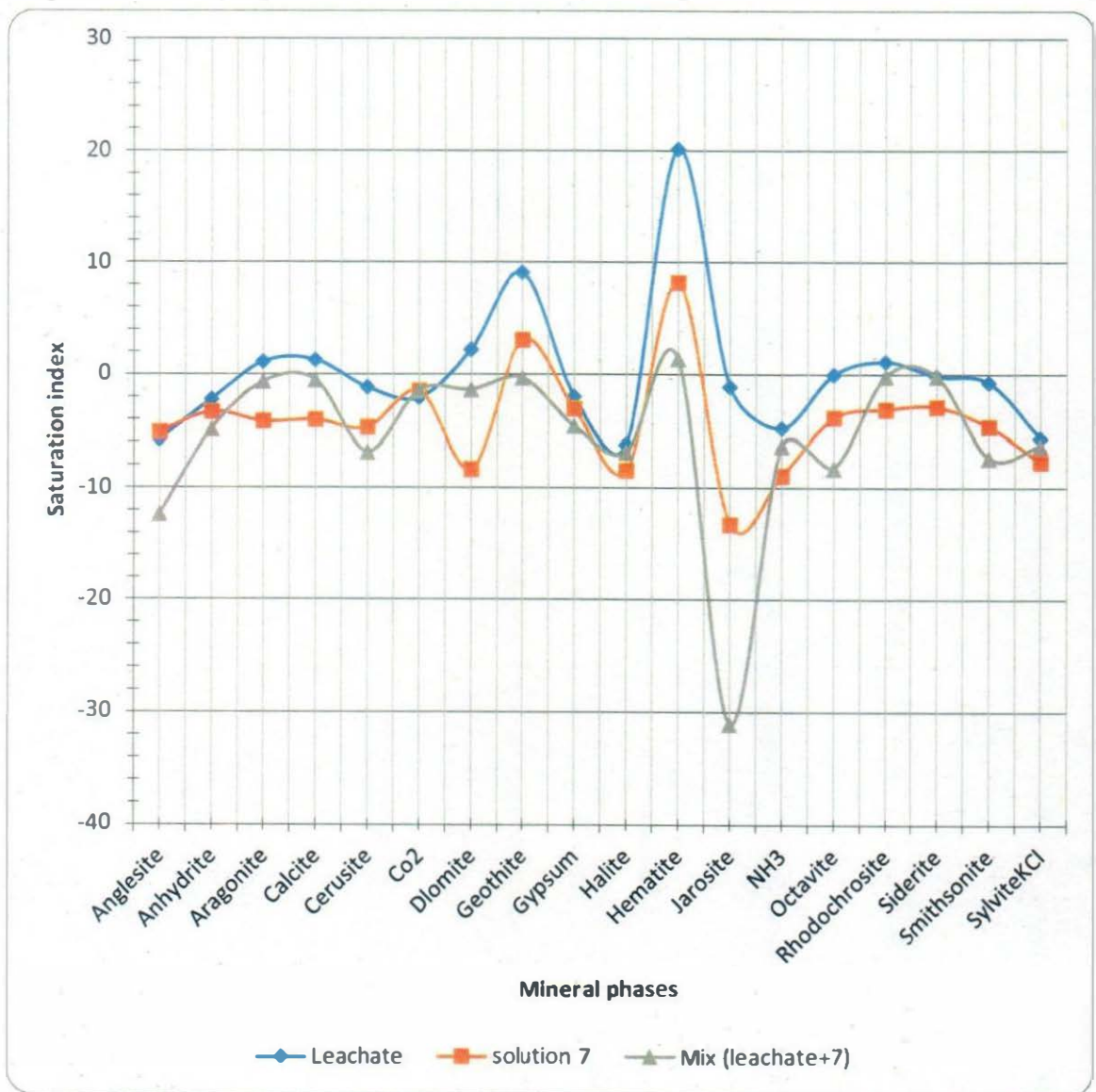


FIG. 29: Comparison of the distribution of the saturation indexes of the mineral phases in the batch reaction.

that the carbonate minerals are more in the groundwater system which could be responsible for the pull of these mineral saturation indexes in the positive direction. While the sulphate minerals tend to undergo dissolution as a result of the scarcity of the reactive sulphur which is being reduced as sulphide minerals (FeS and FeS₂).

4.5.3 Inverse modelling

Inverse modelling calculation was applied to discover the groups of minerals and gases which, when reacted in correct quantities, will provide explanation for the difference in composition between the two solutions. The difference in chemical composition of the two solutions are presumed to be a result of reactions amongst the water and the minerals and gases it made contact with along the flow path. and that there is a hydraulic connection between the two solutions. The simulation was set up to investigate the chemical evolution of the groundwater between locations 19BH and 20BH downstream. The first step involved the speciation modelling of the initial and final solution to obtain the SI of the different mineral phases. All the mineral and gas phase were derived from the results of the speciation calculations from 19BH and 20BH and used for phase equilibrium. Some selected results of the inverse modelling output are shown in Appendix 11. The results of some typical phase mole transfer is shown in Table 21, the predominant reactions determined by the inverse model calculations is the dissolution of carbonate minerals as indicated by their positive mole transfer and the precipitation of sulphate as indicated by the negative mole transfer (Parkhurst & Appelo, 2017). From Table 21, it can be seen that precipitation and dissolution of other minerals (halite, silvite, hydroxyapatite, CO₂ and NH₃) have some influence in the reactions as indicated by their mole transfers at the uncertainty level considered in the simulation. To satisfy the mass balance constraints on Ca and Mg, additional source of

TABLE 21
Phase mole transfers of the inverse models

		Model 1		
Phase mole transfers:		Minimum	Maximum	
Anhydrite	-8.163e-01	-3.631e+00	-8.160e-01	CaSO4
Calcite	-2.133e-05	-8.995e-05	1.380e-04	CaCO3
CO2 (g)	-4.092e-04	-8.435e-04	3.059e-06	CO2
Dolomite	4.926e-05	7.741e-06	1.019e-04	CaMg (CO3) 2
Gypsum	8.163e-01	8.160e-01	3.631e+00	CaSO4 : 2H2O
Halite	-1.799e-05	-5.616e-05	5.406e-05	NaCl
Hydroxyapatite	1.583e-08	-3.235e-07	3.923e-07	Ca5 (PO4) 3OH
NH3 (g)	-1.228e-04	-2.713e-04	4.156e-05	NH3
O2 (g)	8.274e-06	-4.620e-05	7.104e-05	O2
		Model 2		
Phase mole transfers:		Minimum	Maximum	
Anhydrite	-8.165e-01	-1.001e+00	-8.165e-01	CaSO4
Calcite	1.048e-05	7.914e-06	1.152e-05	CaCO3
Dolomite	7.741e-06	7.741e-06	9.024e-06	CaMg (CO3) 2
Gypsum	8.165e-01	8.165e-01	1.001e+00	CaSO4 : 2H2O
NH3 (g)	-1.127e-04	-2.486e-04	-2.454e-05	NH3
		MODEL 3		
Phase mole transfers:		Minimum	Maximum	
Anhydrite	3.128e+00	-2.074e+00	7.745e+00	CaSO4
Calcite	-7.555e-05	-2.087e-04	6.537e-05	CaCO3
CO2 (g)	-4.232e-04	-9.655e-04	6.187e-05	CO2
Dolomite	3.027e-05	-4.670e-05	8.778e-05	CaMg (CO3) 2
Gypsum	-3.128e+00	-7.745e+00	2.074e+00	CaSO4 : 2H2O
Halite	-3.711e-05	-1.022e-04	6.259e-05	NaCl
Hydroxyapatite	-6.065e-08	-5.404e-07	3.718e-07	Ca5 (PO4) 3OH
O2 (g)	6.403e-06	-4.468e-05	6.772e-05	O2
Sylvite	-3.134e-05	-6.897e-05	1.576e-06	KCl

Ca and Mg is required, which is an indication that the dissolution of Ca-Mg silicates or ion exchange is required (Glynn & Brown, 1996) to account for the observed model, as the dissolution of dolomite may not be the case based on the computed Ca/Mg ratio.

4.5.4 Transport modelling

The phase-equilibrium, cation exchange and surface-complexation reaction abilities of PHREEQC in conjunction with advective transport capability was used to model the transformation of the leachate in the aquifer. The conceptual model for this calculation presumes that the leachate at the outset occupied the aquifer, which contains calcite, dolomite, clays with cation-exchange capability and hydrous ferric-oxides surfaces. The aquifer is assumed to be recharged by water with the chemical composition of one of the groundwater upstream. The calculation used advective transport with a single cell representative of the saturated zone, and a total of 200 pore volumes of recharge water are advected into the cell and equilibrated with the minerals, cation exchanger and surfaces within the pores. The results of the inputs and calculated output are presented in Appendix 12. The outcome of the calculations is presented in FIG. 30; the results indicate the dilution of most of the contaminants simulated due to the flushing of the leachate saturated cell with groundwater during the initial 50 pore volumes to the background level. Ca and SO_2 were the dominant ion, their concentration rose slightly during the initial 5 pore volumes then stabilised to the background value till the end of the simulation. Mg concentration decreased sharply during the initial 37 pore volumes, then gradually to the background value after the next 63 pore volumes. The evolution of Na was somewhat erratic in the initial 5 pore volumes, reducing and rising slightly before dropping gradually to the background concentration.

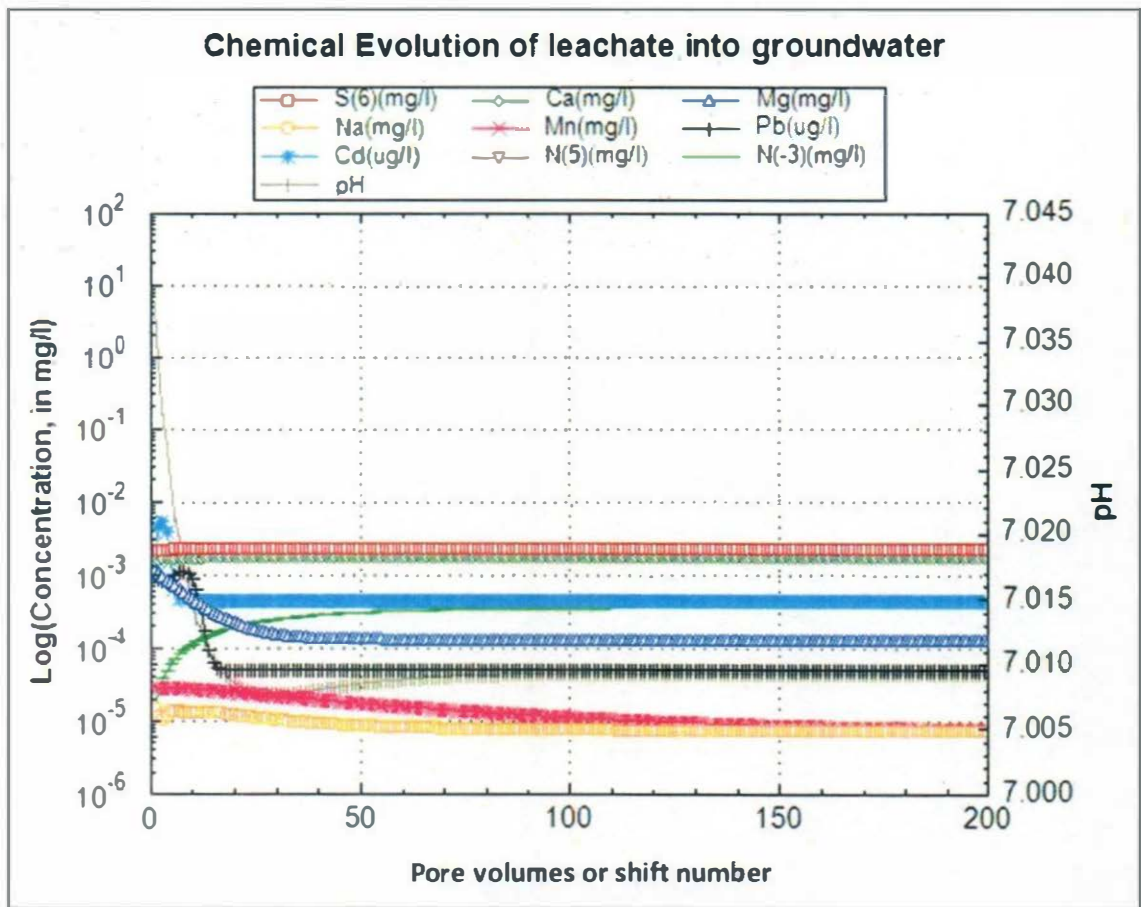


FIG.30: Results of transport simulation of the chemical evolution of the leachate in the aquifer due to inflow of groundwater.

NH_4^+ concentration on the other hand rose sharply during the initial 49 pore volumes then gradually to the end of the simulation while NO_3^- is consumed, the increase in the concentration of NH_4^+ is attributed to the transformation of NO_3^- due to the change in the redox environment from aerobic to anaerobic where NH_4^+ is more stable (Nyaje, 2014).

For the heavy metals, Cd and Pb displayed a sharp decrease in concentration in the initial 17 pore volumes respectively, before gradually reducing to the end of the simulation. While Mn gradually but steadily decreased in concentration throughout the simulation.

The result of the transport simulation indicates that the contaminants in the leachate is being attenuated by the diluting effect of the advected groundwater and sorption by the aquifer materials. The simulation shows that the concentration fronts will gradually but consistently shift as long as the source of leachate is available and is maintained.

CHAPTER FIVE SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Hydrogeological and hydrochemical studies were carried out around a municipal waste dumpsite in Calabar. To investigate the processes governing transport of contaminants released from the dumpsite leachate into the groundwater system, the extent of the leachate migration, simulate the groundwater flow pattern, characterise the aquifer and identify the mineral phases present in the aquifer. Hydrogeological, hydrogeochemical, geophysical data, as well as statistical reduction and geochemical modelling were employed in the investigation. Also results of hydrochemical data from control points were compared in order to assess the difference in the level of the contamination.

Results of the hydrogeological data indicates physical aquifer heterogeneity, with thickness ranging from 18 m to 42 m, extending across the study area and differentiated into unconfined, semiconfined and confined due to the presence of confining layers. The static water level ranged from the surface to 44.5 m. the hydraulic gradient varied from 1.00×10^{-2} to 1.38×10^{-1} with average flow velocity of between 0.53 m/d and 2.76 m/d, with average residence time of 2.11 years. The direction of flow is northward in the dry period and north-eastern direction in the wet period. The aquifer has high transmissivity ranging between 179.84 m²/d and 1280.63 m²/d. the aquifer specific capacity ranged between 48.92 m³/d/m and 205.82 m³/d/m. The hydraulic conductivity measured by the Hazen method ranged between 8.64 m/d and 486 m/d, while that measured through the aquifer test ranged between 22.48 m/d and 160.08 m/d. Simulation of flow indicate the presence of many water divide due to the heterogeneous nature of the aquifer system resulting from the presence of aquitard systems and physiography of the area.

The result of the 2-D resistivity imaging shows that the leachate is migrating into the sandy formation as indicated by the presence of low resistivity zones in profiles close to the dumpsite compared to the high resistivity recorded at the control point profile. The interpretation of the different profiles revealed a pattern in the distribution of areas of very low resistivity in the subsurface, indicating the impact of the dumpsite leachate on the subsurface around the dumpsite and the impact is decreasing with distance from dumpsite.

The levels of the physicochemical parameters and heavy metals, except EC, in the groundwater in the wet season were higher around the dumpsite compared to the control points, while the result for the dry season shows that all parameters, except pH, TDS, Cl^- , CO_3^{2-} , HCO_3^- , PO_4^- , NO_2^- , Ca^{2+} , Mg^{2+} , Fe and Cr were also higher, indicating that the dumpsite leachate and season have influence on the distribution of these parameters in the area. Generally, the concentration levels of the parameters in the composite leachate sample were higher compared to the underground water and surface water samples.

The levels of microbiological parameters in the leachate were significantly higher compared to the levels in groundwater and surface water. and the levels in the surface water was higher compared to groundwater. Also there was substantial difference in the levels of microbiological indicators in the groundwater sampled around the dumpsite compared to the control points, indicating substantial anthropogenic input from the dumpsite.

The results of the hydrochemical data revealed different water types based on three classification scheme. On the basis of piper trilinear diagram three major water types were identified in the order $\text{Ca-HCO}_3 > \text{Ca-Mg-Cl} > \text{Ca-Na-HCO}_3$ and $\text{Ca-HCO}_3 > \text{Ca-}$

Cl>Ca-Mg-Cl in the wet and dry season respectively. While the modified Chadha diagram identified three water types; Ca-Mg-HCO₃>Ca-Mg-Cl>Na-HCO₃. Suggesting carbonate dissolution, mixing and ion exchange as the process controlling the groundwater chemistry. Styfzand classification showed that the main water types were fresh to fresh-brackish and soft to moderately hard types. Twelve classes were identified in the wet season in the following order, FO-MgCl->FX-MgCO₃->FX-NH₄CO₃-=FO-MgCO₃->F_{b0}-FeCO₃-=FX-MgCl-=F_{b0}-NaCO₃+ =FX-NH₄MIX-= FO-NH₄HCO₃-=F_{b1}-MgCl-=FO-NH₄Cl-=B_{s1}-MgCl-, while eleven classes were identified in the dry season in the following order, F_{b1}-CaCO₃->F_{b2}-CaCO₃->FO-CaCO₃-=B1-CaCl->F2-CaCO₃-=F1-CaCO₃-=FX-CaCO₃-=F_{b1}-CaMIX-=B_{s1}-CaCl-=B2-CaCl-=B2-CaCO₃-.

Gibbs plot shows that the dissolved ions are product of water-rock interaction and atmospheric precipitation. Cross plot of SO₄+HCO₃ vs Ca+Mg and Ca+Mg vs HCO₃ indicate that carbonate dissolution and ion exchange are the dominant process. The cross plot of Na vs Cl indicates enrichment of chloride in respect to Na suggesting ion exchange process. Mole ratios of Ca+Mg/HCO₃, Ca/Mg, Mg/Ca, Mg/a, Ca/Na, HCO₃/Na suggest that ion exchange and carbonate weathering dominates the process controlling the water chemistry. The Chloro-alkali indices (CAI 1 and CAI 2) indicate that reverse ion exchange is predominant.

Correlation analysis of the groundwater samples shows positive correlation for Cl,CO₃,HCO₃,SO₄ and Mg,Ca with negative correlation between DO and Ca/Mg/CO₃,/HCO₃/SO₄/NO₂. The result of PCA indicate an eight component model, with the main component suggesting carbonate weathering, ion exchange and

precipitation of Mn and Fe. And HCA indicate a close link in the chemical composition of the groundwater and seasonal influence by precipitation.

Speciation models show that most mineral phases, except goethite and shalerite, were all in under saturated state an indication of short residence time of the groundwater. The result of batch reaction modelling suggests that denitrification and precipitation of pyrite and sphalerite are the major processes controlling the transformation of the leachate in the subsurface. The inverse geochemical modelling favours carbonate dissolution and sulphate reduction as well as the contribution of other minerals like silvite, halite, hydroxyapatite along with NH_3 and CO_2 to the reactions. Also transport model suggest that the contaminants in the leachates are being attenuated by dilution and sorption by the aquifer materials along with nitrate transformation to ammonium.

5.2 Conclusion

The impact of the dumpsite on the groundwater is minimal in terms of inorganic contamination due to the attenuation of the contaminants by dilution and sorption by the aquifer materials and geochemical processes such as, pyrite reduction, sulfide oxidation, denitrification, sulfate reduction. However, the impact is more in terms of microbial indicators and the concentration front of all the contaminants is likely going to expand with time if the source of leachate is maintained. Other processes controlling the water chemistry include carbonate weathering, precipitation, ion exchange and halite dissolution. The water in some locations have concentration of some contaminant above the Standard Organisation of Nigeria (2015) permissible limits for drinking water quality. This study has contributed to the knowledge of water quality and processes controlling the distribution of contaminants around the dumpsites. The results could be

used for further investigation and management of the water resources within the vicinity of the dumpsite.

5.3 Recommendations

Routine monitoring of surface and groundwater around the dumpsite is recommended to identify possible contaminants arising from the leachates, installation of strategic monitoring wells and institution of action plan for remedial measures.

There is the need for treatment of the liquid waste before discharge to reduce the virile load as this is the likely source of the pathogenic microorganisms in the water.

The model used in this study is a simplification of processes and certainly not the case in the natural systems. In fact, transport of contaminants in natural systems are control by more complicated laws with spatial and temporal variations. More studies incorporating isotopic ratios with sensitive and sophisticated equipment for generation of robust data is therefore needed, before firm conclusions can be reached about the hydrogeological and hydrochemical controls on transport of contaminants.

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APPENDIX I

DETAIL CLIMATIC DATA FOR THE STUDY AREA, JANUARY 2016 TO JULY 2018

2016														
PARAMETERS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	Mean
Max Temperature (°C)	33.7	35.2	32.6	32.4	32.1	30.6	29.3	28.7	29.3	30.9	31.9	33.2	379.9	31.66
Min Temperature (°C)	22.9	24.7	24.0	24.2	23.8	22.7	22.6	22.8	23.2	23.0	23.6	23.8	281.3	23.44
Rainfall (mm)	0.0	3.5	194.9	203.4	421.1	261.3	454.6	316.1	363.3	137.6	95.7	1.2	2452.7	204.39
Number of rainy days	0	2	16	15	17	16	28	24	22	12	16	1	169	14.08
Relative Humidity (%)	69	78	87	87	86	88	91	93	91	87	87	83	1027	85.58
Evaporation (ml)	5.6	5.0	2.5	2.3	2.3	2.0	1.4	1.1	1.5	2.1	2.2	3.4	31.4	2.616
2017														
Max Temperature (°C)	33.4	34.9	33.2	32.3	31.3	30.8	29.0	28.2	29.0	30.4	31.4	32.5	376.5	31.38
Min Temperature (°C)	23.4	24.0	24.7	23.3	23.0	23.0	22.8	22.9	23.4	23.4	23.4	23.9	281.2	23.43
Rainfall (mm)	25.4	0.0	133.4	417.2	284.7	352.5	437.2	611.4	356.0	180.3	289.2	32.3	3119.6	259.97
Number of rainy days	4	0	6	13	20	24	21	24	21	17	16	2	168	14
Relative Humidity (%)	82	82	83	86	88	89	91	94	90	88	88	81	1042	86.83
Evaporation (ml)	3.7	4.8	4.0	2.7	2.0	2.0	1.6	1.1	1.3	1.9	2.1	3.3	30.5	2.54
2018														
Max Temperature (°C)	33.8	33.5	32.2	31.7	31.6	31.3	29.2						223.3	31.9
Min Temperature (°C)	23.0	24.4	24.2	24.0	24.5	23.7	23.3						167.1	23.87
Rainfall (mm)	0.0	194.9	113.0	191.4	367.5	294.5	568.5						1729.8	247.11
Number of rainy days	0	9	13	11	21	21	26						101	14.43
Relative Humidity (%)	80	82	84	84	85	86	92						593	84.71
Evaporation (ml)	3.9	3.4	2.8	2.5	2.4	2.2	1.5						18.7	2.67

SOURCE: Nigerian Meteorological Agency, Margaret Ekpo International Airport Calabar station (N 04° 58' E 08°21' Altitude 62.3m)

APPENDIX 2.
DETAILS OF SAMPLING POINTS

S/N	LOCATION ID	COORDINATES		ACTION AT LOCATION					
		LATITUDE	LONGITUDE	BH SAMPLE	SURFACE WATER	LEACHATE SAMPLE	MONITORING WELL	BOREHOLE CUTTINGS	PUMPING TEST
1	1SW	5° 1' 28.8"	8° 21' 57.7"	-	1SW	-	-	-	-
2	2SW	5° 1' 50.7"	8° 21' 51.5"	-	2SW	-	-	-	-
3	3BH	5° 2' 0.8"	8° 21' 47.4"	3BH	-	-	MW1	-	-
4	4BH	5° 2' 4.6"	8° 21' 51.2"	4BH	-	-	MW2	-	-
5	5BH	5° 1' 56.4"	8° 21' 55.8"	5BH	-	-	MW3	-	-
6	6BH	5° 1' 54.0"	8° 22' 2.4"	6BH	-	-	MW4	-	PT1
7	7BH	5° 1' 59.8"	8° 22' 3.3"	7BH	-	-	MW5	-	-
8	8BH	5° 2' 0.8"	8° 22' 11.9"	8BH	-	-	MW6	-	-
9	9BH	5° 1' 34.2"	8° 22' 28.9"	9BH	-	-	MW7	BC1	-
10	10SW	5° 1' 52.6"	8° 22' 24.6"	-	10SW	-	-	-	-
11	11BH	5° 2' 5.2"	8° 21' 45.1"	11BH	-	-	MW8	-	-
12	12BH	5° 2' 9.9"	8° 21' 51.66"	12BH	-	-	MW9	-	PT2
13	13BH	5° 2' 13.98"	8° 21' 55.68"	-	-	-	MW10	BC2	-
14	14BH	5° 2' 11.3"	8° 22' 10.2"	14BH	-	-	MW11	-	-
15	15BH	5° 2' 28.3"	8° 22' 1.7"	15BH	-	-	MW12	-	-
16	16L	5° 2' 0.01"	8° 21' 58.86"	-	-	16L	-	-	-
17	17L	5° 1' 58.58"	8° 21' 57.13"	-	-	17L	-	-	-
18	18SW	5° 2' 9.7"	8° 21' 59.3"	-	18SW	-	-	-	-
19	19BH	5° 1' 58.8"	8° 22' 0.6"	19BH	-	-	-	-	-
20	20BH	5° 2' 9.7"	8° 22' 6.42"	20BH	-	-	MW13	-	-
21	21BH	5° 1' 38.5"	8° 21' 51"	21BH	-	-	-	BC3	-
22	22BH	5° 2' 23.7"	8° 22' 0.6"	22BH	-	-	-	BC4	-
23	23BH	5° 3' 45.4"	8° 21' 19.9"	23BH	-	-	-	-	-
24	24BH	5° 3' 51.2"	8° 20' 43.4"	24BH	-	-	-	-	-
25	25BH	5° 1' 53.3"	8° 20' 41.6"	25BH	-	-	-	-	-
26	26BH	4° 55' 0.3"	8° 23' 1.11"	26BH	-	-	-	-	-
27	27BH	5° 2' 10.2"	8° 21' 11.9"	-	-	-	-	BC5	-
28	28BH	5° 3' 22.7"	8° 22' 44.79"	-	-	-	-	-	PT3
29	29BH	4° 59' 41.30"	8° 20' 51.9"	-	-	-	-	-	PT4
30	30BH	5° 2' 37.71"	8° 21' 26.99"	-	-	-	-	-	PT5
31	31BH	4° 59' 30.98"	8° 21' 30.29"	-	-	-	-	-	PT6

*Note. BH – Sampled boreholes, SW – Sampled surface water, L – Leachate, MW – monitoring boreholes, BC – Borehole cuttings, PT – Pumping test boreholes

APPENDIX 3
RESULT OF PUMPING TEST

Time (Min)	PT1 Pumping rate = 1.33 l/s (114.91 m ³ /d)		PT2 Pumping rate 1.54 l/s (133.06 m ³ /d)		PT3 Pumping rate = 0.91 l/s (78.62 m ³ /d)	
	Pumping water Level (m)	Drawdowns (m)	Pumping water Level (m)	Drawdowns (m)	Pumping water Level (m)	Drawdowns (m)
0	10.6	0	23.56	0	26.5	0
1	11.22	0.62	26.13	2.57	27.3	0.8
2	11.22	0.62	26.18	2.62	27.3	0.8
3	11.22	0.62	26.23	2.67	27.4	0.9
4	11.22	0.62	26.25	2.69	27.4	0.9
5	11.22	0.62	26.26	2.7	27.41	0.91
6	11.22	0.62	26.27	2.71	27.42	0.92
7	11.23	0.63	26.27	2.71	27.42	0.92
8	11.23	0.63	26.27	2.71	27.43	0.93
9	11.23	0.63	26.27	2.71	27.43	0.93
10	11.23	0.63	26.27	2.71	27.43	0.93
12	11.23	0.63	26.27	2.71	27.43	0.93
14	11.25	0.65	26.27	2.71	27.43	0.93
16	11.25	0.65	26.28	2.72	27.43	0.93
18	11.25	0.65	26.28	2.72	27.43	0.93
20	11.26	0.66	26.28	2.72	27.43	0.93
25	11.26	0.66	26.28	2.72	27.44	0.94
30	11.26	0.66	26.28	2.72	27.48	0.98
35	11.26	0.66	26.26	2.7	27.5	1.00
40	11.26	0.66	26.27	2.71	27.51	1.01
45	11.26	0.66	26.27	2.71	27.51	1.01
50	11.26	0.66	26.26	2.7	27.51	1.01
55	11.26	0.66	26.28	2.72	27.51	1.01
60	11.26	0.66	26.28	2.72	27.51	1.01
70	11.26	0.66	26.28	2.72	27.51	1.01
80	11.26	0.66	26.28	2.72	27.51	1.01
90	11.26	0.66	26.28	2.72	27.51	1.01
100	11.26	0.66	26.28	2.72	27.51	1.01
110	11.26	0.66	26.28	2.72	27.51	1.01
120	11.26	0.66	26.28	2.72	27.51	1.01

APPENDIX 3 CONT.
RESULT OF PUMPING TEST

Time (Min)	PT4 Pumping rate = 1.0 l/s (87.26 m ³ /d)		PT5 Pumping rate = 0.8 l/s (69.98 m ³ /d)		PT6 Pumping rate = 1.54 l/s (133.06 m ³ /d)	
	Pumping water Level (m)	Drawdowns (m)	Pumping water Level (m)	Drawdowns (m)	Pumping water Level (m)	Drawdowns (m)
0	38.08	0	52.8	0	29.87	0
1	38.55	0.47	53.1	0.3	30.47	0.6
2	38.55	0.47	53.13	0.33	30.49	0.62
3	38.56	0.48	53.14	0.34	30.5	0.63
4	38.57	0.49	53.14	0.34	30.51	0.64
5	38.57	0.49	53.14	0.34	30.51	0.64
6	38.57	0.49	53.14	0.34	30.51	0.64
7	38.57	0.49	53.14	0.34	30.51	0.64
8	38.58	0.5	53.14	0.34	30.51	0.64
9	38.58	0.5	53.14	0.34	30.52	0.65
10	38.58	0.5	53.14	0.34	30.52	0.65
12	38.58	0.5	53.14	0.34	30.52	0.65
14	38.58	0.5	53.14	0.34	30.52	0.65
16	38.58	0.5	53.14	0.34	30.52	0.65
18	38.58	0.5	53.14	0.34	30.53	0.66
20	38.58	0.5	53.14	0.34	30.53	0.66
25	38.59	0.51	53.14	0.34	30.53	0.66
30	38.59	0.51	53.14	0.34	30.54	0.67
35	38.58	0.5	53.14	0.34	30.54	0.67
40	38.59	0.51	53.14	0.34	30.54	0.67
45	38.59	0.51	53.14	0.34	30.55	0.68
50	38.59	0.51	53.14	0.34	30.55	0.68
55	38.59	0.51	53.14	0.34	30.55	0.68
60	38.59	0.51	53.14	0.34	30.55	0.68
70	38.59	0.51			30.56	0.69
80	38.59	0.51			30.56	0.69
90	38.59	0.51			30.56	0.69
100	38.59	0.51			30.57	0.7
110	38.59	0.51			30.57	0.7
120	38.59	0.51			30.58	0.71
					30.58	0.71
					30.59	0.72
					30.6	0.73
					30.6	0.73

APPENDIX 4

VALUES OF EFFECTIVE DIAMETER, COEFFICIENT OF UNIFORMITY AND HYDRAULIC CONDUCTIVITY ESTIMATED FROM GRAIN SIZE CURVE

S/N	DEPTH(M)	BC3				BC5				BC2				BC4				BC1			
		D ₁₀ (mm)	D ₆₀ (mm)	U	K (m/s) 10 ⁻⁴	D ₁₀ (mm)	D ₆₀ (mm)	U	K (m/s) 10 ⁻⁴	D ₁₀ (mm)	D ₆₀ (mm)	U	K (m/s) 10 ⁻⁴	D ₁₀ (mm)	D ₆₀ (mm)	U	K (m/s) 10 ⁻⁴	D ₁₀ (mm)	D ₆₀ (mm)	U	K (m/s) 10 ⁻⁴
1	2.90	0.25	0.68	2.72	6.25	0.25	0.56	2.24	6.25	0.19	0.57	3	3.61	0.21	0.51	2.43	4.41	0.19	0.65	3.42	3.61
2	5.50	0.20	0.59	2.95	4.0	0.3	2.3	7.67	9.0	0.185	0.75	4.05	3.42	0.17	0.44	2.58	2.89	0.16	0.58	3.62	2.25
3	8.40	0.16	0.50	3.13	2.56	0.31	1.5	4.84	9.61	0.17	0.52	3.06	2.89	0.19	0.52	2.74	3.61	0.17	0.54	3.18	2.89
4	11.60	0.30	0.62	2.0	9.00	0.32	0.7	2.19	10.24	0.17	0.6	3.53	2.89	0.2	0.57	2.85	4	0.17	0.56	3.29	2.89
5	14.50	0.29	0.53	1.83	8.41	C	L	A	Y	0.2	1.5	7.5	4	0.34	1.6	4.7	11.56	0.25	1.15	4.6	6.25
6	17.3	0.30	0.59	2.00	9.0	C	L	A	Y	0.23	0.62	2.69	5.29	0.25	0.54	2.16	6.25	0.19	1	5.26	3.61
7	20.30	0.18	0.44	2.44	3.24	C	L	A	Y	0.12	0.7	5.83	1.44	0.23	0.6	2.6	5.29	0.25	1	4	6.25
8	23.20	0.325	0.60	1.85	10.5	0.33	0.95	2.88	10.89	0.23	0.55	2.39	5.29	0.28	0.58	2.07	7.84	0.21	0.64	3.05	4.41
9	26.10	0.19	0.47	2.47	3.61	0.31	0.75	2.42	9.61	0.2	0.51	2.55	4	0.38	1.25	3.29	14.4	0.22	0.5	3.41	4.84
10	29.00	0.17	0.46	2.71	2.89	0.345	1.15	3.33	11.9	0.1	0.42	4.2	1	0.32	0.55	1.72	10.24	0.14	0.41	2.93	1.96
11	31.90	0.33	1.00	3.03	10.9	0.32	0.75	2.32	10.2	0.23	0.95	4.13	5.29	0.32	0.69	2.15	10.24	0.31	1.5	4.84	9.61
12	34.75	0.32	0.65	2.03	10.24	0.33	0.7	2.12	10.89	0.23	0.67	2.91	5.29	0.35	1.4	4	12.25	0.19	1.3	6.84	3.6
13	37.64	0.215	0.77	3.58	4.62	0.35	1.2	3.43	12.25	0.29	1.6	5.51	8.4	0.32	0.58	1.8	10.24	0.19	0.95	5	3.61
14	40.54	0.27	1.2	4.44	7.27	0.34	0.76	2.23	11.5	0.5	2.5	5	25	0.3	0.75	2.5	9	0.21	0.62	2.95	4.41
15	43.43					0.38	1.6	4.21	14.44					0.34	0.84	2.5	11.56	0.2	0.6	3	4
16	46.32					0.75	2.7	3.6	56.25					0.33	0.9	2.72	10.89	0.2	1.1	5.5	4
17	49.21													0.31	0.49	1.58	9.61	0.25	0.8	3.2	6.25
18	52.1													0.31	0.45	1.45	9.61	0.19	0.52	2.4	3.61
19	54.99													0.3	0.68	2.26	9	0.18	0.5	2.8	3.24
20	57.88																	0.18	0.51	2.83	3.24
21	60.77																	0.18	0.55	3.05	3.24
22	63.66																	0.25	1.8	7.2	6.25

APPENDIX 5
APPARENT RESISTIVITY DATA FOR ALL THE PROFILES

ERT1 NEW – Profile name

3	- Unit electrode spacing
1	- Array type(wenner)
45	- Number of data points
1	- Type of X-location for data point (mid -point)
0	
4.5	3 70.28019429
7.5	3 2.448977143
10.5	3 50.34027429
13.5	3 52.72721143
16.5	3 36.52930286
19.5	3 51.91692
22.5	3 42.29977714
25.5	3 22.20768
28.5	3 1.343382857
31.5	3 4.415211429
34.5	3 12.97277143
37.5	3 0.6468
40.5	3 2.023182857
43.5	3 28.85746286
46.5	3 58.09338857
9	6 37.51062857
12	6 18.75418286
15	6 6.075394286
18	6 32.89364571
21	6 32.60286857
24	6 1.031485714
27	6 31.70904
30	6 21.25690286
33	6 26.5056
36	6 13.60618286
39	6 8.654674286
41	6 22.63385143
13.5	9 18.43549714
16.5	9 12.63579429
19.5	9 6.276034286
22.5	9 29.72715429
25.5	9 0.125588571
28.5	9 27.41168571
31.5	9 52.42248
34.5	9 30.77938286
37.5	9 9.540205714
18	12 26.56669714
21	12 24.9744
24	12 2.710148571
27	12 34.80274286
30	12 27.14825143
33	12 8.46384
22.5	15 27.11185714
25.5	15 31.16897143
28.5	15 24.73302857
0	
0	
0	
0	

ERT2 NESW – Profile name

3
1
63
1

APPENDIX 5 CONT.

0		
4.5	3	223.9908
7.5	3	71.66430857
10.5	3	5.561537143
13.5	3	36.38391429
16.5	3	125.8058057
19.5	3	184.1115257
22.5	3	217.9527429
25.5	3	302.4610286
28.5	3	228.7032
31.5	3	324.7388571
34.5	3	302.0197714
37.5	3	261.3468
40.5	3	202.6954286
43.5	3	50.23278857
46.5	3	174.8570057
49.5	3	139.1078229
52.5	3	155.7711257
55.5	3	383.6976
9	6	94.70886857
12	6	13.86641143
15	6	113.9801143
18	6	302.9418857
21	6	174.81024
24	6	514.4153143
27	6	134.2692686
30	6	203.7940457
33	6	901.6731429
36	6	508.8411429
39	6	334.8342171
42	6	85.17507429
45	6	5.137817143
48	6	55.07492571
51	6	59.83748571
13.5	9	349.9785771
16.5	9	125.9223429
19.5	9	119.1569657
22.5	9	91.88670857
25.5	9	427.1521886
28.5	9	166.6017257
31.5	9	374.1294857
34.5	9	150.3216
37.5	9	689.6170286
40.5	9	4.787074286
43.5	9	118.4922514
46.5	9	158.3943429
18	12	370.79328
21	12	106.3776686
24	12	205.1559086
27	12	125.0055086
30	12	366.8581714
33	12	196.0011429
36	12	448.0389257
39	12	258.7750629
42	12	486.76848
22.5	15	740.3135143
25.5	15	53.54674286
28.5	15	281.6069143
31.5	15	171.0456

APPENDIX 5 CONT.

34.5	15	952.8608571
37.5	15	202.6963714
27	18	1357.782171
30	18	92.89820571
33	18	521.0681143

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0

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0

ERT4 NS

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1

0

7.5	5	441.8542857
12.5	5	2.939514286
17.5	5	155.3206286
22.5	5	373.6982857
27.5	5	250.9417429
32.5	5	153.0703429
37.5	5	355.5074286
42.5	5	152.5857143
47.5	5	89.36117143
52.5	5	40.81785714
57.5	5	71.64331429
62.5	5	56.46142857
67.5	5	100.8128
72.5	5	141.7532286
77.5	5	298.4897143
15	10	419.4394286
20	10	253.3406857
25	10	183.8508571
30	10	77.44628571
35	10	285.4355429
40	10	116.5868
45	10	67.11885714
50	10	55.06285714
55	10	169.8173714
60	10	272.8559429
65	10	71.06666286
70	10	76.10994286
22.5	15	687.4626
27.5	15	207.4691143
32.5	15	694.8593143
37.5	15	25.0932
42.5	15	106.3816286
47.5	15	73.12611429
52.5	15	70.24568571
57.5	15	33.0594
62.5	15	67.42748571
30	20	125.9921143
35	20	98.46948571
40	20	120.5914286
45	20	114.8676571
50	20	324.7778286
55	20	99.48777143

APPENDIX 5 CONT.

37.5	25-	117.5915714
42.5	25	84.55542857
47.5	25	105.2872857
0		
0		
0		
0		

ERTS NS E

5		
1		
92		
1		
0		
7.5	5	632.324
12.5	5	947.0905714
17.5	5	421.2905714
22.5	5	1328.658571
27.5	5	1135.834857
32.5	5	25.46782857
37.5	5	983.6011429
42.5	5	897.688
47.5	5	9859457143
52.5	5	357.1291429
57.5	5	498.3722857
62.5	5	7.376914286
67.5	5	515.9628571
72.5	5	509.3251429
77.5	5	484.2451429
82.5	5	479.8608571
87.5	5	481.7214286
92.5	5	527.0257143
97.5	5	433.4691429
102.5	5	415.7968571
107.5	5	477.664
112.5	5	336.644
15	10	7.346742857
20	10	77.25645714
25	10	631.5257143
30	10	175.8365714
35	10	685.3377143
40	10	540.4362857
45	10	541.2836
50	10	57.8336
55	10	387.8556
60	10	441.2873143
65	10	427.9050286
70	10	319.2319429
75	10	56.03651429
80	10	63.31285714
85	10	294.8565714
90	10	332.2509143
95	10	356.5508571
100	10	376.9769143
105	10	489.4208
22.5	15	270.4519714
27.5	15	540.1600286
32.5	15	94.84105714

APPENDIX 5 CONT.

37.5	15	37.38617143
42.5	15	314.7096857
47.5	15	209.0182286
52.5	15	140.4414
57.5	15	286.4447143
62.5	15	310.9769143
67.5	15	320.6402571
72.5	15	316.0730571
77.5	15	228.8804571
82.5	15	183.9222
87.5	15	243.9275143
92.5	15	283.7934
97.5	15	349.5190286
30	20	297.3029714
35	20	248.9746286
40	20	235.4088
45	20	188.6456
50	20	173.052
55	20	185.9176
60	20	180.3811429
65	20	243.2244571
70	20	257.3032
75	20	224.4176
80	20	221.3049143
85	20	208.0998857
90	20	241.5285714
37.5	25	199.441
42.5	25	167.585
47.5	25	150.0415714
52.5	25	156.4797143
57.5	25	71.85357143
62.5	25	160.0405714
67.5	25	183.4642857
72.5	25	225.7184286
77.5	25	191.3104286
82.5	25	219.0021429
45	30	182.2505143
50	30	151.5114857
55	30	147.6910286
60	30	149.4221143
65	30	152.4694286
70	30	176.352
75	30	187.3362857
52.5	35	163.2004
57.5	35	150.8716
62.5	35	146.9358
67.5	35	148.6342
60	40	149.1323429
0		
0		
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0		

ERT6WE S

5		
1		
35		
1		
0		
7.5	5	46.42911429

APPENDIX 5 CONT.

12.5	5	46.48317143
17.5	5	48.76834286
22.5	5	52.53411429
27.5	5	54.43585714
32.5	5	61.6418
37.5	5	80.608
42.5	5	78.51422857
47.5	5	99.13168571
52.5	5	143.2882
57.5	5	177.2530571
62.5	5	210.4614286
67.5	5	189.3700286
15	10	50.32657143
20	10	6.16
25	10	58.21954286
30	10	43.33874286
35	10	70.47354286
40	10	88.836
45	10	86.68125714
50	10	97.71394286
55	10	169.664
60	10	154.8410286
22.5	15	70.33148571
27.5	15	82.5066
32.5	15	79.3122
37.5	15	90.68588571
42.5	15	97.32454286
47.5	15	43.02728571
52.5	15	132.6213429
30	20	92.38491429
35	20	61.1336
40	20	99.69017143
45	20	118.7270857
37.5	25	64.58257143
0		
0		
0		
0		

ERT7 WES

5		
1		
31		
1		
0		
7.5	5	39.16691429
12.5	5	44.82122857
17.5	5	54.71965714
22.5	5	65.68602857
27.5	5	61.45668571
32.5	5	3.131542857
37.5	5	62.57397143
42.5	5	80.73182857
47.5	5	79.30277143
52.5	5	47.7004
57.5	5	148.6266571
62.5	5	203.8073714
15	10	51.85651429
20	10	63.57497143

APPENDIX 5 CONT.

25	10	74.44108571
30	10	64.68
35	10	71.632
40	10	126.6232
45	10	156.3565143
50	10	92.54582857
55	10	113.9738286
22.5	15	81.21017143
27.5	15	82.0248
32.5	15	77.02294286
37.5	15	156.6142286
42.5	15	177.9378857
47.5	15	121.5361714
30	20	124.5401143
35	20	150.7452571
40	20	139.7490286
37.5	25	153.2205714
0		
0		
0		
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ERT8 NS S

5		
1		
63		
1		
0		
7.5	5	52.01302857
12.5	5	44.60437143
17.5	5	31.34654286
22.5	5	30.79717143
27.5	5	21.63825714
32.5	5	13.87571429
37.5	5	16.10462857
42.5	5	34.44288571
47.5	5	36.0756
52.5	5	45.05097143
57.5	5	11.13985714
62.5	5	41.98825714
67.5	5	50.50131429
72.5	5	48.20105714
77.5	5	50.30111429
82.5	5	68.00168571
87.5	5	60.71748571
92.5	5	1.9272
15	10	57.40177143
20	10	44.9328
25	10	50.05
30	10	45.6324
35	10	3.312571429
40	10	42.19977143
45	10	42.23182857
50	10	40.19085714
55	10	65.49337143
60	10	48.21771429
65	10	41.54605714
70	10	57.61297143
75	10	57.23645714

APPENDIX 5 CONT.

80	10	62.38005714
85	10	77.1056
22.5	15	79.893
27.5	15	72.08048571
32.5	15	38.76462857
37.5	15	20.60048571
42.5	15	60.83408571
47.5	15	65.46257143
52.5	15	68.9766
57.5	15	71.75897143
62.5	15	69.13594286
67.5	15	69.53382857
72.5	15	67.93097143
77.5	15	69.23022857
30	20	97.90251429
35	20	63.42411429
40	20	82.48365714
45	20	89.8128
50	20	86.23748571
55	20	86.41348571
60	20	93.14171429
65	20	82.03108571
70	20	86.41474286
37.5	25	115.0191429
42.5	25	111.1471429
47.5	25	104.8944286
52.5	25	116.6581429
57.5	25	96.46057143
62.5	25	109.6401429
45	30	131.7096
50	30	120.384
55	30	125.3811429
0		
0		
0		
0		

ERT9 WE

5		
1		
260		
1		
0		
7.5	5	919.0437143
12.5	5	735.8277143
17.5	5	981.5394286
22.5	5	852.5
7.5	5	826.9045714
32.5	5	812.372
37.5	5	928.1894286
42.5	5	249.0723714
47.5	5	7971354.286
52.5	5	536.7748571
57.5	5	108.8072857
62.5	5	982.9914286
67.5	5	1074.558571
72.5	5	984.7734286
77.5	5	951.7514286
82.5	5	766.4297143

APPENDIX 5 CONT.

87.5	5	959.4608571
92.5	5	969.2697143
97.5	5	1225.887143
102.5	5	1183.015429
107.5	5	1062.879714
112.5	5	948.0271429
117.5	5	1052.099714
122.5	5	648.7674286
127.5	5	1137.409429
132.5	5	1182.424571
137.5	5	1549.353143
142.5	5	967.1545714
147.5	5	1347.333429
152.5	5	1009.58
157.5	5	1042.312857
162.5	5	933.7302857
167.5	5	817.3911429
172.5	5	846.1891429
177.5	5	735.6548571
182.5	5	688.3265714
187.5	5	636.4945714
192.5	5	343.86
15	10	1295.743429
20	10	970.5457143
25	10	895.7331429
30	10	793.5337143
35	10	833.0268571
40	10	919.3674286
45	10	211.4300571
50	10	867.4851429
55	10	891.704
60	10	119.6416571
65	10	717.9417143
70	10	315.1474857
75	10	1054.975429
80	10	949.4697143
85	10	886.3485714
90	10	868.4405714
95	10	917.3182857
100	10	911.9251429
105	10	888.1274286
110	10	589.0097714
115	10	488.4647429
120	10	730.1485714
125	10	904.1622857
130	10	1048.614286
135	10	1101.841714
140	10	916.9914286
145	10	900.8371429
150	10	1123.414286
155	10	1190.319429
160	10	975.2851429
165	10	828.8908571
170	10	852.9211429
175	10	934.3085714
180	10	867.0765714
185	10	727.5085714
22.5	15	382.635
27.5	15	506.1587143

APPENDIX 5 CONT.

32.5	15	838.1368286
37.5	15	729.1434857
42.5	15	1071.048
47.5	15	936.7738286
52.5	15	787.4865429
57.5	15	863.94
62.5	15	900.6661714
67.5	15	358.3734
72.5	15	978.0728571
77.5	15	802.7014286
82.5	15	691.8836571
87.5	15	637.3535143
92.5	15	809.589
97.5	15	937.6214571
102.5	15	855.1120286
107.5	15	484.6917429
112.5	15	392.3549143
117.5	15	417.5103429
122.5	15	664.5313714
127.5	15	121.8011143
132.5	15	1126.007143
137.5	15	740.5662
142.5	15	687.8821714
147.5	15	557.5444286
152.5	15	724.1246571
157.5	15	769.8277714
162.5	15	848.001
167.5	15	606.5682857
172.5	15	845.5137429
177.5	15	663.6394286
30	20	1053.205371
35	20	803.5669714
40	20	790.2362286
45	20	795.4521143
50	20	710.5685714
55	20	673.3106286
60	20	589.2216
65	20	774.2931429
70	20	896.6068571
75	20	41.21417143
80	20	629.7921143
85	20	609.5204343
90	20	740.1617143
95	20	1087.597029
100	20	735.6272
105	20	589.2417143
110	20	381.2587429
115	20	325.4139429
120	20	414.6220571
125	20	569.492
130	20	805.2653714
135	20	323.6124571
140	20	667.6723429
145	20	216.0060571
150	20	402.6754286
155	20	427.5769143
160	20	530.9605714
165	20	603.5530286
170	20	691.8308571

APPENDIX 5 CONT.

37.5	25	651.5237143
42.5	25	553.6205714
47.5	25	625.4128571
52.5	25	775.7105714
57.5	25	684.0302857
62.5	25	607.2314286
67.5	25	596.2141429
72.5	25	729.2858571
77.5	25	711.0855714
82.5	25	751.6881429
87.5	25	718.135
92.5	25	629.3712857
97.5	25	529.1974286
102.5	25	472.7045714
107.5	25	413.2715714
112.5	25	205.8618571
117.5	25	339.8905714
122.5	25	358.369
127.5	25	460.5652857
132.5	25	40.22857143
137.5	25	728.1968571
142.5	25	517.1005714
147.5	25	416.8622857
152.5	25	370.0242857
157.5	25	389.9028571
162.5	25	381.9184286
45	30	66.24891429
50	30	349.5567429
55	30	38.04428571
60	30	248.886
65	30	275.4010286
70	30	124.7645143
75	30	1133.423657
80	30	776.8765714
85	30	1948.018286
90	30	227.4492
95	30	2736.096
100	30	163.3896
105	30	125.0832
110	30	247.0549714
115	30	286.3947429
120	30	325.6873714
125	30	321.5576571
130	30	323.3679429
135	30	388.4194286
140	30	490.8118286
145	30	573.6833143
150	30	474.7964571
155	30	347.6182286
52.5	35	514.9936
57.5	35	114.9808
62.5	35	442.8446
67.5	35	1513.1622
72.5	35	193.468
77.5	35	2254.516
82.5	35	70.9896
87.5	35	625.0354
92.5	35	239.3842
97.5	35	42.7702

APPENDIX 5 CONT.

102.5	35	254.0472
107.5	35	510.7916
112.5	35	142.3488
117.5	35	79.3804
122.5	35	31.0794
127.5	35	496.969
132.5	35	952.9014
137.5	35	866.5448
142.5	35	180.8906
147.5	35	431.4596
60	40	1505.265143
65	40	222.5017143
70	40	138.8916571
75	40	11.34948571
80	40	54.49211429
85	40	373.1753143
90	40	188.7750857
95	40	193.9997714
100	40	104.1693714
105	40	58.40182857
110	40	122.0107429
115	40	126.9488
120	40	248.0217143
125	40	97.2928
130	40	70.90034286
135	40	291.6571429
140	40	1097.847771
67.5	45	64.20291429
72.5	45	104.5892571
77.5	45	123.2776286
82.5	45	264.2988857
87.5	45	257.4226286
92.5	45	175.5864
97.5	45	146.9980286
102.5	45	1033.591114
107.5	45	360.1874571
112.5	45	421.0639714
117.5	45	217.4803714
122.5	45	158.9459143
127.5	45	150.1801714
132.5	45	35.35431429
75	50	378.8714286
80	50	1181.783429
85	50	364.5085714
90	50	228.3034286
95	50	581.1394286
100	50	459.8848571
105	50	252.7077143
110	50	1311.303714
115	50	403.128
120	50	302.4811429
125	50	489.4968571
82.5	55	330.7414
87.5	55	22.34005714
92.5	55	7.270371429
97.5	55	109.9406
102.5	55	118.4140571
107.5	55	317.2585429
112.5	55	129.9125143

APPENDIX 5 CONT.

117.5	55	621.5977429
90	60	76.36765714
95	60	39.73577143
100	60	49.01348571
105	60	67.02205714
110	60	163.0878857
97.5	65	44.13797143
102.5	65	37.37202857
0		
0		
0		
0		

APPENDIX 6
RESULTS OF HYDROCHEMICAL ANALYSIS OF WATER SAMPLE IN THE WET SEASON (SEPTEMBER 2017)

Sample ID	1SW	2SW	10SW	3BH	5BH	6BH	7BH	8BH	9BH	11BH	12BH	14BH	15BH	21BH	22BH	23BH	24BH	25BH	26BH	16L
Tested Parameters	Surface water			Groundwater (Borehole)																
Temp °C	27.05	26.07	26.30	27.05	26.35	27.10	27.02	26.21	27.00	26.10	27.03	26.15	26.15	27.40	26.65	27.20	27.20	28.20	27.14	27.32
PH	6.75	6.55	4.95	4.05	4.70	4.50	5.15	4.70	5.50	3.85	5.05	5.25	5.30	4.70	5.55	5.05	5.05	6.10	6.25	7.80
EC (µs/cm)	30.00	40.00	11.00	42.00	50.00	40.10	20.02	30.00	14.14	85.45	10.10	10.10	35.00	30.00	30.00	50.00	50.00	10.00	30.50	5363
Dissolved Oxygen (DO) mg/L	3.45	2.00	2.65	3.11	3.01	3.09	3.00	2.80	2.05	2.99	4.35	3.4	3.00	3.8	3.12	3.00	3.00	3.35	2.85	2.75
Total Dissolved (TDS) mg/L	30.00	40.50	28.50	68.00	70.15	42.00	38.50	28.00	10.00	68.50	41.05	60.50	93.05	30.00	28.00	45.50	45.50	10.00	30.50	6300
Chloride (Cl) mg/L	122.89	184.32	61.45	122.89	86.02	122.52	122.5	120.2	184.32	99.45	98.76	86.03	184.33	61.45	122.88	123.55	61.45	123.33	122.9	1228.85
Carbonate (CO ₃ ²⁻) mg/L	110.40	120.0	36.0	520	116.0	112.0	72.0	96.0	140.0	84.0	48.0	56.0	38.0	40.0	40.0	36.0	24.0	50.0	130.5	600.0
Bicarbonate (HCO ₃ ⁻) mg/L	111.1	120.5	50.01	400	30.1	80.0	20.0	50.05	148.15	300.5	120.2	50.0	140.16	40.0	60.10	90.0	50.07	50.2	131.0	73.6
Nitrate (NO ₃ ⁻) mg/L	0.98	2.14	1.15	4.29	2.14	1.95	2.93	1.56	10.53	5.07	5.64	3.51	3.32	0.98	1.95	4.28	2.34	1.17	1.15	3.7
Sulphate (SO ₄ ²⁻) mg/L	1.7	2.54	159.52	3.39	3.39	5.94	5.74	4.23	4.23	3.39	1.65	0.81	1.65	1.41	1.69	1.52	0.85	1.69	4.24	34.79
Phosphate (PO ₄ ⁻) mg/L	0.075	0.034	0.07	0.08	0.10	0.095	0.05	0.05	0.215	0.06	0.105	0.095	0.061	0.04	0.041	0.028	0.05	0.031	0.052	4.70
Total organic carbon mg/l	ND	ND	ND	ND	ND	ND	ND	ND	0.87	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.2
Nitrite (NO ₂ ⁻) mg/L	0.004	0.008	0.035	0.05	0.01	0.08	0.003	0.003	0.154	0.03	0.04	0.03	0.02	0.002	0.01	0.03	0.04	0.007	0.006	0.145
Dissolved inorganic carbon	ND	ND	ND	ND	ND	ND	ND	ND	0.11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.10
Salinity (pt)	0.30	0.41	0.28	0.71	0.69	0.42	0.40	0.38	0.10	0.70	0.40	0.60	0.85	0.31	0.28	0.5	0.48	0.29	0.34	63.10
Ammonium (NH ₄ ⁺) mg/L	16.00	13.00	11.61	9.00	7.01	12.24	10.95	15.8	36.01	8.11	19.01	18.50	10.45	14.15	15.45	16.20	18.00	11.10	12.40	380.00
Chemical Oxygen demand (mg/L)	9.35	8.85	10.90	13.45	8.81	11.60	7.56	5.50	224.00	7.10	6.27	9.03	11.13	10.15	10.10	11.20	16.00	12.00	13.20	840.00
Biological Oxygen demand (mg/L)	1.20	1.10	0.83	1.10	1.10	1.20	1.00	0.90	0.80	0.99	2.05	1.46	1.00	1.30	1.10	1.25	1.30	1.10	0.95	0.99
Hardness (mg/L)	7.00	6.61	4.00	6.00	3.60	2.30	4.01	7.10	5.10	3.15	6.15	4.40	10.20	5.25	7.10	5.11	6.00	6.30	4.20	14.17
Calcium (Ca ²⁺) (mg/L)	56.00	88.00	16.20	47.00	32.35	16.10	32.00	66.00	64.00	16.00	32.00	16.40	128.00	48.00	32.00	32.00	48.00	48.00	45.25	232.05
Magnesium (mg ²⁺) mg/L	9.85	16.60	3.20	7.05	6.60	3.20	7.00	6.70	13.20	3.06	6.15	3.10	27.50	6.15	6.41	6.45	9.60	10.70	6.10	46.20
Potassium (K ⁺) mg/L	1.20	6.81	1.05	0.99	1.32	1.10	1.98	2.09	103.18	2.15	0.33	0.21	0.88	0.77	2.09	0.73	0.55	0.44	0.22	30.90
Sodium (Na ⁺) mg/L	2.88	5.76	0.40	0.44	0.40	0.46	0.96	1.00	117.11	0.47	0.96	0.46	2.40	2.84	2.88	2.86	0.48	2.40	1.94	21.12
Total dissolved carbon (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	0.87	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.20
Copper (Cu) mg/l	-	0.783	0.285	0.596	0.627	0.124	0.152	0.374	0.338	0.184	0.194	0.332	0.272	0.196	0.756	-	-	-	-	0.832
Lead (Pb) mg/l	-	0.410	0.020	0.013	0.030	0.008	0.001	0.044	0.006	0.012	0.010	0.014	0.009	0.016	0.016	-	-	-	-	0.022
Zinc (Zn) mg/l	-	0.612	0.642	0.384	0.240	0.344	0.410	0.263	0.452	0.545	0.582	0.620	0.414	0.495	0.680	-	-	-	-	0.646
Cadmium (Cd) mg/l	-	0.038	0.045	0.062	0.006	0.682	0.046	0.081	0.040	0.010	0.060	0.044	0.012	0.067	0.080	-	-	-	-	0.022
Manganese (Mn) mg/l	-	1.422	1.146	0.860	0.924	1.456	0.844	1.260	1.045	0.862	0.862	1.126	0.980	1.040	1.238	-	-	-	-	1.110
Chromium (Cr) mg/l	-	0.124	0.010	0.010	0.016	0.120	0.018	0.010	0.014	0.018	0.006	0.006	0.010	0.174	0.016	-	-	-	-	0.016
Iron (Fe) mg/l	-	90.089	2.009	6.500	2.022	3.610	2.501	5.634	2.020	2.867	2.312	1.876	2.310	4082	2.024	-	-	-	-	2.600

APPENDIX 7
RESULTS OF HYDROCHEMICAL ANALYSIS OF WATER SAMPLE IN THE DRY SEASON (JANUARY, 2017)

Tested Parameters	SURFACE WATER				GROUNDWATER (BOREHOLES)													LEACHATES	
	ISW	2SW	10SW	18SW	3BH	4BH	5BH	6BH	7BH	8BH	9BH	11BH	12BH	14BH	15BH	19BH	20BH	16L	17L
Temp °C	26.52	26.51	26.35	27.05	26.35	26.45	26.45	26.4	26.4	26.45	26.5	26.4	26.4	26.55	27.75	27.15	26.85	26.6	26.5
pH	5.35	5.45	3.55	5.31	4.05	3.75	3.65	4.65	4.00	4.85	5.1	3.35	4.05	4.55	5.05	5.07	4.90	7.85	6.75
EC (µs/cm)	30	90	30	20.55	70	90	80	75	40	50	105	10	130	10	50	19.00	60.01	8605	3110
Dissolved Oxygen (DO) mg/L	1.80	2.35	1.35	5.05	2.55	2.25	3.20	3.40	1.35	2.25	1.85	2.30	2.45	1.40	1.90	5.60	4.30	1.50	2.50
Total Dissolved (TDS) mg/L	31.5	76.0	20.5	7	57.0	69.5	64.5	55.5	36.5	41.0	78.5	40.0	31.5	19.5	46.0	15	6	19880	1980.3
Chloride (Cl) mg/L	257.08	331.81	221.20	57.15	193.55	184.77	110.60	267.29	138.25	387.11	258.07	248.85	268.68	230.42	470.988	40.754	36.868	829.53	792.66
Carbonate (CO ₃ ²⁻) mg/L	200.0	80.0	240.0	48.05	270.0	210.0	160.0	280.0	140.0	130.0	240.0	120.0	230.0	200.0	200.0	45.60	24.00	210.0	1100.0
Bicarbonate (HCO ₃ ⁻) mg/L	330.0	240.0	188.0	19.20	183.0	100.0	130.0	160.0	250.0	130.0	210.0	203.0	187.0	260.0	206.0	26.40	39.80	206.0	2120.0
Nitrate (NO ₃ ⁻) mg/L	1.59	2.079	0.611	0.56	2.202	2.568	3.547	4.037	2.324	1.100	1.223	0.978	3.180	3.547	2.079	0.55	0.615	135.145	4.281
Sulphate (SO ₄ ²⁻) mg/L	63.680	44.040	20.830	0.75	33.923	33.328	33.923	30.352	29.757	30.352	18.449	19.639	18.449	22.615	20.235	1.88	1.50	133.900	16.068
Phosphate (PO ₄ ⁻) mg/L	0.05	0.075	0.175	0.055	0.037	0.063	0.150	0.062	0.050	0.011	0.150	0.150	0.162	0.137	0.200	0.05	0.045	20.600	2.82
Total organic carbon mg/l	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.42	0.25
TIC mg/l	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0235	0.006
Nitrite (NO ₂ ⁻) mg/L	0.225	0.25	0.19	0.06	0.22	0.19	0.20	0.15	0.15	0.03	0.21	0.21	0.28	0.215	0.25	0.075	0.035	1.045	0.795
Dissolved inorganic carbon	ND	ND	ND	8.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved organic carbon	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Salinity (pt)	0.31	0.81	0.20	0.20	0.60	0.70	0.62	0.61	0.40	0.40	0.81	0.44	0.30	0.23	0.42	0.90	0.60	198.80	19.82
Ammonium (NH ₄ ⁺) mg/L	22.63	13.3	21.85	5.95	21.0	23.62	21.15	23.11	19.25	14.85	14.0	15.75	19.30	19.27	9.28	6.10	6.40	211.50	17.85
Chemical Oxygen demand (mg/L)	13.40	13.53	14.69	8.05	8.0	21.11	19.10	11.84	11.39	15.32	10.25	10.35	7.63	10.10	12.81	7.20	7.15	992.5	89.35
Biological Oxygen demand (mg/L)	1.0	1.05	1.25	2.65	1.2	1.35	1.1	1.07	1.55	0.75	1.00	0.60	1.25	1.05	0.80	4.25	2.55	1.1	2.15
Hardness (mg/L)	13.75	10.20	22.05	5.95	22.45	20.30	20.35	19.75	16.70	14.06	19.44	17.81	12.60	15.14	14.07	6.10	4.39	23.40	20.90
Calcium (Ca ²⁺) (mg/L)	82.60	81.00	81.10	24.00	64.00	96.15	80.00	80.30	40.00	144.35	80.50	64.20	66.35	112.00	191.00	16.35	32.20	1064.00	224.15
Magnesium (mg ²⁺) mg/L	17.15	16.45	18.30	4.80	13.04	19.10	16.89	17.03	6.60	28.8	16.65	14.06	15.53	22.25	38.20	3.25	6.40	212.80	43.19
Potassium (K ⁺) mg/L	1.81	6.93	1.92	0.60	1.68	1.91	2.23	1.8	2.84	3.38	11.29	2.74	0.63	0.36	0.83	2.00	1.00	949.63	457.50
Sodium (Na ⁺) mg/L	4.45	4.25	2.02	2.05	2.00	2.15	2.04	2.05	2.31	2.35	9.10	2.41	1.21	1.26	1.61	2.60	3.00	97.60	46.05
Total dissolved carbon (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.33	1.41
Copper (Cu) mg/l	0.320	0.372	0.126	0.180	0.408	0.367	0.264	0.412	0.192	0.164	0.148	0.417	0.422	0.340	0.284	0.069	0.212	6.70	0.168
Lead (Pb) mg/l	0.092	0.064	0.008	0.020	0.001	0.001	0.3048	0.064	0.012	0.046	0.014	0.001	0.001	0.006	0.002	0.064	0.010	0.413	0.018
Zinc (Zn) mg/l	0.332	0.324	0.346	0.066	0.462	0.396	0.314	0.268	0.287	0.486	0.312	0.422	0.284	0.456	0.360	0.410	0.382	6.05	0.497
Cadmium (Cd) mg/l	0.072	0.028	0.684	0.022	0.016	0.049	0.012	0.024	0.014	0.024	0.040	0.001	0.001	0.0432	0.046	0.021	0.046	0.400	0.068
Manganese (Mn) mg/l	0.756	0.862	1.457	0.810	1.242	1.164	1.270	1.082	0.764	1.426	0.668	0.846	1.262	1.048	0.782	0.741	0.380	15.225	1.042
Chromium (Cr) mg/l	0.12	0.01	0.14	0.040	0.14	0.10	0.18	0.16	0.01	0.12	0.18	0.01	0.01	0.16	0.12	0.005	0.002	0.125	0.18
Iron (Fe) mg/l	1.589	0.578	3.612	0.529	0.578	1.121	1.784	1.587	5.589	1.887	1.445	1.878	2.167	2.023	2.100	0.600	0.420	90.091	9.083

APPENDIX 9
MINERAL SATURATION INDICES CALCULATED WITH PHREEQC

Sample ID	Anglesite PbSO4	Anhydrite CaSO4	Aragonite CaCO3	Calcite CaCO3	Cerussite PbCO3	Co2	Dolomite CaMg(CO3) 2	Gypsum CaSO4·2H2 O	Halite NaCl	NH3	O2	Octavite CdCO3	Rhodochrosite MnCO3	Siderite FeCO3	Smithsonite ZnCO3	Sylvite/KCl
1SW	-2.41	-2.05	-3.03	-2.89	-2.11	-1.04	-6.10	-1.77	-7.49	-8.46	-45.28	-2.97	-2.43	-2.35	-3.99	-7.45
2SW	-2.7	-2.21	-3.25	-3.10	-2.45	-1.45	-6.54	-1.93	-7.43	-8.59	-44.88	-3.61	-2.58	-2.99	-4.2	-6.79
3BH	-4.5	-2.38	-5.54	-5.4	-6.38	-0.87	-11.13	-2.09	-7.98	-9.79	-50.54	-5.98	-4.61	-5.18	-6.24	-7.62
4BH	-4.56	-2.27	-6.09	-5.94	-7.1	-0.98	-12.22	-1.98	-7.98	-10.04	-51.70	-6.2	-5.35	-5.61	-7.02	-7.6
5BH	-2.01	-2.3	-6.47	-6.33	-4.9	-1.10	-12.97	-2.01	-8.21	-10.18	-52.10	-7.08	-5.62	-5.71	-7.74	-7.74
6BH	-2.81	-2.37	-4.25	-4.11	-3.41	-0.86	-8.52	-2.08	-7.84	-9.15	-48.12	-4.65	-3.48	-3.55	-5.28	-7.46
7BH	-3.39	-2.57	-6.11	-5.97	-5.65	-1.16	-12.35	-2.29	-8.05	-9.87	-50.72	-6.37	-5.18	-4.55	-6.80	-7.53
8BH	-3.07	-2.22	-3.96	-3.82	-3.54	-1.20	-7.98	-1.93	-7.63	-9.15	-47.3	-4.66	-3.33	-3.44	-4.99	-7.04
9BH	-3.70	-2.58	-3.43	-3.28	-3.27	-0.95	-6.88	-2.29	-7.20	-8.91	-46.28	-3.60	-2.86	-2.77	-4.40	-6.68
10SW	-3.85	-2.53	-6.50	-6.35	-6.53	-0.92	-12.99	-2.24	-7.92	-10.28	-52.53	-5.42	-5.59	-5.44	-7.42	-7.51
11BH	-4.75	-2.63	-7.29	-7.15	-8.14	-1.22	-14.59	-2.34	-7.79	-10.61	-53.32	-8.96	-6.52	-6.42	-8.03	-7.30
12BH	-4.79	-2.64	-5.60	-5.46	-6.47	-0.94	-11.18	-2.36	-8.06	-9.83	-50.52	-7.30	-4.67	-4.68	-6.52	-7.91
14BH	-3.98	-2.39	-4.31	-4.31	-4.77	-1.00	-8.95	-2.10	-8.12	-9.32	-48.47	-4.72	-3.83	-3.79	-5.39	-8.23
15BH	-4.71	-2.32	-3.26	-3.11	-4.37	-1.01	-6.55	-2.05	-7.72	-9.09	-46.07	-3.83	-3.01	-2.81	-4.54	-7.59
16L	-3.65	-1.32	1.19	1.33	0.14	-2.70	2.34	-1.04	-5.80	-5.08	-35.25	0.78	1.89	0.77	0.10	-4.39
17L	-5.32	-2.52	0.23	0.37	-1.29	-0.88	0.41	-2.23	-6.08	-7.20	-39.68	-0.32	0.35	1.04	-1.27	-4.65
8SW	-4.64	-4.27	-4.15	-4.01	-3.23	-1.65	-1.65	-3.99	-8.46	-9.02	-45.26	-3.94	-2.97	-3.4	-5.26	-8.57
19BH	-3.68	-4.01	-4.79	-4.65	-3.19	-4.66	-9.62	-3.73	-8.50	-9.24	-46.19	-4.42	-3.48	-3.82	-4.93	-8.19
20BH	-4.63	-3.87	-5.13	-4.99	-4.61	-1.93	-10.30	-3.58	-8.49	-9.41	-46.97	-4.70	-4.41	-4.60	-5.60	-8.54
1SWB		-3.68	-1.14	-0.99		-0.99	-2.37	-3.40	-8.01	-7.17	-39.50					-7.96
2SWB	-3.59	-3.47	-1.26	-1.12	-0.11	-1.70	-2.60	-3.18	-1.12	-7.56	-40.63	-1.45	-0.43	1.12	-2.02	-7.05
3BH B	-4.27	-3.43	-6.34	-6.20	-5.91	-1.58	-12.85	-3.15	-8.82	-10.11	-50.30	-6.02	-5.43	-4.9	-6.97	-8.04
5BH B	-3.85	-3.54	-4.86	-4.72	-3.89	-1.25	-9.76	-3.25	-9.00	-9.60	-47.93	-5.36	-3.75	-3.65	-5.54	-8.05
6BH B	-4.1	-3.57	-5.56	-5.41	-4.88	-1.25	-11.16	-3.29	-8.79	-9.52	-48.48	-3.73	-3.95	-3.80	-5.77	-7.98
7BH B	-5.14	-3.33	-4.19	-4.04	-4.72	-1.47	-8.38	-3.05	-4.48	-8.93	-45.91	-3.83	-3.12	-2.89	-4.63	-7.73
8BH B	-3.68	-3.22	-4.66	-4.52	-3.84	-1.33	-9.67	-2.93	-8.48	-9.26	-47.98	-4.36	-3.73	-3.32	-5.61	-7.72
9BH B	-4.73	-3.33	-3.00	-2.86	-3.12	-1.21	-6.03	-3.05	-6.25	-8.08	-44.52	-3.03	-2.15	-2.10	-3.71	-5.8
10SWB	-2.50	-2.24	-5.25	-5.11	-9.47	-1.76	-10.58	-1.95	-9.15	-9.16	-46.95	-4.58	-3.75	-3.75	-5.22	-8.31
11BH B	-4.20	-3.81	-6.99	-6.85	-6.10	-1.38	-14.05	-3.52	-8.87	-10.40	-51.42	-6.97	-5.61	-5.33	-0.1	-7.77
12BH B	-4.66	-3.87	-4.55	-4.41	-4.07	-1.64	-9.17	-3.59	-8.57	-8.79	-46.31	-4.06	-3.48	-3.29	-4.84	-8.60
14BH B	-4.77	-4.42	-4.39	-4.25	-3.46	-1.59	-8.65	-4.13	-8.94	-8.64	-45.80	-3.73	-2.90	-2.92	-4.36	-8.85
15BH B	-4.92	-3.48	-3.65	-3.51	-3.61	-1.77	-7.52	-3.19	-7.93	-8.86	-45.60	-4.50	-3.12	-2.99	-4.69	-7.94
16LB	-5.80	-2.24	1.11	1.26	-1.17	-2.09	2.20	-1.96	-6.24	-4.80	-35.21	-0.04	1.12	-0.17	-0.74	-5.65
21BH B	-4.53	-3.78	-5.14	-5.00	-4.61	-1.70	-10.51	-3.50	-8.31	-9.25	-47.58	-4.75	-4.15	-3.45	-5.67	-8.44
22BH B	-4.47	-3.87	-3.78	-3.64	-3.11	-1.76	-7.61	-3.58	-8.00	-8.45	-44.63	-3.18	-2.55	-2.58	-4.00	-7.71
23BH B		-3.90	-4.68	-4.53		-1.76	-9.39	-3.62	-8.00	-8.85	-46.25					-8.16
24BH B		-4.00	-4.68	-4.54		-1.93	-9.40	-3.72	-9.08	-8.80	-46.25					-8.59
25BH B		-3.71	-2.44	-2.30		-1.80	-4.87	-3.44	-8.08	-7.92	-41.72					-8.39
26BH B		-3.34	-1.84	-1.69		-1.45	-3.88	-3.06	-8.17	-7.77	-41.47					-8.69

APPENDIX 10
BATCH REACTION MODELING

Input file: C:\Users\LEHIOWO-PC\Documents\BATCH REACTION L-7.pqi
Output file: C:\Users\LEHIOWO-PC\Documents\BATCH REACTION L-7.pqo
Database file: C:\Program Files\USGS\Phreeqc Interactive 3.3.12-
12704\database\phreeqc.dat

Reading data base.

SOLUTION_MASTER_SPECIES
SOLUTION_SPECIES
PHASES
EXCHANGE_MASTER_SPECIES
EXCHANGE_SPECIES
SURFACE_MASTER_SPECIES
SURFACE_SPECIES
RATES
END

Reading input data for simulation 1.

DATABASE C:\Program Files\USGS\Phreeqc Interactive 3.3.12-
12704\database\phreeqc.dat

SOLUTION 1 BATCH REACTION MODELING

temp	27.32
pH	7.8
pe	4
redox	pe
units	mg/l
density	1
Cl	1228.85
C(4)	600
N(5)	3.7
S(6)	34.79
N(3)	0.145
N(-3)	380
Ca	232.05
Mg	46.2
K	30.9
Na	21.12
Cu	0.832
Pb	0.022
Zn	0.646
Cd	0.022
Mn	1.11
Fe	2.6
water	1 # kg

SOLUTION 2 BATCH REACTION MODELING

temp	27.02
pH	5.15
pe	4
redox	pe
units	mg/l
density	1
Cl	122.5
C(4)	72
N(5)	2.93
S(6)	5.74
N(3)	0.003
N(-3)	10.94
Ca	32
Mg	7
K	1.98
Na	0.96
Cu	0.152
Pb	0.001
Zn	0.41
Cd	0.046
Mn	0.844
Fe	2.501
water	1 # kg

APPENDIX 10 CONT.

MIX 1
 1 2
 2 3
 END

 Beginning of initial solution calculations.

Initial solution 1. BATCH REACTION MODELING

-----Solution composition-----

Elements	Molality	Moles
C(4)	9.858e-03	9.858e-03
Ca	5.805e-03	5.805e-03
Cd	1.962e-07	1.962e-07
Cl	3.475e-02	3.475e-02
Cu	1.313e-05	1.313e-05
Fe	4.668e-05	4.668e-05
K	7.923e-04	7.923e-04
Mg	1.905e-03	1.905e-03
Mn	2.026e-05	2.026e-05
N(-3)	2.720e-02	2.720e-02
N(3)	1.038e-05	1.038e-05
N(5)	2.648e-04	2.648e-04
Na	9.210e-04	9.210e-04
Pb	1.065e-07	1.065e-07
S(6)	3.631e-04	3.631e-04
Zn	9.908e-06	9.908e-06

-----Description of solution-----

pH = 7.800
 pe = 4.000
 Specific Conductance ($\mu\text{S}/\text{cm}$, 27°C) = 5436
 Density (g/cm^3) = 0.99787
 Volume (L) = 1.00485
 Activity of water = 0.999
 Ionic strength (mol/kg_w) = 5.112e-02
 Mass of water (kg) = 1.000e+00
 Total alkalinity (eq/kg) = 1.073e-02
 Total CO2 (mol/kg) = 9.858e-03
 Temperature (°C) = 27.32
 Electrical balance (eq) = -2.016e-03
 Percent error, $100 \cdot (\text{Cat} - |\text{An}|) / (\text{Cat} + |\text{An}|)$ = -2.31
 Iterations = 12
 Total H = 1.111299e+02
 Total O = 5.553795e+01

-----Redox couples-----

Redox couple	pe	Eh (volts)
N(-3)/N(3)	3.9828	0.2374
N(-3)/N(5)	4.7533	0.2834
N(3)/N(5)	7.0649	0.4212

-----Distribution of species-----

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm^3/mol
OH-	9.385e-07	7.596e-07	-6.028	-6.119	-0.092	-3.78
H+	1.859e-08	1.585e-08	-7.731	-7.800	-0.069	0.00
H2O	5.551e+01	9.986e-01	1.744	-0.001	0.000	18.08
C(4)	9.858e-03					
HCO3-	9.010e-03	7.449e-03	-2.045	-2.128	-0.083	25.14
CaHCO3+	2.967e-04	2.467e-04	-3.528	-3.608	-0.080	9.88
CO2	2.557e-04	2.587e-04	-3.592	-3.587	0.005	34.55
CaCO3	1.009e-04	1.021e-04	-3.996	-3.991	0.005	-14.59
MgHCO3+	9.200e-05	7.491e-05	-4.036	-4.125	-0.089	5.67
CO3-2	4.936e-05	2.307e-05	-4.307	-4.637	-0.330	-4.35
MgCO3	1.916e-05	1.939e-05	-4.718	-4.712	0.005	-17.09
MnCO3	7.529e-06	7.618e-06	-5.123	-5.118	0.005	(0)

APPENDIX 10 CONT.

CuCO3	6.756e-06	6.836e-06	-5.170	-5.165	0.005	(0)
Zn(CO3)2-2	3.768e-06	1.697e-06	-5.424	-5.770	-0.346	(0)
ZnCO3	3.402e-06	3.442e-06	-5.468	-5.463	0.005	(0)
MnHCO3+	3.353e-06	2.761e-06	-5.475	-5.559	-0.084	(0)
NaHCO3	3.084e-06	3.120e-06	-5.511	-5.506	0.005	1.80
ZnHCO3+	8.561e-07	7.014e-07	-6.067	-6.154	-0.087	(0)
NaCO3-	4.443e-07	3.640e-07	-6.352	-6.439	-0.087	-0.41
Cu(CO3)2-2	4.406e-07	1.985e-07	-6.356	-6.702	-0.346	(0)
FeHCO3+	3.333e-07	2.731e-07	-6.477	-6.564	-0.087	(0)
CuHCO3+	2.515e-07	2.060e-07	-6.599	-6.686	-0.087	(0)
FeCO3	2.005e-07	2.028e-07	-6.698	-6.693	0.005	(0)
PbCO3	9.163e-08	9.272e-08	-7.038	-7.033	0.005	(0)
Pb(CO3)2-2	1.192e-08	5.372e-09	-7.924	-8.270	-0.346	(0)
CdHCO3+	8.979e-09	7.356e-09	-8.047	-8.133	-0.087	(0)
PbHCO3+	1.671e-09	1.369e-09	-8.777	-8.864	-0.087	(0)
(CO2)2	1.310e-09	1.325e-09	-8.883	-8.878	0.005	69.09
CdCO3	5.654e-10	5.721e-10	-9.248	-9.243	0.005	(0)
Cd(CO3)2-2	9.263e-11	4.173e-11	-10.033	-10.380	-0.346	(0)
Ca	5.805e-03					
Ca+2	5.356e-03	2.510e-03	-2.271	-2.600	-0.329	-17.58
CaHCO3+	2.967e-04	2.467e-04	-3.528	-3.608	-0.080	9.88
CaCO3	1.009e-04	1.021e-04	-3.996	-3.991	0.005	-14.59
CaSO4	5.116e-05	5.177e-05	-4.291	-4.286	0.005	7.58
CaOH+	3.204e-08	2.625e-08	-7.494	-7.581	-0.087	(0)
CaHSO4+	6.809e-12	5.579e-12	-11.167	-11.253	-0.087	(0)
Cd	1.962e-07					
CdCl+	1.035e-07	8.482e-08	-6.985	-7.071	-0.087	6.94
Cd+2	6.931e-08	3.123e-08	-7.159	-7.505	-0.346	-18.13
CdCl2	9.947e-09	1.006e-08	-8.002	-7.997	0.005	23.14
CdHCO3+	8.979e-09	7.356e-09	-8.047	-8.133	-0.087	(0)
CdOHCl	2.291e-09	2.319e-09	-8.640	-8.635	0.005	(0)
CdSO4	1.029e-09	1.041e-09	-8.988	-8.982	0.005	76.94
CdCO3	5.654e-10	5.721e-10	-9.248	-9.243	0.005	(0)
CdOH+	2.369e-10	1.941e-10	-9.625	-9.712	-0.087	(0)
CdCl3-	2.265e-10	1.856e-10	-9.645	-9.731	-0.087	67.90
Cd(CO3)2-2	9.263e-11	4.173e-11	-10.033	-10.380	-0.346	(0)
CdNO3+	1.905e-11	1.561e-11	-10.720	-10.807	-0.087	17.61
Cd(SO4)2-2	2.848e-12	1.283e-12	-11.545	-11.892	-0.346	-103.78
Cd(OH)2	5.473e-13	5.538e-13	-12.262	-12.257	0.005	(0)
Cd2OH+3	1.735e-16	2.885e-17	-15.761	-16.540	-0.779	(0)
Cd(OH)3-	4.779e-18	3.915e-18	-17.321	-17.407	-0.087	(0)
Cd(OH)4-2	4.880e-24	2.198e-24	-23.312	-23.658	-0.346	(0)
Cl	3.475e-02					
Cl-	3.475e-02	2.822e-02	-1.459	-1.549	-0.090	18.32
CuCl2-	9.105e-07	7.414e-07	-6.041	-6.130	-0.089	(0)
MnCl+	5.806e-07	4.781e-07	-6.236	-6.320	-0.084	-2.42
CdCl+	1.035e-07	8.482e-08	-6.985	-7.071	-0.087	6.94
ZnCl+	7.724e-08	6.289e-08	-7.112	-7.201	-0.089	-11.75
CuCl3-2	7.280e-08	3.346e-08	-7.138	-7.475	-0.338	(0)
ZnOHCl	4.353e-08	4.404e-08	-7.361	-7.356	0.005	(0)
FeCl+	1.743e-08	1.428e-08	-7.759	-7.845	-0.087	(0)
CdCl2	9.947e-09	1.006e-08	-8.002	-7.997	0.005	23.14
MnCl2	5.822e-09	5.890e-09	-8.235	-8.230	0.005	83.14
CuCl+	5.763e-09	4.693e-09	-8.239	-8.329	-0.089	0.26
CdOHCl	2.291e-09	2.319e-09	-8.640	-8.635	0.005	(0)
ZnCl2	1.854e-09	1.876e-09	-8.732	-8.727	0.005	97.64
PbCl+	3.359e-10	2.752e-10	-9.474	-9.560	-0.087	8.16
CdCl3-	2.265e-10	1.856e-10	-9.645	-9.731	-0.087	67.90
ZnCl3-	7.398e-11	6.024e-11	-10.131	-10.220	-0.089	16.99
CuCl2	7.207e-11	7.292e-11	-10.142	-10.137	0.005	33.61
MnCl3-	5.561e-11	4.579e-11	-10.255	-10.339	-0.084	43.57
PbCl2	1.165e-11	1.179e-11	-10.934	-10.928	0.005	35.15
ZnCl4-2	1.888e-12	8.678e-13	-11.724	-12.062	-0.338	146.37
PbCl3-	3.273e-13	2.682e-13	-12.485	-12.572	-0.087	66.41
CuCl3-	9.342e-15	7.607e-15	-14.030	-14.119	-0.089	(0)
PbCl4-2	8.185e-15	3.687e-15	-14.087	-14.433	-0.346	102.44
FeCl+2	7.923e-16	3.642e-16	-15.101	-15.439	-0.338	(0)
FeCl2+	5.184e-17	4.268e-17	-16.285	-16.370	-0.084	(0)
CuCl4-2	2.469e-18	1.135e-18	-17.607	-17.945	-0.338	(0)
FeCl3	1.191e-19	1.205e-19	-18.924	-18.919	0.005	(0)
Cu(1)	9.870e-07					
CuCl2-	9.105e-07	7.414e-07	-6.041	-6.130	-0.089	(0)
CuCl3-2	7.280e-08	3.346e-08	-7.138	-7.475	-0.338	(0)
Cu+	3.705e-09	2.959e-09	-8.431	-8.529	-0.098	(0)
Cu(2)	1.214e-05					

APPENDIX 10 CONT.

CuCO ₃	6.756e-06	6.836e-06	-5.170	-5.165	0.005	(0)
Cu(OH) ₂	4.524e-06	4.577e-06	-5.344	-5.339	0.005	(0)
Cu(CO ₃) ₂₋₂	4.406e-07	1.985e-07	-6.356	-6.702	-0.346	(0)
CuHCO ₃ ⁺	2.515e-07	2.060e-07	-6.599	-6.686	-0.087	(0)
Cu ⁺²	1.154e-07	5.518e-08	-6.938	-7.258	-0.320	-26.13
CuOH ⁺	4.270e-08	3.477e-08	-7.370	-7.459	-0.089	(0)
CuCl ⁺	5.763e-09	4.693e-09	-8.239	-8.329	-0.089	0.26
Cu ₂ (OH) ₂ ⁺²	1.476e-09	6.649e-10	-8.831	-9.177	-0.346	(0)
CuSO ₄	1.290e-09	1.305e-09	-8.890	-8.884	0.005	13.37
CuCl ₂	7.207e-11	7.292e-11	-10.142	-10.137	0.005	33.61
Cu(OH) ₃₋	2.121e-11	1.738e-11	-10.673	-10.760	-0.087	(0)
CuCl ₃₋	9.342e-15	7.607e-15	-14.030	-14.119	-0.089	(0)
Cu(OH) ₄₋₂	4.850e-16	2.185e-16	-15.314	-15.661	-0.346	(0)
CuCl ₄₋₂	2.469e-18	1.135e-18	-17.607	-17.945	-0.338	(0)
Fe (2)	1.336e-06					
Fe ⁺²	7.664e-07	3.666e-07	-6.116	-6.436	-0.320	-21.49
FeHCO ₃ ⁺	3.333e-07	2.731e-07	-6.477	-6.564	-0.087	(0)
FeCO ₃	2.005e-07	2.028e-07	-6.698	-6.693	0.005	(0)
FeCl ⁺	1.743e-08	1.428e-08	-7.759	-7.845	-0.087	(0)
FeOH ⁺	1.054e-08	8.676e-09	-7.977	-8.062	-0.084	(0)
FeSO ₄	7.660e-09	7.751e-09	-8.116	-8.111	0.005	16.62
Fe(OH) ₂	5.618e-12	5.684e-12	-11.250	-11.245	0.005	(0)
Fe(OH) ₃₋	1.653e-14	1.361e-14	-13.782	-13.866	-0.084	(0)
FeHSO ₄ ⁺	9.946e-16	8.148e-16	-15.002	-15.089	-0.087	(0)
Fe (3)	4.534e-05					
Fe(OH) ₃	3.736e-05	3.780e-05	-4.428	-4.422	0.005	(0)
Fe(OH) ₂ ⁺	5.095e-06	4.213e-06	-5.293	-5.375	-0.083	(0)
Fe(OH) ₄₋	2.882e-06	2.383e-06	-5.540	-5.623	-0.083	(0)
FeOH ₂ ⁺	4.026e-10	1.850e-10	-9.395	-9.733	-0.338	(0)
Fe ⁺³	1.672e-15	3.972e-16	-14.777	-15.401	-0.624	(0)
FeCl ₂ ⁺	7.923e-16	3.642e-16	-15.101	-15.439	-0.338	(0)
FeSO ₄ ⁺	6.345e-16	5.224e-16	-15.198	-15.282	-0.084	(0)
FeCl ₂ ⁺	5.184e-17	4.268e-17	-16.285	-16.370	-0.084	(0)
Fe ₂ (OH) ₂ ⁺⁴	2.034e-17	8.379e-19	-16.692	-18.077	-1.385	(0)
Fe(SO ₄) ₂₋	1.605e-18	1.315e-18	-17.795	-17.881	-0.087	(0)
FeCl ₃	1.191e-19	1.205e-19	-18.924	-18.919	0.005	(0)
Fe ₃ (OH) ₄ ⁺⁵	8.706e-20	5.964e-22	-19.060	-21.224	-2.164	(0)
FeHSO ₄ ⁺²	4.922e-23	2.217e-23	-22.308	-22.654	-0.346	(0)
H (0)	3.435e-27					
H ₂	1.718e-27	1.738e-27	-26.765	-26.760	0.005	28.60
K	7.923e-04					
K ⁺	7.916e-04	6.418e-04	-3.101	-3.193	-0.091	9.24
KSO ₄₋	6.473e-07	5.352e-07	-6.189	-6.272	-0.083	34.34
Mg	1.905e-03					
Mg ⁺²	1.770e-03	8.502e-04	-2.752	-3.071	-0.318	-21.39
MgHCO ₃ ⁺	9.200e-05	7.491e-05	-4.036	-4.125	-0.089	5.67
MgSO ₄	2.382e-05	2.411e-05	-4.623	-4.618	0.005	5.92
MgCO ₃	1.916e-05	1.939e-05	-4.718	-4.712	0.005	-17.09
MgOH ⁺	2.866e-07	2.394e-07	-6.543	-6.621	-0.078	(0)
Mn (2)	2.026e-05					
Mn ⁺²	8.692e-06	4.158e-06	-5.061	-5.381	-0.320	-18.67
MnCO ₃	7.529e-06	7.618e-06	-5.123	-5.118	0.005	(0)
MnHCO ₃ ⁺	3.353e-06	2.761e-06	-5.475	-5.559	-0.084	(0)
MnCl ⁺	5.806e-07	4.781e-07	-6.236	-6.320	-0.084	-2.42
MnSO ₄	8.704e-08	8.807e-08	-7.060	-7.055	0.005	21.55
MnOH ⁺	9.867e-09	8.124e-09	-8.006	-8.090	-0.084	(0)
MnCl ₂	5.822e-09	5.890e-09	-8.235	-8.230	0.005	83.14
MnCl ₃₋	5.561e-11	4.579e-11	-10.255	-10.339	-0.084	43.57
Mn(NO ₃) ₂	7.382e-13	7.470e-13	-12.132	-12.127	0.005	40.44
Mn(OH) ₃₋	2.002e-17	1.648e-17	-16.699	-16.783	-0.084	(0)
Mn (3)	7.571e-27					
Mn ⁺³	7.571e-27	1.798e-27	-26.121	-26.745	-0.624	(0)
N (-3)	2.720e-02					
NH ₄ ⁺	2.628e-02	2.099e-02	-1.580	-1.678	-0.098	18.18
NH ₃	8.777e-04	8.881e-04	-3.057	-3.052	0.005	24.51
NH ₄ SO ₄₋	3.763e-05	3.083e-05	-4.424	-4.511	-0.087	38.58
N (3)	1.038e-05					
NO ₂₋	1.038e-05	8.346e-06	-4.984	-5.079	-0.095	25.26
N (5)	2.648e-04					
NO ₃₋	2.648e-04	2.130e-04	-3.577	-3.672	-0.095	29.89
CdNO ₃ ⁺	1.905e-11	1.561e-11	-10.720	-10.807	-0.087	17.61
PbNO ₃ ⁺	8.894e-13	7.287e-13	-12.051	-12.137	-0.087	(0)
Mn(NO ₃) ₂	7.382e-13	7.470e-13	-12.132	-12.127	0.005	40.44
Na	9.210e-04					
Na ⁺	9.170e-04	7.546e-04	-3.038	-3.122	-0.085	-1.09

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NaHCO3	3.084e-06	3.120e-06	-5.511	-5.506	0.005	1.80
NaSO4-	5.291e-07	4.375e-07	-6.276	-6.359	-0.083	15.40
NaCO3-	4.443e-07	3.640e-07	-6.352	-6.439	-0.087	-0.41
NaOH	5.665e-20	5.732e-20	-19.247	-19.242	0.005	(0)
O(0)	1.505e-38					
O2	7.526e-39	7.615e-39	-38.123	-38.118	0.005	30.58
Pb	1.065e-07					
PbCO3	9.163e-08	9.272e-08	-7.038	-7.033	0.005	(0)
Pb(CO3)2-2	1.192e-08	5.372e-09	-7.924	-8.270	-0.346	(0)
PbHCO3+	1.671e-09	1.369e-09	-8.777	-8.864	-0.087	(0)
Pb+2	5.134e-10	2.313e-10	-9.290	-9.636	-0.346	-15.03
PbOH+	3.469e-10	2.842e-10	-9.460	-9.546	-0.087	(0)
PbCl+	3.359e-10	2.752e-10	-9.474	-9.560	-0.087	8.16
PbSO4	1.465e-11	1.483e-11	-10.834	-10.829	0.005	(0)
PbCl2	1.165e-11	1.179e-11	-10.934	-10.928	0.005	35.15
Pb(OH)2	6.885e-12	6.966e-12	-11.162	-11.157	0.005	(0)
PbNO3+	8.894e-13	7.287e-13	-12.051	-12.137	-0.087	(0)
PbCl3-	3.273e-13	2.682e-13	-12.485	-12.572	-0.087	66.41
Pb(SO4)2-2	1.969e-14	8.871e-15	-13.706	-14.052	-0.346	(0)
PbCl4-2	8.185e-15	3.687e-15	-14.087	-14.433	-0.346	102.44
Pb(OH)3-	6.151e-15	5.040e-15	-14.211	-14.298	-0.087	(0)
Pb2OH+3	8.850e-18	1.472e-18	-17.053	-17.832	-0.779	(0)
Pb(OH)4-2	1.615e-18	7.274e-19	-17.792	-18.138	-0.346	(0)
Pb3(OH)4+2	8.062e-22	3.632e-22	-21.094	-21.440	-0.346	(0)
S(6)	3.631e-04					
SO4-2	2.492e-04	1.140e-04	-3.603	-3.943	-0.340	15.54
CaSO4	5.116e-05	5.177e-05	-4.291	-4.286	0.005	7.58
NH4SO4-	3.763e-05	3.083e-05	-4.424	-4.511	-0.087	38.58
MgSO4	2.382e-05	2.411e-05	-4.623	-4.618	0.005	5.92
KSO4-	6.473e-07	5.352e-07	-6.189	-6.272	-0.083	34.34
NaSO4-	5.291e-07	4.375e-07	-6.276	-6.359	-0.083	15.40
MnSO4	8.704e-08	8.807e-08	-7.060	-7.055	0.005	21.55
ZnSO4	2.011e-08	2.034e-08	-7.697	-7.692	0.005	21.36
FeSO4	7.660e-09	7.751e-09	-8.116	-8.111	0.005	16.62
CuSO4	1.290e-09	1.305e-09	-8.890	-8.884	0.005	13.37
CdSO4	1.029e-09	1.041e-09	-8.988	-8.982	0.005	76.94
HSO4-	2.256e-10	1.849e-10	-9.647	-9.733	-0.087	40.61
Zn(SO4)2-2	4.111e-11	1.852e-11	-10.386	-10.732	-0.346	-10.15
PbSO4	1.465e-11	1.483e-11	-10.834	-10.829	0.005	(0)
CaHSO4+	6.809e-12	5.579e-12	-11.167	-11.253	-0.087	(0)
Cd(SO4)2-2	2.848e-12	1.283e-12	-11.545	-11.892	-0.346	-103.78
Pb(SO4)2-2	1.969e-14	8.871e-15	-13.706	-14.052	-0.346	(0)
FeHSO4+	9.946e-16	8.148e-16	-15.002	-15.089	-0.087	(0)
FeSO4+	6.345e-16	5.224e-16	-15.198	-15.282	-0.084	(0)
Fe(SO4)2-	1.605e-18	1.315e-18	-17.795	-17.881	-0.087	(0)
FeHSO4+2	4.922e-23	2.217e-23	-22.308	-22.654	-0.346	(0)
Zn	9.908e-06					
Zn(CO3)2-2	3.768e-06	1.697e-06	-5.424	-5.770	-0.346	(0)
ZnCO3	3.402e-06	3.442e-06	-5.468	-5.463	0.005	(0)
Zn+2	1.627e-06	7.479e-07	-5.789	-6.126	-0.338	-24.99
ZnHCO3+	8.561e-07	7.014e-07	-6.067	-6.154	-0.087	(0)
ZnCl+	7.724e-08	6.289e-08	-7.112	-7.201	-0.089	-11.75
ZnOH+	7.511e-08	6.153e-08	-7.124	-7.211	-0.087	(0)
ZnOHCl	4.353e-08	4.404e-08	-7.361	-7.356	0.005	(0)
Zn(OH)2	3.694e-08	3.738e-08	-7.432	-7.427	0.005	(0)
ZnSO4	2.011e-08	2.034e-08	-7.697	-7.692	0.005	21.36
ZnCl2	1.854e-09	1.876e-09	-8.732	-8.727	0.005	97.64
ZnCl3-	7.398e-11	6.024e-11	-10.131	-10.220	-0.089	16.99
Zn(SO4)2-2	4.111e-11	1.852e-11	-10.386	-10.732	-0.346	-10.15
Zn(OH)3-	9.091e-12	7.448e-12	-11.041	-11.128	-0.087	(0)
ZnCl4-2	1.888e-12	8.678e-13	-11.724	-12.062	-0.338	146.37
Zn(OH)4-2	1.651e-16	7.438e-17	-15.782	-16.129	-0.346	(0)

-----Saturation indices-----

Phase	SI**	log IAP	log K(300 K, 1 atm)	
Anglesite	-5.80	-13.58	-7.78	PbSO4
Anhydrite	-2.24	-6.54	-4.30	CaSO4
Aragonite	1.11	-7.24	-8.35	CaCO3
Calcite	1.26	-7.24	-8.49	CaCO3
Cd(OH)2	-5.56	8.09	13.65	Cd(OH)2
CdSO4	-11.27	-11.45	-0.18	CdSO4
Cerussite	-1.17	-14.27	-13.10	PbCO3
CO2(g)	-2.09	-3.59	-1.49	CO2

APPENDIX 10 CONT.

Dolomite	2.20	-14.94	-17.14	CaMg(CO3)2
Fe(OH)3(a)	3.11	8.00	4.89	Fe(OH)3
Goethite	9.08	8.00	-1.08	FeOOH
Gypsum	-1.96	-6.54	-4.58	CaSO4:2H2O
H2(g)	-23.65	-26.76	-3.11	H2
H2O(g)	-1.44	-0.00	1.44	H2O
Halite	-6.24	-4.67	1.57	NaCl
Hausmannite	-6.21	54.25	60.46	Mn3O4
Hematite	20.18	16.00	-4.18	Fe2O3
Jarosite-K	-1.10	-10.49	-9.39	KFe3(SO4)2(OH)6
Manganite	-3.32	22.02	25.34	MnOOH
Melanterite	-8.20	-10.38	-2.18	FeSO4:7H2O
NH3(g)	-4.80	-3.05	1.75	NH3
O2(g)	-35.21	-38.12	-2.91	O2
Otavite	-0.04	-12.14	-12.10	CdCO3
Pb(OH)2	-2.11	5.96	8.07	Pb(OH)2
Pyrochroite	-4.98	10.22	15.20	Mn(OH)2
Pyrolusite	-7.19	33.82	41.01	MnO2:H2O
Rhodochrosite	1.12	-10.02	-11.14	MnCO3
Siderite	-0.17	-11.07	-10.90	FeCO3
Smithsonite	-0.74	-10.76	-10.02	ZnCO3
Sylvite	-5.65	-4.74	0.91	KCl
Zn(OH)2(e)	-2.03	9.47	11.50	Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

Initial solution 2. BATCH REACTION MODELING

-----Solution composition-----

Elements	Molality	Moles
C(4)	1.180e-03	1.180e-03
Ca	7.986e-04	7.986e-04
Cd	4.094e-07	4.094e-07
Cl	3.456e-03	3.456e-03
Cu	2.393e-06	2.393e-06
Fe	4.479e-05	4.479e-05
K	5.065e-05	5.065e-05
Mg	2.880e-04	2.880e-04
Mn	1.537e-05	1.537e-05
N(-3)	7.813e-04	7.813e-04
N(3)	2.142e-07	2.142e-07
N(5)	2.092e-04	2.092e-04
Na	4.177e-05	4.177e-05
Pb	4.828e-09	4.828e-09
S(6)	5.977e-05	5.977e-05
Zn	6.274e-06	6.274e-06

-----Description of solution-----

pH	=	5.150
pe	=	4.000
Specific Conductance (μ S/cm, 27°C)	=	478
Density (g/cm ³)	=	0.99666
Volume (L)	=	1.00361
Activity of water	=	1.000
Ionic strength (mol/kgw)	=	4.712e-03
Mass of water (kg)	=	1.000e+00
Total alkalinity (eq/kg)	=	7.003e-05
Total CO2 (mol/kg)	=	1.180e-03
Temperature (°C)	=	27.02
Electrical balance (eq)	=	-6.702e-04
Percent error, 100*(Cat- An)/(Cat+ An)	=	-9.54
Iterations	=	10
Total H	=	1.110156e+02
Total O	=	5.550952e+01

-----Redox couples-----

Redox couple	pe	Eh (volts)
N(-3)/N(3)	7.5065	0.4471
N(-3)/N(5)	8.2604	0.4920

APPENDIX 10 CONT.

N(3)/N(5)

10.5220

0.6267

-----Distribution of species-----

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm ³ /mol
H+	7.572e-06	7.079e-06	-5.121	-5.150	-0.029	0.00
OH-	1.795e-09	1.665e-09	-8.746	-8.779	-0.033	-4.00
H2O	5.551e+01	9.999e-01	1.744	-0.000	0.000	18.08
C(4)	1.180e-03					
CO2	1.103e-03	1.104e-03	-2.958	-2.957	0.000	34.53
HCO3-	7.632e-05	7.101e-05	-4.117	-4.149	-0.031	24.87
CaHCO3+	5.957e-07	5.548e-07	-6.225	-6.256	-0.031	9.77
FeHCO3+	2.538e-07	2.357e-07	-6.595	-6.628	-0.032	(0)
MgHCO3+	1.940e-07	1.801e-07	-6.712	-6.745	-0.032	5.56
MnHCO3+	7.702e-08	7.162e-08	-7.113	-7.145	-0.032	(0)
CuHCO3+	5.603e-08	5.204e-08	-7.252	-7.284	-0.032	(0)
ZnHCO3+	4.418e-08	4.103e-08	-7.355	-7.387	-0.032	(0)
(CO2)2	2.386e-08	2.389e-08	-7.622	-7.622	0.000	69.06
CuCO3	3.839e-09	3.843e-09	-8.416	-8.415	0.000	(0)
NaHCO3	1.531e-09	1.532e-09	-8.815	-8.815	0.000	1.80
CO3-2	6.530e-10	4.894e-10	-9.185	-9.310	-0.125	-4.99
CdHCO3+	5.839e-10	5.422e-10	-9.234	-9.266	-0.032	(0)
CaCO3	5.092e-10	5.098e-10	-9.293	-9.293	0.000	-14.59
ZnCO3	4.477e-10	4.482e-10	-9.349	-9.349	0.000	(0)
MnCO3	4.395e-10	4.399e-10	-9.357	-9.357	0.000	(0)
FeCO3	3.893e-10	3.897e-10	-9.410	-9.409	0.000	(0)
PbHCO3+	1.847e-10	1.716e-10	-9.733	-9.766	-0.032	(0)
MgCO3	1.033e-10	1.034e-10	-9.986	-9.985	0.000	-17.09
PbCO3	2.584e-11	2.587e-11	-10.588	-10.587	0.000	(0)
NaCO3-	4.214e-13	3.914e-13	-12.375	-12.407	-0.032	-0.81
CdCO3	9.377e-14	9.388e-14	-13.028	-13.027	0.000	(0)
Zn(CO3)2-2	6.306e-15	4.690e-15	-14.200	-14.329	-0.129	(0)
Cu(CO3)2-2	3.184e-15	2.368e-15	-14.497	-14.626	-0.129	(0)
Pb(CO3)2-2	4.276e-17	3.180e-17	-16.369	-16.498	-0.129	(0)
Cd(CO3)2-2	1.954e-19	1.453e-19	-18.709	-18.838	-0.129	(0)
Ca	7.986e-04					
Ca+2	7.938e-04	5.946e-04	-3.100	-3.226	-0.125	-18.00
CaSO4	4.218e-06	4.223e-06	-5.375	-5.374	0.000	7.57
CaHCO3+	5.957e-07	5.548e-07	-6.225	-6.256	-0.031	9.77
CaCO3	5.092e-10	5.098e-10	-9.293	-9.293	0.000	-14.59
CaHSO4+	2.179e-10	2.024e-10	-9.662	-9.694	-0.032	(0)
CaOH+	1.501e-11	1.394e-11	-10.824	-10.856	-0.032	(0)
Cd	4.094e-07					
Cd+2	3.247e-07	2.415e-07	-6.489	-6.617	-0.129	-18.54
CdCl+	8.017e-08	7.445e-08	-7.096	-7.128	-0.032	6.39
CdSO4	2.771e-09	2.774e-09	-8.557	-8.557	0.000	77.08
CdCl2	1.002e-09	1.003e-09	-8.999	-8.999	0.000	23.14
CdHCO3+	5.839e-10	5.422e-10	-9.234	-9.266	-0.032	(0)
CdNO3+	1.194e-10	1.109e-10	-9.923	-9.955	-0.032	17.49
CdOHCl	4.528e-12	4.533e-12	-11.344	-11.344	0.000	(0)
CdOH+	3.545e-12	3.292e-12	-11.450	-11.483	-0.032	(0)
CdCl3-	2.252e-12	2.091e-12	-11.647	-11.680	-0.032	67.95
Cd(SO4)2-2	1.589e-12	1.182e-12	-11.799	-11.927	-0.129	-104.30
CdCO3	9.377e-14	9.388e-14	-13.028	-13.027	0.000	(0)
Cd(OH)2	2.149e-17	2.152e-17	-16.668	-16.667	0.000	(0)
Cd2OH+3	7.393e-18	3.797e-18	-17.131	-17.421	-0.289	(0)
Cd(CO3)2-2	1.954e-19	1.453e-19	-18.709	-18.838	-0.129	(0)
Cd(OH)3-	3.672e-25	3.410e-25	-24.435	-24.467	-0.032	(0)
Cd(OH)4-2	5.771e-34	4.292e-34	-33.239	-33.367	-0.129	(0)
Cl	3.456e-03					
Cl-	3.455e-03	3.207e-03	-2.462	-2.494	-0.032	18.16
CuCl2-	2.725e-07	2.531e-07	-6.565	-6.597	-0.032	(0)
MnCl+	1.590e-07	1.478e-07	-6.799	-6.830	-0.032	-2.59
FeCl+	1.582e-07	1.469e-07	-6.801	-6.833	-0.032	(0)
CdCl+	8.017e-08	7.445e-08	-7.096	-7.128	-0.032	6.39
ZnCl+	4.661e-08	4.328e-08	-7.332	-7.364	-0.032	-11.96
CuCl+	1.500e-08	1.392e-08	-7.824	-7.856	-0.032	0.16
CuCl3-2	1.733e-09	1.296e-09	-8.761	-8.887	-0.126	(0)
CdCl2	1.002e-09	1.003e-09	-8.999	-8.999	0.000	23.14
PbCl+	4.395e-10	4.081e-10	-9.357	-9.389	-0.032	8.05
MnCl2	2.067e-10	2.070e-10	-9.685	-9.684	0.000	83.48
ZnCl2	1.463e-10	1.465e-10	-9.835	-9.834	0.000	98.19
ZnOHCl	6.876e-11	6.883e-11	-10.163	-10.162	0.000	(0)

APPENDIX 10 CONT.

CuCl2	2.448e-11	2.450e-11	-10.611	-10.611	0.000	33.29
CdOHC1	4.528e-12	4.533e-12	-11.344	-11.344	0.000	(0)
CdCl3-	2.252e-12	2.091e-12	-11.647	-11.680	-0.032	67.95
PbCl2	1.996e-12	1.998e-12	-11.700	-11.699	0.000	35.13
ZnCl3-	5.746e-13	5.335e-13	-12.241	-12.273	-0.032	17.17
MnCl3-	1.966e-13	1.828e-13	-12.706	-12.738	-0.032	43.31
PbCl3-	5.549e-15	5.153e-15	-14.256	-14.288	-0.032	66.22
FeCl+2	4.884e-15	3.652e-15	-14.311	-14.438	-0.126	(0)
ZnCl4-2	1.165e-15	8.713e-16	-14.934	-15.060	-0.126	145.57
CuCl3-	3.112e-16	2.889e-16	-15.507	-15.539	-0.032	(0)
FeCl2+	5.279e-17	4.909e-17	-16.277	-16.309	-0.032	(0)
PbCl4-2	1.080e-17	8.032e-18	-16.967	-17.095	-0.129	101.79
FeCl3	1.572e-20	1.574e-20	-19.803	-19.803	0.000	(0)
CuCl4-2	6.506e-21	4.864e-21	-20.187	-20.313	-0.126	(0)
Cu(1)	3.587e-07					
CuCl2-	2.725e-07	2.531e-07	-6.565	-6.597	-0.032	(0)
Cu+	8.441e-08	7.819e-08	-7.074	-7.107	-0.033	(0)
CuCl3-2	1.733e-09	1.296e-09	-8.761	-8.887	-0.126	(0)
Cu(2)	2.034e-06					
Cu+2	1.944e-06	1.462e-06	-5.711	-5.835	-0.124	-26.51
CuHCO3+	5.603e-08	5.204e-08	-7.252	-7.284	-0.032	(0)
CuCl+	1.500e-08	1.392e-08	-7.824	-7.856	-0.032	0.16
CuSO4	1.190e-08	1.191e-08	-7.925	-7.924	0.000	13.33
CuCO3	3.839e-09	3.843e-09	-8.416	-8.415	0.000	(0)
CuOH+	2.224e-09	2.065e-09	-8.653	-8.685	-0.032	(0)
Cu(OH)2	6.087e-10	6.094e-10	-9.216	-9.215	0.000	(0)
CuCl2	2.448e-11	2.450e-11	-10.611	-10.611	0.000	33.29
Cu2(OH)2+2	3.062e-12	2.277e-12	-11.514	-11.643	-0.129	(0)
Cu(CO3)2-2	3.184e-15	2.368e-15	-14.497	-14.626	-0.129	(0)
CuCl3-	3.112e-16	2.889e-16	-15.507	-15.539	-0.032	(0)
Cu(OH)3-	5.585e-18	5.186e-18	-17.253	-17.285	-0.032	(0)
CuCl4-2	6.506e-21	4.864e-21	-20.187	-20.313	-0.126	(0)
Cu(OH)4-2	1.965e-25	1.461e-25	-24.707	-24.835	-0.129	(0)
Fe(2)	4.479e-05					
Fe+2	4.414e-05	3.319e-05	-4.355	-4.479	-0.124	-21.90
FeHCO3+	2.538e-07	2.357e-07	-6.595	-6.628	-0.032	(0)
FeSO4	2.406e-07	2.409e-07	-6.619	-6.618	0.000	16.92
FeCl+	1.582e-07	1.469e-07	-6.801	-6.833	-0.032	(0)
FeOH+	1.852e-09	1.722e-09	-8.732	-8.764	-0.032	(0)
FeCO3	3.893e-10	3.897e-10	-9.410	-9.409	0.000	(0)
FeHSO4+	1.216e-11	1.130e-11	-10.915	-10.947	-0.032	(0)
Fe(OH)2	2.462e-15	2.465e-15	-14.609	-14.608	0.000	(0)
Fe(OH)3-	1.419e-20	1.319e-20	-19.848	-19.880	-0.032	(0)
Fe(3)	2.054e-09					
Fe(OH)2+	1.969e-09	1.832e-09	-8.706	-8.737	-0.031	(0)
FeOH+2	4.856e-11	3.631e-11	-10.314	-10.440	-0.126	(0)
Fe(OH)3	3.635e-11	3.639e-11	-10.440	-10.439	0.000	(0)
Fe+3	6.480e-14	3.538e-14	-13.188	-13.451	-0.263	(0)
FeSO4+	1.716e-14	1.596e-14	-13.766	-13.797	-0.032	(0)
Fe(OH)4-	5.461e-15	5.081e-15	-14.263	-14.294	-0.031	(0)
FeCl+2	4.884e-15	3.652e-15	-14.311	-14.438	-0.126	(0)
FeCl2+	5.279e-17	4.909e-17	-16.277	-16.309	-0.032	(0)
Fe(SO4)2-	1.490e-17	1.384e-17	-16.827	-16.859	-0.032	(0)
FeHSO4+2	4.067e-19	3.025e-19	-18.391	-18.519	-0.129	(0)
Fe2(OH)2+4	1.068e-19	3.266e-20	-18.972	-19.486	-0.514	(0)
FeCl3	1.572e-20	1.574e-20	-19.803	-19.803	0.000	(0)
Fe3(OH)4+5	6.614e-26	1.039e-26	-25.180	-25.983	-0.804	(0)
H(0)	6.948e-22					
H2	3.474e-22	3.478e-22	-21.459	-21.459	0.000	28.60
K	5.065e-05					
K+	5.064e-05	4.699e-05	-4.296	-4.328	-0.032	9.10
KSO4-	1.446e-08	1.345e-08	-7.840	-7.871	-0.031	34.19
Mg	2.880e-04					
Mg+2	2.857e-04	2.147e-04	-3.544	-3.668	-0.124	-21.78
MgSO4	2.083e-06	2.085e-06	-5.681	-5.681	0.000	5.91
MgHCO3+	1.940e-07	1.801e-07	-6.712	-6.745	-0.032	5.56
MgOH+	1.416e-10	1.320e-10	-9.849	-9.879	-0.031	(0)
MgCO3	1.033e-10	1.034e-10	-9.986	-9.985	0.000	-17.09
Mn(2)	1.537e-05					
Mn+2	1.505e-05	1.132e-05	-4.823	-4.946	-0.124	-20.25
MnCl+	1.590e-07	1.478e-07	-6.799	-6.830	-0.032	-2.59
MnSO4	8.217e-08	8.226e-08	-7.085	-7.085	0.000	21.68
MnHCO3+	7.702e-08	7.162e-08	-7.113	-7.145	-0.032	(0)
MnCO3	4.395e-10	4.399e-10	-9.357	-9.357	0.000	(0)
MnCl2	2.067e-10	2.070e-10	-9.685	-9.684	0.000	83.48

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MnOH+	5.203e-11	4.838e-11	-10.284	-10.315	-0.032	(0)
Mn(NO3)2	1.686e-12	1.687e-12	-11.773	-11.773	0.000	40.52
MnCl3-	1.966e-13	1.828e-13	-12.706	-12.738	-0.032	43.31
Mn(OH)3-	5.434e-25	5.053e-25	-24.265	-24.296	-0.032	(0)
Mn(3)	8.586e-27					
Mn+3	8.586e-27	4.688e-27	-26.066	-26.329	-0.263	(0)
N(-3)	7.813e-04					
NH4+	7.808e-04	7.232e-04	-3.107	-3.141	-0.033	18.05
NH4SO4-	3.947e-07	3.665e-07	-6.404	-6.436	-0.032	38.25
NH3	6.701e-08	6.708e-08	-7.174	-7.173	0.000	24.49
N(3)	2.142e-07					
NO2-	2.142e-07	1.986e-07	-6.669	-6.702	-0.033	25.10
N(5)	2.092e-04					
NO3-	2.092e-04	1.940e-04	-3.679	-3.712	-0.033	29.71
CdNO3+	1.194e-10	1.109e-10	-9.923	-9.955	-0.032	17.49
PbNO3+	9.397e-12	8.727e-12	-11.027	-11.059	-0.032	(0)
Mn(NO3)2	1.686e-12	1.687e-12	-11.773	-11.773	0.000	40.52
Na	4.177e-05					
Na+	4.177e-05	3.881e-05	-4.379	-4.411	-0.032	-1.32
NaSO4-	8.330e-09	7.750e-09	-8.079	-8.111	-0.031	13.98
NaHCO3	1.531e-09	1.532e-09	-8.815	-8.815	0.000	1.80
NaCO3-	4.214e-13	3.914e-13	-12.375	-12.407	-0.032	-0.81
NaOH	6.455e-24	6.462e-24	-23.190	-23.190	0.000	(0)
O(0)	0.000e+00					
O2	0.000e+00	0.000e+00	-48.816	-48.815	0.000	30.56
Pb	4.828e-09					
Pb+2	4.090e-09	3.042e-09	-8.388	-8.517	-0.129	-15.44
PbCl+	4.395e-10	4.081e-10	-9.357	-9.389	-0.032	8.05
PbHCO3+	1.847e-10	1.716e-10	-9.733	-9.766	-0.032	(0)
PbSO4	6.722e-11	6.729e-11	-10.173	-10.172	0.000	(0)
PbCO3	2.584e-11	2.587e-11	-10.588	-10.587	0.000	(0)
PbNO3+	9.397e-12	8.727e-12	-11.027	-11.059	-0.032	(0)
PbOH+	9.020e-12	8.377e-12	-11.045	-11.077	-0.032	(0)
PbCl2	1.996e-12	1.998e-12	-11.700	-11.699	0.000	35.13
Pb(SO4)2-2	1.868e-14	1.389e-14	-13.729	-13.857	-0.129	(0)
PbCl3-	5.549e-15	5.153e-15	-14.256	-14.288	-0.032	66.22
Pb(OH)2	4.598e-16	4.603e-16	-15.337	-15.337	0.000	(0)
Pb(CO3)2-2	4.276e-17	3.180e-17	-16.369	-16.498	-0.129	(0)
PbCl4-2	1.080e-17	8.032e-18	-16.967	-17.095	-0.129	101.79
Pb2OH+3	1.111e-18	5.704e-19	-17.954	-18.244	-0.289	(0)
Pb(OH)3-	8.037e-22	7.464e-22	-21.095	-21.127	-0.032	(0)
Pb(OH)4-2	3.247e-28	2.415e-28	-27.488	-27.617	-0.129	(0)
Pb3(OH)4+2	2.682e-29	1.995e-29	-28.572	-28.700	-0.129	(0)
S(6)	5.977e-05					
SO4-2	5.264e-05	3.934e-05	-4.279	-4.405	-0.126	14.90
CaSO4	4.218e-06	4.223e-06	-5.375	-5.374	0.000	7.57
MgSO4	2.083e-06	2.085e-06	-5.681	-5.681	0.000	5.91
NH4SO4-	3.947e-07	3.665e-07	-6.404	-6.436	-0.032	38.25
FeSO4	2.406e-07	2.409e-07	-6.619	-6.618	0.000	16.92
MnSO4	8.217e-08	8.226e-08	-7.085	-7.085	0.000	21.68
ZnSO4	4.294e-08	4.298e-08	-7.367	-7.367	0.000	21.40
HSO4-	3.048e-08	2.831e-08	-7.516	-7.548	-0.032	40.44
KSO4-	1.446e-08	1.345e-08	-7.840	-7.871	-0.031	34.19
CuSO4	1.190e-08	1.191e-08	-7.925	-7.924	0.000	13.33
NaSO4-	8.330e-09	7.750e-09	-8.079	-8.111	-0.031	13.98
CdSO4	2.771e-09	2.774e-09	-8.557	-8.557	0.000	77.08
CaHSO4+	2.179e-10	2.024e-10	-9.662	-9.694	-0.032	(0)
PbSO4	6.722e-11	6.729e-11	-10.173	-10.172	0.000	(0)
Zn(SO4)2-2	1.820e-11	1.353e-11	-10.740	-10.869	-0.129	-11.32
FeHSO4+	1.216e-11	1.130e-11	-10.915	-10.947	-0.032	(0)
Cd(SO4)2-2	1.589e-12	1.182e-12	-11.799	-11.927	-0.129	-104.30
Pb(SO4)2-2	1.868e-14	1.389e-14	-13.729	-13.857	-0.129	(0)
FeSO4+	1.716e-14	1.596e-14	-13.766	-13.797	-0.032	(0)
Fe(SO4)2-	1.490e-17	1.384e-17	-16.827	-16.859	-0.032	(0)
FeHSO4+2	4.067e-19	3.025e-19	-18.391	-18.519	-0.129	(0)
Zn	6.274e-06					
Zn+2	6.138e-06	4.590e-06	-5.212	-5.338	-0.126	-25.37
ZnCl+	4.661e-08	4.328e-08	-7.332	-7.364	-0.032	-11.96
ZnHCO3+	4.418e-08	4.103e-08	-7.355	-7.387	-0.032	(0)
ZnSO4	4.294e-08	4.298e-08	-7.367	-7.367	0.000	21.40
ZnOH+	8.912e-10	8.276e-10	-9.050	-9.082	-0.032	(0)
ZnCO3	4.477e-10	4.482e-10	-9.349	-9.349	0.000	(0)
ZnCl2	1.463e-10	1.465e-10	-9.835	-9.834	0.000	98.19
ZnOHCl	6.876e-11	6.883e-11	-10.163	-10.162	0.000	(0)
Zn(SO4)2-2	1.820e-11	1.353e-11	-10.740	-10.869	-0.129	-11.32

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Zn(OH)2	1.151e-12	1.153e-12	-11.939	-11.938	0.000	(0)
ZnCl3-	5.746e-13	5.335e-13	-12.241	-12.273	-0.032	17.17
Zn(CO3)2-2	6.306e-15	4.690e-15	-14.200	-14.329	-0.129	(0)
ZnCl4-2	1.165e-15	8.713e-16	-14.934	-15.060	-0.126	145.57
Zn(OH)3-	5.543e-19	5.148e-19	-18.256	-18.288	-0.032	(0)
Zn(OH)4-2	1.549e-26	1.152e-26	-25.810	-25.938	-0.129	(0)

-----Saturation indices-----

Phase	SI**	log IAP	log K(300 K, 1 atm)	
Anglesite	-5.14	-12.92	-7.78	PbSO4
Anhydrite	-3.33	-7.63	-4.30	CaSO4
Aragonite	-4.19	-12.54	-8.35	CaCO3
Calcite	-4.04	-12.54	-8.49	CaCO3
Cd(OH)2	-9.97	3.68	13.65	Cd(OH)2
CdSO4	-10.85	-11.02	-0.17	CdSO4
Cerussite	-4.72	-17.83	-13.11	PbCO3
CO2(g)	-1.47	-2.96	-1.49	CO2
Dolomite	-8.38	-25.51	-17.14	CaMg(CO3)2
Fe(OH)3(a)	-2.89	2.00	4.89	Fe(OH)3
Goethite	3.07	2.00	-1.07	FeOOH
Gypsum	-3.05	-7.63	-4.58	CaSO4:2H2O
H2(g)	-18.35	-21.46	-3.11	H2
H2O(g)	-1.45	-0.00	1.45	H2O
Halite	-8.48	-6.90	1.57	NaCl
Hausmannite	-26.17	34.36	60.53	Mn3O4
Hematite	8.16	4.00	-4.16	Fe2O3
Jarosite-K	-13.23	-22.59	-9.36	KFe3(SO4)2(OH)6
Manganite	-10.84	14.50	25.34	MnOOH
Melanterite	-6.70	-8.88	-2.19	FeSO4:7H2O
NH3(g)	-8.93	-7.17	1.75	NH3
O2(g)	-45.91	-48.82	-2.91	O2
Otavite	-3.83	-15.93	-12.10	CdCO3
Pb(OH)2	-6.30	1.78	8.08	Pb(OH)2
Pyrochroite	-9.85	5.35	15.20	Mn(OH)2
Pyrolusite	-17.41	23.65	41.06	MnO2:H2O
Rhodochrosite	-3.12	-14.26	-11.14	MnCO3
Siderite	-2.89	-13.79	-10.90	FeCO3
Smithsonite	-4.63	-14.65	-10.02	ZnCO3
Sylvite	-7.73	-6.82	0.91	KCl
Zn(OH)2(e)	-6.54	4.96	11.50	Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

Beginning of batch-reaction calculations.

Reaction step 1.

Using mix 1.

Mixture 1.

2.000e+00 Solution 1 BATCH REACTION MODELING
3.000e+00 Solution 2 BATCH REACTION MODELING

-----Solution composition-----

Elements	Molality	Moles
C	4.651e-03	2.326e-02
Ca	2.801e-03	1.401e-02
Cd	3.241e-07	1.621e-06
Cl	1.597e-02	7.987e-02
Cu	6.686e-06	3.343e-05
Fe	4.555e-05	2.277e-04
K	3.473e-04	1.737e-03
Mg	9.348e-04	4.674e-03
Mn	1.732e-05	8.661e-05
N	1.158e-02	5.792e-02
Na	3.935e-04	1.967e-03
Pb	4.548e-08	2.274e-07

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S 1.811e-04 9.055e-04
 Zn 7.727e-06 3.864e-05

-----Description of solution-----

equilibrium
 pH = 6.679 Charge balance
 pe = -3.589 Adjusted to redox

Specific Conductance ($\mu\text{S}/\text{cm}$, 27°C) = 2389
 Density (g/cm^3) = 0.99710
 Volume (L) = 5.02076
 Activity of water = 0.999
 Ionic strength (mol/kgw) = 2.216e-02
 Mass of water (kg) = 5.000e+00
 Total alkalinity (eq/kg) = 3.288e-03
 Total CO2 (mol/kg) = 4.357e-03
 Temperature (°C) = 27.14
 Electrical balance (eq) = -6.042e-03
 Percent error, $100 \cdot (\text{Cat} - |\text{An}|) / (\text{Cat} + |\text{An}|)$ = -3.27
 Iterations = 19
 Total H = 5.553067e+02
 Total O = 2.776045e+02

-----Distribution of species-----

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm^3/mol
H+	2.366e-07	2.095e-07	-6.626	-6.679	-0.053	0.00
OH-	6.592e-08	5.675e-08	-7.181	-7.246	-0.065	-3.90
H2O	5.551e+01	9.994e-01	1.744	-0.000	0.000	18.08
C(-4)	2.943e-04					
CH4	2.943e-04	2.958e-04	-3.531	-3.529	0.002	35.63
C(4)	4.357e-03					
HCO3-	3.050e-03	2.655e-03	-2.516	-2.576	-0.060	24.99
CO2	1.214e-03	1.220e-03	-2.916	-2.914	0.002	34.54
CaHCO3+	6.283e-05	5.486e-05	-4.202	-4.261	-0.059	9.83
MgHCO3+	1.932e-05	1.669e-05	-4.714	-4.778	-0.064	5.62
FeHCO3+	4.177e-06	3.613e-06	-5.379	-5.442	-0.063	(0)
MnHCO3+	2.240e-06	1.945e-06	-5.650	-5.711	-0.061	(0)
CaCO3	1.701e-06	1.709e-06	-5.769	-5.767	0.002	-14.59
CO3-2	1.080e-06	6.198e-07	-5.967	-6.208	-0.241	-4.67
NaHCO3	5.003e-07	5.029e-07	-6.301	-6.299	0.002	1.80
MnCO3	4.027e-07	4.048e-07	-6.395	-6.393	0.002	(0)
MgCO3	3.234e-07	3.250e-07	-6.490	-6.488	0.002	-17.09
FeCO3	2.013e-07	2.024e-07	-6.696	-6.694	0.002	(0)
(CO2)2	2.915e-08	2.930e-08	-7.535	-7.533	0.002	69.07
NaCO3-	5.063e-09	4.380e-09	-8.296	-8.359	-0.063	-0.64
ZnHCO3+	2.396e-12	2.073e-12	-11.621	-11.683	-0.063	(0)
ZnCO3	7.630e-13	7.669e-13	-12.117	-12.115	0.002	(0)
PbCO3	1.829e-13	1.838e-13	-12.738	-12.736	0.002	(0)
PbHCO3+	4.160e-14	3.599e-14	-13.381	-13.444	-0.063	(0)
Zn(CO3)2-2	1.814e-14	1.016e-14	-13.741	-13.993	-0.252	(0)
CdHCO3+	6.364e-16	5.506e-16	-15.196	-15.259	-0.063	(0)
Pb(CO3)2-2	5.110e-16	2.862e-16	-15.292	-15.543	-0.252	(0)
CuCO3	4.427e-18	4.449e-18	-17.354	-17.352	0.002	(0)
CdCO3	3.212e-18	3.229e-18	-17.493	-17.491	0.002	(0)
CuHCO3+	2.056e-18	1.779e-18	-17.687	-17.750	-0.063	(0)
Cd(CO3)2-2	1.130e-20	6.329e-21	-19.947	-20.199	-0.252	(0)
Cu(CO3)2-2	6.199e-21	3.472e-21	-20.208	-20.459	-0.252	(0)
Ca	2.801e-03					
Ca+2	2.736e-03	1.570e-03	-2.563	-2.804	-0.241	-17.77
CaHCO3+	6.283e-05	5.486e-05	-4.202	-4.261	-0.059	9.83
CaCO3	1.701e-06	1.709e-06	-5.769	-5.767	0.002	-14.59
CaSO4	1.224e-07	1.230e-07	-6.912	-6.910	0.002	7.58
CaOH+	1.437e-09	1.243e-09	-8.843	-8.905	-0.063	(0)
CaHSO4+	2.020e-13	1.748e-13	-12.695	-12.757	-0.063	(0)
Cd	3.241e-07					
Cd(HS)2	3.177e-07	3.193e-07	-6.498	-6.496	0.002	(0)
CdHS+	4.250e-09	3.677e-09	-8.372	-8.434	-0.063	(0)
Cd(HS)3-	2.118e-09	1.832e-09	-8.674	-8.737	-0.063	(0)
Cd(HS)4-2	1.921e-11	1.076e-11	-10.717	-10.968	-0.252	(0)
Cd+2	1.171e-14	6.558e-15	-13.931	-14.183	-0.252	-18.32
CdCl+	1.004e-14	8.687e-15	-13.998	-14.061	-0.063	6.62
CdHCO3+	6.364e-16	5.506e-16	-15.196	-15.259	-0.063	(0)

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CdCl2	5.002e-16	5.027e-16	-15.301	-15.299	0.002	23.14
CdOHCl	1.782e-17	1.791e-17	-16.749	-16.747	0.002	(0)
CdCl3-	5.214e-18	4.511e-18	-17.283	-17.346	-0.063	67.95
CdOH+	3.522e-18	3.046e-18	-17.453	-17.516	-0.063	(0)
CdCO3	3.212e-18	3.229e-18	-17.493	-17.491	0.002	(0)
CdSO4	8.269e-19	8.311e-19	-18.083	-18.080	0.002	77.03
Cd(CO3)2-2	1.130e-20	6.329e-21	-19.947	-20.199	-0.252	(0)
Cd(OH)2	6.634e-22	6.668e-22	-21.178	-21.176	0.002	(0)
Cd(SO4)2-2	6.966e-24	3.902e-24	-23.157	-23.409	-0.252	-104.03
Cd(OH)3-	4.126e-28	3.569e-28	-27.385	-27.447	-0.063	(0)
Cd2OH+3	3.511e-31	9.530e-32	-30.455	-31.021	-0.566	(0)
Cd(OH)4-2	2.709e-35	1.518e-35	-34.567	-34.819	-0.252	(0)
CdNO3+	0.000e+00	0.000e+00	-95.857	-95.920	-0.063	17.55
Cl	1.597e-02					
Cl-	1.597e-02	1.377e-02	-1.797	-1.861	-0.064	18.24
MnCl+	5.311e-07	4.613e-07	-6.275	-6.336	-0.061	-2.51
FeCl+	2.991e-07	2.588e-07	-6.524	-6.587	-0.063	(0)
MnCl2	2.759e-09	2.773e-09	-8.559	-8.557	0.002	83.34
CuCl2-	1.921e-10	1.659e-10	-9.716	-9.780	-0.064	(0)
MnCl3-	1.211e-11	1.052e-11	-10.917	-10.978	-0.061	43.43
CuCl3-2	6.416e-12	3.651e-12	-11.193	-11.438	-0.245	(0)
ZnCl+	2.924e-13	2.525e-13	-12.534	-12.598	-0.064	-11.85
ZnOHCl	1.342e-14	1.349e-14	-13.872	-13.870	0.002	(0)
PbCl+	1.140e-14	9.865e-15	-13.943	-14.006	-0.063	8.11
CdCl+	1.004e-14	8.687e-15	-13.998	-14.061	-0.063	6.62
ZnCl2	3.654e-15	3.672e-15	-14.437	-14.435	0.002	97.97
CdCl2	5.002e-16	5.027e-16	-15.301	-15.299	0.002	23.14
PbCl2	2.059e-16	2.070e-16	-15.686	-15.684	0.002	35.14
ZnCl3-	6.657e-17	5.748e-17	-16.177	-16.240	-0.064	17.12
CdOHCl	1.782e-17	1.791e-17	-16.749	-16.747	0.002	(0)
CdCl3-	5.214e-18	4.511e-18	-17.283	-17.346	-0.063	67.95
PbCl3-	2.652e-18	2.294e-18	-17.576	-17.639	-0.063	66.31
ZnCl4-2	7.092e-19	4.035e-19	-18.149	-18.394	-0.245	145.95
CuCl+	6.367e-20	5.498e-20	-19.196	-19.260	-0.064	0.21
PbCl4-2	2.745e-20	1.537e-20	-19.562	-19.813	-0.252	102.12
CuCl2	4.140e-22	4.161e-22	-21.383	-21.381	0.002	33.42
FeCl+2	2.940e-22	1.673e-22	-21.532	-21.777	-0.245	(0)
FeCl2+	1.108e-23	9.620e-24	-22.956	-23.017	-0.061	(0)
CuCl3-	2.446e-26	2.112e-26	-25.612	-25.675	-0.064	(0)
FeCl3	1.318e-26	1.325e-26	-25.880	-25.878	0.002	(0)
CuCl4-2	2.691e-30	1.531e-30	-29.570	-29.815	-0.245	(0)
Cu(1)	2.018e-10					
CuCl2-	1.921e-10	1.659e-10	-9.716	-9.780	-0.064	(0)
CuCl3-2	6.416e-12	3.651e-12	-11.193	-11.438	-0.245	(0)
Cu+	3.250e-12	2.779e-12	-11.488	-11.556	-0.068	(0)
Cu(2)	6.686e-06					
Cu(HS)3-	6.686e-06	5.784e-06	-5.175	-5.238	-0.063	(0)
CuCO3	4.427e-18	4.449e-18	-17.354	-17.352	0.002	(0)
Cu+2	2.300e-18	1.337e-18	-17.638	-17.874	-0.236	-26.30
CuHCO3+	2.056e-18	1.779e-18	-17.687	-17.750	-0.063	(0)
Cu(OH)2	6.324e-19	6.356e-19	-18.199	-18.197	0.002	(0)
CuOH+	7.385e-20	6.377e-20	-19.132	-19.195	-0.064	(0)
CuCl+	6.367e-20	5.498e-20	-19.196	-19.260	-0.064	0.21
Cu(CO3)2-2	6.199e-21	3.472e-21	-20.208	-20.459	-0.252	(0)
CuCl2	4.140e-22	4.161e-22	-21.383	-21.381	0.002	33.42
CuSO4	1.195e-22	1.201e-22	-21.923	-21.920	0.002	13.35
Cu(OH)3-	2.112e-25	1.827e-25	-24.675	-24.738	-0.063	(0)
CuCl3-	2.446e-26	2.112e-26	-25.612	-25.675	-0.064	(0)
CuCl4-2	2.691e-30	1.531e-30	-29.570	-29.815	-0.245	(0)
Cu(OH)4-2	3.105e-31	1.739e-31	-30.508	-30.760	-0.252	(0)
Cu2(OH)2+2	3.923e-33	2.197e-33	-32.406	-32.658	-0.252	(0)
Fe(2)	4.555e-05					
Fe+2	2.341e-05	1.361e-05	-4.631	-4.866	-0.236	-21.67
Fe(HS)2	1.734e-05	1.743e-05	-4.761	-4.759	0.002	(0)
FeHCO3+	4.177e-06	3.613e-06	-5.379	-5.442	-0.063	(0)
FeCl+	2.991e-07	2.588e-07	-6.524	-6.587	-0.063	(0)
FeCO3	2.013e-07	2.024e-07	-6.696	-6.694	0.002	(0)
Fe(HS)3-	8.317e-08	7.195e-08	-7.080	-7.143	-0.063	(0)
FeOH+	2.771e-08	2.407e-08	-7.557	-7.619	-0.061	(0)
FeSO4	1.086e-09	1.091e-09	-8.964	-8.962	0.002	16.80
Fe(OH)2	1.170e-12	1.176e-12	-11.932	-11.930	0.002	(0)
FeHSO4+	1.751e-15	1.515e-15	-14.757	-14.820	-0.063	(0)
Fe(OH)3-	2.450e-16	2.128e-16	-15.611	-15.672	-0.061	(0)
Fe(3)	4.100e-14					
Fe(OH)2+	2.582e-14	2.247e-14	-13.588	-13.648	-0.060	(0)

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Fe(OH)3	1.507e-14	1.515e-14	-13.822	-13.820	0.002	(0)
Fe(OH)4-	8.249e-17	7.180e-17	-16.084	-16.144	-0.060	(0)
FeOH+2	2.306e-17	1.312e-17	-16.637	-16.882	-0.245	(0)
Fe+3	1.125e-21	3.759e-22	-20.949	-21.425	-0.476	(0)
FeCl+2	2.940e-22	1.673e-22	-21.532	-21.777	-0.245	(0)
FeCl2+	1.108e-23	9.620e-24	-22.956	-23.017	-0.061	(0)
FeSO4+	2.158e-24	1.874e-24	-23.666	-23.727	-0.061	(0)
FeCl3	1.318e-26	1.325e-26	-25.880	-25.878	0.002	(0)
Fe(SO4)2-	2.073e-29	1.793e-29	-28.683	-28.746	-0.063	(0)
FeHSO4+2	1.877e-30	1.051e-30	-29.727	-29.978	-0.252	(0)
Fe2(OH)2+4	4.314e-32	4.246e-33	-31.365	-32.372	-1.007	(0)
Fe3(OH)4+5	0.000e+00	0.000e+00	-42.212	-43.786	-1.573	(0)
H(0)	9.130e-10					
H2	4.565e-10	4.589e-10	-9.341	-9.338	0.002	28.60
K	3.473e-04					
K+	3.473e-04	2.992e-04	-3.459	-3.524	-0.065	9.18
KSO4-	1.087e-09	9.463e-10	-8.964	-9.024	-0.060	34.27
Mg	9.348e-04					
Mg+2	9.151e-04	5.318e-04	-3.039	-3.274	-0.236	-21.56
MgHCO3+	1.932e-05	1.669e-05	-4.714	-4.778	-0.064	5.62
MgCO3	3.234e-07	3.250e-07	-6.490	-6.488	0.002	-17.09
MgSO4	5.682e-08	5.711e-08	-7.245	-7.243	0.002	5.91
MgOH+	1.275e-08	1.116e-08	-7.895	-7.952	-0.058	(0)
Mn(2)	1.732e-05					
Mn+2	1.414e-05	8.221e-06	-4.849	-5.085	-0.236	-19.30
MnHCO3+	2.240e-06	1.945e-06	-5.650	-5.711	-0.061	(0)
MnCl+	5.311e-07	4.613e-07	-6.275	-6.336	-0.061	-2.51
MnCO3	4.027e-07	4.048e-07	-6.395	-6.393	0.002	(0)
MnCl2	2.759e-09	2.773e-09	-8.559	-8.557	0.002	83.34
MnOH+	1.380e-09	1.199e-09	-8.860	-8.921	-0.061	(0)
MnSO4	6.570e-10	6.603e-10	-9.182	-9.180	0.002	21.63
MnCl3-	1.211e-11	1.052e-11	-10.917	-10.978	-0.061	43.43
Mn(OH)3-	1.629e-20	1.415e-20	-19.788	-19.849	-0.061	(0)
Mn(NO3)2	0.000e+00	0.000e+00	-168.708	-168.706	0.002	40.49
Mn(3)	2.670e-34					
Mn+3	2.670e-34	8.921e-35	-33.573	-34.050	-0.476	(0)
N(-3)	9.687e-03					
NH4+	9.661e-03	8.263e-03	-2.015	-2.083	-0.068	18.12
NH3	2.598e-05	2.612e-05	-4.585	-4.583	0.002	24.50
NH4SO4-	5.337e-08	4.617e-08	-7.273	-7.336	-0.063	38.39
N(0)	1.897e-03					
N2	9.483e-04	9.532e-04	-3.023	-3.021	0.002	29.29
N(3)	0.000e+00					
NO2-	0.000e+00	0.000e+00	-59.880	-59.947	-0.066	25.18
N(5)	0.000e+00					
NO3-	0.000e+00	0.000e+00	-82.043	-82.109	-0.066	29.80
PbNO3+	0.000e+00	0.000e+00	-94.644	-94.707	-0.063	(0)
CdNO3+	0.000e+00	0.000e+00	-95.857	-95.920	-0.063	17.55
Mn(NO3)2	0.000e+00	0.000e+00	-168.708	-168.706	0.002	40.49
Na	3.935e-04					
Na+	3.930e-04	3.409e-04	-3.406	-3.467	-0.062	-1.20
NaHCO3	5.003e-07	5.029e-07	-6.301	-6.299	0.002	1.80
NaCO3-	5.063e-09	4.380e-09	-8.296	-8.359	-0.063	-0.64
NaSO4-	8.630e-10	7.511e-10	-9.064	-9.124	-0.060	14.70
NaOH	1.925e-21	1.935e-21	-20.716	-20.713	0.002	(0)
O(0)	0.000e+00					
O2	0.000e+00	0.000e+00	-73.020	-73.018	0.002	30.56
Pb	4.548e-08					
Pb(HS)2	4.544e-08	4.567e-08	-7.343	-7.340	0.002	(0)
Pb(HS)3-	3.993e-11	3.454e-11	-10.399	-10.462	-0.063	(0)
PbCO3	1.829e-13	1.838e-13	-12.738	-12.736	0.002	(0)
PbHCO3+	4.160e-14	3.599e-14	-13.381	-13.444	-0.063	(0)
Pb+2	3.047e-14	1.707e-14	-13.516	-13.768	-0.252	-15.22
PbCl+	1.140e-14	9.865e-15	-13.943	-14.006	-0.063	8.11
PbOH+	1.835e-15	1.588e-15	-14.736	-14.799	-0.063	(0)
Pb(CO3)2-2	5.110e-16	2.862e-16	-15.292	-15.543	-0.252	(0)
PbCl2	2.059e-16	2.070e-16	-15.686	-15.684	0.002	35.14
PbSO4	4.142e-18	4.163e-18	-17.383	-17.381	0.002	(0)
Pb(OH)2	2.932e-18	2.947e-18	-17.533	-17.531	0.002	(0)
PbCl3-	2.652e-18	2.294e-18	-17.576	-17.639	-0.063	66.31
PbCl4-2	2.745e-20	1.537e-20	-19.562	-19.813	-0.252	102.12
Pb(OH)3-	1.866e-22	1.614e-22	-21.729	-21.792	-0.063	(0)
Pb(SO4)2-2	1.692e-23	9.476e-24	-22.772	-23.023	-0.252	(0)
Pb(OH)4-2	3.150e-27	1.764e-27	-26.502	-26.753	-0.252	(0)
Pb2OH+3	2.235e-27	6.066e-28	-26.651	-27.217	-0.566	(0)

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Pb3(OH)4+2	8.337e-39	4.670e-39	-38.079	-38.331	-0.252	(0)
PbNO3+	0.000e+00	0.000e+00	-94.644	-94.707	-0.063	(0)
S(-2)	1.801e-04					
H2S	6.487e-05	6.520e-05	-4.188	-4.186	0.002	37.17
HS-	4.404e-05	3.791e-05	-4.356	-4.421	-0.065	20.81
Fe(HS)2	1.734e-05	1.743e-05	-4.761	-4.759	0.002	(0)
Zn(HS)2	7.722e-06	7.761e-06	-5.112	-5.110	0.002	(0)
Cu(HS)3-	6.686e-06	5.784e-06	-5.175	-5.238	-0.063	(0)
Cd(HS)2	3.177e-07	3.193e-07	-6.498	-6.496	0.002	(0)
Fe(HS)3-	8.317e-08	7.195e-08	-7.080	-7.143	-0.063	(0)
Pb(HS)2	4.544e-08	4.567e-08	-7.343	-7.340	0.002	(0)
Zn(HS)3-	4.916e-09	4.253e-09	-8.308	-8.371	-0.063	(0)
CdHS+	4.250e-09	3.677e-09	-8.372	-8.434	-0.063	(0)
Cd(HS)3-	2.118e-09	1.832e-09	-8.674	-8.737	-0.063	(0)
S-2	4.443e-11	2.528e-11	-10.352	-10.597	-0.245	(0)
Pb(HS)3-	3.993e-11	3.454e-11	-10.399	-10.462	-0.063	(0)
Cd(HS)4-2	1.921e-11	1.076e-11	-10.717	-10.968	-0.252	(0)
S(6)	1.000e-06					
SO4-2	7.639e-07	4.337e-07	-6.117	-6.363	-0.246	15.22
CaSO4	1.224e-07	1.230e-07	-6.912	-6.910	0.002	7.58
MgSO4	5.682e-08	5.711e-08	-7.245	-7.243	0.002	5.91
NH4SO4-	5.337e-08	4.617e-08	-7.273	-7.336	-0.063	38.39
KSO4-	1.087e-09	9.463e-10	-8.964	-9.024	-0.060	34.27
FeSO4	1.086e-09	1.091e-09	-8.964	-8.962	0.002	16.80
NaSO4-	8.630e-10	7.511e-10	-9.064	-9.124	-0.060	14.70
MnSO4	6.570e-10	6.603e-10	-9.182	-9.180	0.002	21.63
HSO4-	1.070e-11	9.260e-12	-10.970	-11.033	-0.063	40.52
CaHSO4+	2.020e-13	1.748e-13	-12.695	-12.757	-0.063	(0)
FeHSO4+	1.751e-15	1.515e-15	-14.757	-14.820	-0.063	(0)
ZnSO4	6.377e-16	6.409e-16	-15.195	-15.193	0.002	21.38
PbSO4	4.142e-18	4.163e-18	-17.383	-17.381	0.002	(0)
CdSO4	8.269e-19	8.311e-19	-18.083	-18.080	0.002	77.03
Zn(SO4)2-2	3.969e-21	2.223e-21	-20.401	-20.653	-0.252	-10.79
CuSO4	1.195e-22	1.201e-22	-21.923	-21.920	0.002	13.35
Pb(SO4)2-2	1.692e-23	9.476e-24	-22.772	-23.023	-0.252	(0)
Cd(SO4)2-2	6.966e-24	3.902e-24	-23.157	-23.409	-0.252	-104.03
FeSO4+	2.158e-24	1.874e-24	-23.666	-23.727	-0.061	(0)
Fe(SO4)2-	2.073e-29	1.793e-29	-28.683	-28.746	-0.063	(0)
FeHSO4+2	1.877e-30	1.051e-30	-29.727	-29.978	-0.252	(0)
Zn	7.727e-06					
Zn(HS)2	7.722e-06	7.761e-06	-5.112	-5.110	0.002	(0)
Zn(HS)3-	4.916e-09	4.253e-09	-8.308	-8.371	-0.063	(0)
Zn+2	1.090e-11	6.201e-12	-10.963	-11.208	-0.245	-25.16
ZnHCO3+	2.396e-12	2.073e-12	-11.621	-11.683	-0.063	(0)
ZnCO3	7.630e-13	7.669e-13	-12.117	-12.115	0.002	(0)
ZnCl+	2.924e-13	2.525e-13	-12.534	-12.598	-0.064	-11.85
ZnOH+	4.406e-14	3.811e-14	-13.356	-13.419	-0.063	(0)
Zn(CO3)2-2	1.814e-14	1.016e-14	-13.741	-13.993	-0.252	(0)
ZnOHCl	1.342e-14	1.349e-14	-13.872	-13.870	0.002	(0)
ZnCl2	3.654e-15	3.672e-15	-14.437	-14.435	0.002	97.97
Zn(OH)2	1.768e-15	1.777e-15	-14.753	-14.750	0.002	(0)
ZnSO4	6.377e-16	6.409e-16	-15.195	-15.193	0.002	21.38
ZnCl3-	6.657e-17	5.748e-17	-16.177	-16.240	-0.064	17.12
ZnCl4-2	7.092e-19	4.035e-19	-18.149	-18.394	-0.245	145.95
Zn(OH)3-	3.099e-20	2.681e-20	-19.509	-19.572	-0.063	(0)
Zn(SO4)2-2	3.969e-21	2.223e-21	-20.401	-20.653	-0.252	-10.79
Zn(OH)4-2	3.619e-26	2.027e-26	-25.441	-25.693	-0.252	(0)

----- Saturation indices -----

Phase	SI**	log IAP	log K(300 K, 1 atm)	
Anglesite	-12.35	-20.13	-7.78	PbSO4
Anhydrite	-4.87	-9.17	-4.30	CaSO4
Aragonite	-0.66	-9.01	-8.35	CaCO3
Calcite	-0.52	-9.01	-8.49	CaCO3
Cd(OH)2	-14.48	-0.83	13.65	Cd(OH)2
CdSO4	-20.37	-20.55	-0.18	CdSO4
Cerussite	-6.87	-19.98	-13.10	PbCO3
CH4(g)	-0.71	-3.53	-2.82	CH4
CO2(g)	-1.42	-2.91	-1.49	CO2
Dolomite	-1.35	-18.49	-17.14	CaMg(CO3)2
Fe(OH)3(a)	-6.28	-1.39	4.89	Fe(OH)3
FeS(pppt)	1.31	-2.61	-3.92	FeS
Goethite	-0.31	-1.39	-1.08	FeOOH

APPENDIX 10 CONT.

Gypsum	-4.59	-9.17	-4.58	CaSO4:2H2O
H2(g)	-6.23	-9.34	-3.11	H2
H2O(g)	-1.45	-0.00	1.45	H2O
H2S(g)	-3.11	-11.10	-7.99	H2S
Halite	-6.90	-5.33	1.57	NaCl
Hausmannite	-29.51	31.00	60.50	Mn3O4
Hematite	1.39	-2.78	-4.17	Fe2O3
Jarosite-K	-31.08	-40.45	-9.37	KFe3(SO4)2(OH)6
Mackinawite	2.04	-2.61	-4.65	FeS
Manganite	-13.98	11.36	25.34	MnOOH
Melanterite	-9.05	-11.23	-2.18	FeSO4:7H2O
N2(g)	0.17	-3.02	-3.19	N2
NH3(g)	-6.34	-4.58	1.75	NH3
O2(g)	-70.11	-73.02	-2.91	O2
Otavite	-8.29	-20.39	-12.10	CdCO3
Pb(OH)2	-8.49	-0.41	8.08	Pb(OH)2
Pyrite	10.89	-7.53	-18.42	FeS2
Pyrochroite	-6.93	8.27	15.20	Mn(OH)2
Pyrolusite	-26.59	14.45	41.04	MnO2:H2O
Rhodochrosite	-0.16	-11.29	-11.14	MnCO3
Siderite	-0.17	-11.07	-10.90	FeCO3
Smithsonite	-7.39	-17.42	-10.02	ZnCO3
Sphalerite	2.62	-8.95	-11.57	ZnS
Sulfur	-2.84	1.99	4.83	S
Sylvite	-6.30	-5.39	0.91	KCl
Zn(OH)2(e)	-9.35	2.15	11.50	Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

End of simulation.

Reading input data for simulation 2.

END

End of simulation.

Reading input data for simulation 3.

End of Run after 0.671 Seconds.

APPENDIX 11
SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

Input file: C:\Users\BLESSING OCHELEBE\Documents\INVERSE19-20.pqi
 Output file: C:\Users\BLESSING OCHELEBE\Documents\INVERSE19-20.pqo
 Database file: C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.12-12704\database\phreeqc.dat

 Reading data base.

SOLUTION_MASTER_SPECIES
 SOLUTION_SPECIES
 PHASES
 EXCHANGE_MASTER_SPECIES
 EXCHANGE_SPECIES
 SURFACE_MASTER_SPECIES
 SURFACE_SPECIES
 RATES
 END

 Reading input data for simulation 1.

DATABASE C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.12-12704\database\phreeqc.dat

SOLUTION 1 19BH
 temp 25
 pH 7
 pe 4
 redox pe
 units mg/l
 density 1
 Cl 40.75
 C(4) 45.6
 N(5) 0.55
 S(6) 1.88
 P 0.05
 N(3) 0.08
 N(-3) 6.1
 Ca 16.32
 Mg 3.25
 K 2
 Na 2.6
 water 1 # kg

END

 Beginning of initial solution calculations.

Initial solution 1. 19BH

-----Solution composition-----

Elements	Molality	Moles
C(4)	7.474e-04	7.474e-04
Ca	4.072e-04	4.072e-04
Cl	1.150e-03	1.150e-03
K	5.115e-05	5.115e-05
Mg	1.337e-04	1.337e-04
N(-3)	4.356e-04	4.356e-04
N(3)	5.712e-06	5.712e-06
N(5)	3.927e-05	3.927e-05
Na	1.131e-04	1.131e-04
P	1.614e-06	1.614e-06
S(6)	1.957e-05	1.957e-05

-----Description of solution-----

pH = 7.000
 pe = 4.000
 Specific Conductance ($\mu\text{S}/\text{cm}$, 25°C) = 214
 Density (g/cm^3) = 0.99712
 Volume (L) = 1.00301

APPENDIX 11 Cont.
SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

Activity of water = 1.000
 Ionic strength (mol/kgw) = 2.315e-03
 Mass of water (kg) = 1.000e+00
 Total alkalinity (eq/kg) = 6.203e-04
 Total CO2 (mol/kg) = 7.474e-04
 Temperature (°C) = 25.00
 Electrical balance (eq) = -1.739e-04
 Percent error, $100 \cdot (\text{Cat} - |\text{An}|) / (\text{Cat} + |\text{An}|)$ = -4.94
 Iterations = 9
 Total H = 1.110148e+02
 Total O = 5.550854e+01

-----Redox couples-----

Redox couple	pe	Eh (volts)
N(-3)/N(3)	5.4379	0.3217
N(-3)/N(5)	6.0043	0.3552
N(3)/N(5)	7.7036	0.4557

-----Distribution of species-----

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm ³ /mol
OH-	1.068e-07	1.012e-07	-6.972	-6.995	-0.023	-4.09
H+	1.051e-07	1.000e-07	-6.979	-7.000	-0.021	0.00
H2O	5.551e+01	9.999e-01	1.744	-0.000	0.000	18.07
C(4)	7.474e-04					
HCO3-	6.128e-04	5.817e-04	-3.213	-3.235	-0.023	24.70
CO2	1.307e-04	1.308e-04	-3.884	-3.883	0.000	34.43
CaHCO3+	2.560e-06	2.431e-06	-5.592	-5.614	-0.022	9.69
MgHCO3+	7.732e-07	7.332e-07	-6.112	-6.135	-0.023	5.49
CO3-2	3.360e-07	2.728e-07	-6.474	-6.564	-0.090	-5.21
CaCO3	1.500e-07	1.501e-07	-6.824	-6.824	0.000	-14.60
NaHCO3	3.507e-08	3.509e-08	-7.455	-7.455	0.000	1.80
MgCO3	2.803e-08	2.804e-08	-7.552	-7.552	0.000	-17.09
NaCO3-	5.746e-10	5.449e-10	-9.241	-9.264	-0.023	-1.01
(CO2)2	3.138e-10	3.140e-10	-9.503	-9.503	0.000	68.87
Ca	4.072e-04					
Ca+2	4.036e-04	3.276e-04	-3.394	-3.485	-0.091	-18.09
CaHCO3+	2.560e-06	2.431e-06	-5.592	-5.614	-0.022	9.69
CaSO4	8.612e-07	8.616e-07	-6.065	-6.065	0.000	7.50
CaCO3	1.500e-07	1.501e-07	-6.824	-6.824	0.000	-14.60
CaHPO4	9.011e-08	9.016e-08	-7.045	-7.045	0.000	(0)
CaH2PO4+	7.139e-09	6.777e-09	-8.146	-8.169	-0.023	(0)
CaPO4-	2.247e-09	2.133e-09	-8.648	-8.671	-0.023	(0)
CaOH+	5.733e-10	5.436e-10	-9.242	-9.265	-0.023	(0)
CaHSO4+	5.973e-13	5.664e-13	-12.224	-12.247	-0.023	(0)
Cl	1.150e-03					
Cl-	1.150e-03	1.090e-03	-2.939	-2.963	-0.023	18.09
H(0)	1.415e-25					
H2	7.076e-26	7.079e-26	-25.150	-25.150	0.000	28.61
K	5.115e-05					
K+	5.115e-05	4.849e-05	-4.291	-4.314	-0.023	9.02
KSO4-	5.308e-09	5.039e-09	-8.275	-8.298	-0.023	34.12
KHPO4-	5.000e-11	4.746e-11	-10.301	-10.324	-0.023	38.13
Mg	1.337e-04					
Mg+2	1.325e-04	1.077e-04	-3.878	-3.968	-0.090	-21.77
MgHCO3+	7.732e-07	7.332e-07	-6.112	-6.135	-0.023	5.49
MgSO4	3.733e-07	3.735e-07	-6.428	-6.428	0.000	5.84
MgHPO4	4.006e-08	4.009e-08	-7.397	-7.397	0.000	(0)
MgCO3	2.803e-08	2.804e-08	-7.552	-7.552	0.000	-17.09
MgOH+	4.116e-09	3.911e-09	-8.385	-8.408	-0.022	(0)
MgH2PO4+	2.989e-09	2.838e-09	-8.524	-8.547	-0.023	(0)
MgPO4-	9.968e-10	9.462e-10	-9.001	-9.024	-0.023	(0)
N(-3)	4.356e-04					
NH4+	4.331e-04	4.102e-04	-3.363	-3.387	-0.024	17.98
NH3	2.337e-06	2.338e-06	-5.631	-5.631	0.000	24.42
NH4SO4-	8.243e-08	7.817e-08	-7.084	-7.107	-0.023	37.63
N(3)	5.712e-06					
NO2-	5.712e-06	5.412e-06	-5.243	-5.267	-0.023	24.98
N(5)	3.927e-05					

APPENDIX 11 Cont.
SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

NO3-	3.927e-05	3.721e-05	-4.406	-4.429	-0.023	29.50
Na	1.131e-04					
Na+	1.131e-04	1.073e-04	-3.947	-3.970	-0.023	-1.45
NaHCO3	3.507e-08	3.509e-08	-7.455	-7.455	0.000	1.80
NaSO4-	8.377e-09	7.952e-09	-8.077	-8.100	-0.023	13.87
NaCO3-	5.746e-10	5.449e-10	-9.241	-9.264	-0.023	-1.01
NaHPO4-	1.106e-10	1.050e-10	-9.956	-9.979	-0.023	33.60
NaOH	1.085e-21	1.086e-21	-20.965	-20.964	0.000	(0)
O(0)	0.000e+00					
O2	0.000e+00	0.000e+00	-42.080	-42.080	0.000	30.40
P	1.614e-06					
H2PO4-	8.518e-07	8.085e-07	-6.070	-6.092	-0.023	33.22
HPO4-2	6.190e-07	5.020e-07	-6.208	-6.299	-0.091	6.77
CaHPO4	9.011e-08	9.016e-08	-7.045	-7.045	0.000	(0)
MgHPO4	4.006e-08	4.009e-08	-7.397	-7.397	0.000	(0)
CaH2PO4+	7.139e-09	6.777e-09	-8.146	-8.169	-0.023	(0)
MgH2PO4+	2.989e-09	2.838e-09	-8.524	-8.547	-0.023	(0)
CaPO4-	2.247e-09	2.133e-09	-8.648	-8.671	-0.023	(0)
MgPO4-	9.968e-10	9.462e-10	-9.001	-9.024	-0.023	(0)
NaHPO4-	1.106e-10	1.050e-10	-9.956	-9.979	-0.023	33.60
KHPO4-	5.000e-11	4.746e-11	-10.301	-10.324	-0.023	38.13
H3PO4	1.190e-11	1.190e-11	-10.925	-10.924	0.000	47.41
PO4-3	3.651e-12	2.263e-12	-11.438	-11.645	-0.208	-23.10
S(6)	1.957e-05					
SO4-2	1.824e-05	1.479e-05	-4.739	-4.830	-0.091	14.57
CaSO4	8.612e-07	8.616e-07	-6.065	-6.065	0.000	7.50
MgSO4	3.733e-07	3.735e-07	-6.428	-6.428	0.000	5.84
NH4SO4-	8.243e-08	7.817e-08	-7.084	-7.107	-0.023	37.63
NaSO4-	8.377e-09	7.952e-09	-8.077	-8.100	-0.023	13.87
KSO4-	5.308e-09	5.039e-09	-8.275	-8.298	-0.023	34.12
HSO4-	1.516e-10	1.438e-10	-9.819	-9.842	-0.023	40.29
CaHSO4+	5.973e-13	5.664e-13	-12.224	-12.247	-0.023	(0)

-----Saturation indices-----

Phase	SI**	log IAP	log K(298 K, 1 atm)	
Anhydrite	-4.04	-8.31	-4.28	CaSO4
Aragonite	-1.71	-10.05	-8.34	CaCO3
Calcite	-1.57	-10.05	-8.48	CaCO3
CO2(g)	-2.42	-3.88	-1.47	CO2
Dolomite	-3.49	-20.58	-17.09	CaMg(CO3)2
Gypsum	-3.73	-8.31	-4.58	CaSO4·2H2O
H2(g)	-22.05	-25.15	-3.10	H2
H2O(g)	-1.50	-0.00	1.50	H2O
Halite	-8.50	-6.93	1.57	NaCl
Hydroxyapatite	-4.90	-8.32	-3.42	Ca5(PO4)3OH
NH3(g)	-7.43	-5.63	1.80	NH3
O2(g)	-39.19	-42.08	-2.89	O2
Sylvite	-8.18	-7.28	0.90	KCl

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

End of simulation.

Reading input data for simulation 2.

SOLUTION 2 20BH
temp 25
pH 7
pe 4
redox pe
units mg/l
density 1
Cl 36.87
C(4) 24
N(5) 0.62
S(6) 1.5

APPENDIX II Cont.
 - SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

```
P          0.05
N(3)       0.04
N(-3)      6.4
Ca         32.2
Mg         6.4
K          1
Na         3
water     1 # kg
```

END

 Beginning of initial solution calculations.

Initial solution 2. 20BH

-----Solution composition-----

Elements	Molality	Moles
C(4)	3.934e-04	3.934e-04
Ca	8.035e-04	8.035e-04
Cl	1.040e-03	1.040e-03
K	2.558e-05	2.558e-05
Mg	2.633e-04	2.633e-04
N(-3)	4.570e-04	4.570e-04
N(3)	2.856e-06	2.856e-06
N(5)	4.427e-05	4.427e-05
Na	1.305e-04	1.305e-04
P	1.614e-06	1.614e-06
S(6)	1.562e-05	1.562e-05

-----Description of solution-----

```
pH = 7.000
pe = 4.000
Specific Conductance (µS/cm, 25°C) = 247
Density (g/cm³) = 0.99714
Volume (L) = 1.00298
Activity of water = 1.000
Ionic strength (mol/kgw) = 3.164e-03
Mass of water (kg) = 1.000e+00
Total alkalinity (eq/kg) = 3.289e-04
Total CO2 (mol/kg) = 3.934e-04
Temperature (°C) = 25.00
Electrical balance (eq) = 1.298e-03
Percent error, 100*(Cat-|An|)/(Cat+|An|) = 31.08
Iterations = 9
Total H = 1.110146e+02
Total O = 5.550754e+01
```

-----Redox couples-----

Redox couple	pe	Eh (volts)
N(-3)/N(3)	5.3843	0.3185
N(-3)/N(5)	6.0082	0.3554
N(3)/N(5)	7.8802	0.4662

-----Distribution of species-----

Species	Molality	Activity	Log		Log Gamma	mole V cm³/mol
			Molality	Activity		
OH-	1.077e-07	1.012e-07	-6.968	-6.995	-0.027	-4.08
H+	1.058e-07	1.000e-07	-6.975	-7.000	-0.025	0.00
H2O	5.551e+01	9.999e-01	1.744	-0.000	0.000	18.07
C(4)	3.934e-04					
HCO3-	3.216e-04	3.028e-04	-3.493	-3.519	-0.026	24.71
CO2	6.804e-05	6.809e-05	-4.167	-4.167	0.000	34.43
CaHCO3+	2.577e-06	2.428e-06	-5.589	-5.615	-0.026	9.69
MgHCO3+	7.775e-07	7.311e-07	-6.109	-6.136	-0.027	5.50
CO3-2	1.806e-07	1.420e-07	-6.743	-6.848	-0.104	-5.18
CaCO3	1.498e-07	1.499e-07	-6.824	-6.824	0.000	-14.60

APPENDIX 11 Cont.
SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

MgCO3	2.794e-08	2.796e-08	-7.554	-7.553	0.000	-17.09
NaHCO3	2.089e-08	2.091e-08	-7.680	-7.680	0.000	1.80
NaCO3-	3.453e-10	3.247e-10	-9.462	-9.489	-0.027	-1.00
(CO2)2	8.504e-11	8.511e-11	-10.070	-10.070	0.000	68.87
Ca	8.035e-04					
Ca+2	7.994e-04	6.284e-04	-3.097	-3.202	-0.105	-18.06
CaHCO3+	2.577e-06	2.428e-06	-5.589	-5.615	-0.026	9.69
CaSO4	1.210e-06	1.211e-06	-5.917	-5.917	0.000	7.50
CaHPO4	1.573e-07	1.574e-07	-6.803	-6.803	0.000	(0)
CaCO3	1.498e-07	1.499e-07	-6.824	-6.824	0.000	-14.60
CaH2PO4+	1.257e-08	1.183e-08	-7.901	-7.927	-0.026	(0)
CaPO4-	3.956e-09	3.725e-09	-8.403	-8.429	-0.026	(0)
CaOH+	1.109e-09	1.043e-09	-8.955	-8.982	-0.027	(0)
CaHSO4+	8.466e-13	7.962e-13	-12.072	-12.099	-0.027	(0)
Cl	1.040e-03					
Cl-	1.040e-03	9.778e-04	-2.983	-3.010	-0.027	18.10
H(0)	1.415e-25					
H2	7.074e-26	7.079e-26	-25.150	-25.150	0.000	28.61
K	2.558e-05					
K+	2.558e-05	2.404e-05	-4.592	-4.619	-0.027	9.03
KSO4-	1.944e-09	1.831e-09	-8.711	-8.737	-0.026	34.13
KHPO4-	2.275e-11	2.142e-11	-10.643	-10.669	-0.026	38.14
Mg	2.633e-04					
Mg+2	2.619e-04	2.063e-04	-3.582	-3.685	-0.104	-21.74
MgHCO3+	7.775e-07	7.311e-07	-6.109	-6.136	-0.027	5.50
MgSO4	5.239e-07	5.243e-07	-6.281	-6.280	0.000	5.84
MgHPO4	6.984e-08	6.989e-08	-7.156	-7.156	0.000	(0)
MgCO3	2.794e-08	2.796e-08	-7.554	-7.553	0.000	-17.09
MgOH+	7.946e-09	7.491e-09	-8.100	-8.125	-0.026	(0)
MgH2PO4+	5.254e-09	4.948e-09	-8.279	-8.306	-0.026	(0)
MgPO4-	1.752e-09	1.650e-09	-8.756	-8.783	-0.026	(0)
N(-3)	4.570e-04					
NH4+	4.545e-04	4.267e-04	-3.342	-3.370	-0.027	17.98
NH3	2.430e-06	2.432e-06	-5.614	-5.614	0.000	24.42
NH4SO4-	6.336e-08	5.958e-08	-7.198	-7.225	-0.027	37.64
N(3)	2.856e-06					
NO2-	2.856e-06	2.683e-06	-5.544	-5.571	-0.027	24.99
N(5)	4.427e-05					
NO3-	4.427e-05	4.158e-05	-4.354	-4.381	-0.027	29.51
Na	1.305e-04					
Na+	1.305e-04	1.228e-04	-3.884	-3.911	-0.026	-1.44
NaHCO3	2.089e-08	2.091e-08	-7.680	-7.680	0.000	1.80
NaSO4-	7.083e-09	6.670e-09	-8.150	-8.176	-0.026	13.94
NaCO3-	3.453e-10	3.247e-10	-9.462	-9.489	-0.027	-1.00
NaHPO4-	1.162e-10	1.094e-10	-9.935	-9.961	-0.026	33.66
NaOH	1.242e-21	1.243e-21	-20.906	-20.906	0.000	(0)
O(0)	0.000e+00					
O2	0.000e+00	0.000e+00	-42.080	-42.080	0.000	30.40
P	1.614e-06					
H2PO4-	7.816e-07	7.360e-07	-6.107	-6.133	-0.026	33.23
HPO4-2	5.820e-07	4.570e-07	-6.235	-6.340	-0.105	6.80
CaHPO4	1.573e-07	1.574e-07	-6.803	-6.803	0.000	(0)
MgHPO4	6.984e-08	6.989e-08	-7.156	-7.156	0.000	(0)
CaH2PO4+	1.257e-08	1.183e-08	-7.901	-7.927	-0.026	(0)
MgH2PO4+	5.254e-09	4.948e-09	-8.279	-8.306	-0.026	(0)
CaPO4-	3.956e-09	3.725e-09	-8.403	-8.429	-0.026	(0)
MgPO4-	1.752e-09	1.650e-09	-8.756	-8.783	-0.026	(0)
NaHPO4-	1.162e-10	1.094e-10	-9.935	-9.961	-0.026	33.66
KHPO4-	2.275e-11	2.142e-11	-10.643	-10.669	-0.026	38.14
H3PO4	1.083e-11	1.084e-11	-10.965	-10.965	0.000	47.41
PO4-3	3.583e-12	2.060e-12	-11.446	-11.686	-0.240	-23.03
S(6)	1.562e-05					
SO4-2	1.381e-05	1.084e-05	-4.860	-4.965	-0.105	14.61
CaSO4	1.210e-06	1.211e-06	-5.917	-5.917	0.000	7.50
MgSO4	5.239e-07	5.243e-07	-6.281	-6.280	0.000	5.84
NH4SO4-	6.336e-08	5.958e-08	-7.198	-7.225	-0.027	37.64
NaSO4-	7.083e-09	6.670e-09	-8.150	-8.176	-0.026	13.94
KSO4-	1.944e-09	1.831e-09	-8.711	-8.737	-0.026	34.13
HSO4-	1.121e-10	1.054e-10	-9.951	-9.977	-0.027	40.30
CaHSO4+	8.466e-13	7.962e-13	-12.072	-12.099	-0.027	(0)

-----Saturation indices-----

APPENDIX 11 Cont.
SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

Phase	SI**	log IAP	log K(298 K,	1 atm)
Anhydrite	-3.89	-8.17	-4.28	CaSO4
Aragonite	-1.71	-10.05	-8.34	CaCO3
Calcite	-1.57	-10.05	-8.48	CaCO3
CO2(g)	-2.70	-4.17	-1.47	CO2
Dolomite	-3.49	-20.58	-17.09	CaMg(CO3)2
Gypsum	-3.59	-8.17	-4.58	CaSO4:2H2O
H2(g)	-22.05	-25.15	-3.10	H2
H2O(g)	-1.50	-0.00	1.50	H2O
Halite	-8.49	-6.92	1.57	NaCl
Hydroxyapatite	-3.61	-7.03	-3.42	Ca5(PO4)3OH
NH3(g)	-7.41	-5.61	1.80	NH3
O2(g)	-39.19	-42.08	-2.89	O2
Sylvite	-8.53	-7.63	0.90	KCl

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

End of simulation.

Reading input data for simulation 3.

```

INVERSE_MODELING 1 INVERSE19-20
  solutions      1      2
  uncertainty    0.32   0.32
  phases
    Anhydrite
    Aragonite
    Calcite
    CO2(g)
    Dolomite
    Gypsum
    H2(g)
    Halite
    Hydroxyapatite
    NH3(g)
    O2(g)
    Sylvite
  range
  
```

Beginning of inverse modeling 1 calculations.

CL1: Roundoff errors in optimization.
Try using -multiple_precision in INVERSE_MODELING
Error in subroutine range. Kode = 1

Solution 1: 19BH

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00
Alkalinity	6.203e-04	+	-1.985e-04	=	4.218e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	7.474e-04	+	0.000e+00	=	7.474e-04
Ca	4.072e-04	+	1.303e-04	=	5.375e-04
Cl	1.150e-03	+	2.835e-04	=	1.433e-03
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	5.115e-05	+	-1.637e-05	=	3.478e-05
Mg	1.337e-04	+	0.000e+00	=	1.337e-04
N(-3)	4.356e-04	+	1.466e-05	=	4.502e-04
N(0)	0.000e+00	+	0.000e+00	=	0.000e+00
N(3)	5.712e-06	+	0.000e+00	=	5.712e-06
N(5)	3.927e-05	+	0.000e+00	=	3.927e-05
Na	1.131e-04	+	0.000e+00	=	1.131e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
P	1.614e-06	+	0.000e+00	=	1.614e-06
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.957e-05	+	0.000e+00	=	1.957e-05

APPENDIX 11 Cont.
 SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

Solution 2: 20BH

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00
Alkalinity	3.289e-04	+	1.053e-04	=	4.342e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	3.934e-04	+	0.000e+00	=	3.934e-04
Ca	8.035e-04	+	-2.571e-04	=	5.464e-04
Cl	1.040e-03	+	3.328e-04	=	1.373e-03
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	2.558e-05	+	8.185e-06	=	3.376e-05
Mg	2.633e-04	+	-8.425e-05	=	1.790e-04
N(-3)	4.570e-04	+	-1.462e-04	=	3.107e-04
N(0)	0.000e+00	+	0.000e+00	=	0.000e+00
N(3)	2.856e-06	+	0.000e+00	=	2.856e-06
N(5)	4.427e-05	+	0.000e+00	=	4.427e-05
Na	1.305e-04	+	-3.872e-05	=	9.179e-05
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
P	1.614e-06	+	0.000e+00	=	1.614e-06
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.562e-05	+	0.000e+00	=	1.562e-05

Solution fractions:		Minimum	Maximum
Solution 1	9.706e-01	8.692e-01	9.706e-01
Solution 2	1.000e+00	1.000e+00	1.000e+00

Phase mole transfers:		Minimum	Maximum	
Anhydrite	-8.163e-01	-3.631e+00	-8.160e-01	CaSO4
Calcite	-2.133e-05	-8.995e-05	1.380e-04	CaCO3
CO2(g)	-4.092e-04	-8.435e-04	3.059e-06	CO2
Dolomite	4.926e-05	7.741e-06	1.019e-04	CaMg(CO3)2
Gypsum	8.163e-01	8.160e-01	3.631e+00	CaSO4:2H2O
Halite	-1.799e-05	-5.616e-05	5.406e-05	NaCl
Hydroxyapatite	1.583e-08	-3.235e-07	3.923e-07	Ca5(PO4)3OH
NH3(g)	-1.228e-04	-2.713e-04	4.156e-05	NH3
O2(g)	8.274e-06	-4.620e-05	7.104e-05	O2

Redox mole transfers:	
N(-3)	3.465e-06
N(3)	2.688e-06
O(0)	1.655e-05

Sum of residuals (epsilons in documentation): 1.069e+01
 Sum of delta/uncertainty limit: 1.080e+01
 Maximum fractional error in element concentration: 3.200e-01

CL1: Roundoff errors in optimization.
 Try using -multiple_precision in INVERSE_MODELING

CL1: Roundoff errors in optimization.
 Try using -multiple_precision in INVERSE_MODELING

Solution 1: 19BH

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00
Alkalinity	6.203e-04	+	-1.117e-04	=	5.086e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	7.474e-04	+	-2.392e-04	=	5.082e-04
Ca	4.072e-04	+	1.303e-04	=	5.375e-04
Cl	1.150e-03	+	2.650e-04	=	1.415e-03
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	5.115e-05	+	-1.637e-05	=	3.478e-05
Mg	1.337e-04	+	4.278e-05	=	1.765e-04
N(-3)	4.356e-04	+	0.000e+00	=	4.356e-04
N(0)	0.000e+00	+	0.000e+00	=	0.000e+00
N(3)	5.712e-06	+	0.000e+00	=	5.712e-06
N(5)	3.927e-05	+	4.263e-06	=	4.353e-05
Na	1.131e-04	+	-8.236e-06	=	1.049e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
P	1.614e-06	+	4.892e-08	=	1.663e-06

APPENDIX II Cont.
SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

S(-2) 0.000e+00 + 0.000e+00 = 0.000e+00
S(6) 1.957e-05 + -4.941e-06 = 1.463e-05

Solution 2: 20BH

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00
Alkalinity	3.289e-04	+	1.053e-04	=	4.342e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	3.934e-04	+	1.259e-04	=	5.192e-04
Ca	8.035e-04	+	-2.571e-04	=	5.464e-04
Cl	1.040e-03	+	3.328e-04	=	1.373e-03
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	2.558e-05	+	8.185e-06	=	3.376e-05
Mg	2.633e-04	+	-8.425e-05	=	1.790e-04
N(-3)	4.570e-04	+	-1.462e-04	=	3.107e-04
N(0)	0.000e+00	+	0.000e+00	=	0.000e+00
N(3)	2.856e-06	+	0.000e+00	=	2.856e-06
N(5)	4.427e-05	+	0.000e+00	=	4.427e-05
Na	1.305e-04	+	-2.872e-05	=	1.018e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
P	1.614e-06	+	0.000e+00	=	1.614e-06
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.562e-05	+	4.997e-06	=	2.061e-05

Solution fractions:		Minimum	Maximum
Solution 1	9.706e-01	9.639e-01	9.706e-01
Solution 2	1.000e+00	1.000e+00	1.000e+00

Phase mole transfers:		Minimum	Maximum	
Anhydrite	-8.165e-01	-1.001e+00	-8.165e-01	CaSO4
Calcite	1.048e-05	7.914e-06	1.152e-05	CaCO3
Dolomite	7.741e-06	7.741e-06	9.024e-06	CaMg(CO3)2
Gypsum	8.165e-01	8.165e-01	1.001e+00	CaSO4·2H2O
NH3(g)	-1.127e-04	-2.486e-04	-2.454e-05	NH3

Redox mole transfers:
N(-3) -6.720e-07
N(3) 2.688e-06

Sum of residuals (epsilons in documentation): 1.522e+01
Sum of delta/uncertainty limit: 1.542e+01
Maximum fractional error in element concentration: 3.200e-01

Model contains minimum number of phases.

Solution 1: 19BH

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00
Alkalinity	6.203e-04	+	-1.985e-04	=	4.218e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	7.474e-04	+	0.000e+00	=	7.474e-04
Ca	4.072e-04	+	1.303e-04	=	5.375e-04
Cl	1.150e-03	+	1.458e-04	=	1.295e-03
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	5.115e-05	+	0.000e+00	=	5.115e-05
Mg	1.337e-04	+	0.000e+00	=	1.337e-04
N(-3)	4.356e-04	+	-1.394e-04	=	2.962e-04
N(0)	0.000e+00	+	0.000e+00	=	0.000e+00
N(3)	5.712e-06	+	0.000e+00	=	5.712e-06
N(5)	3.927e-05	+	0.000e+00	=	3.927e-05
Na	1.131e-04	+	0.000e+00	=	1.131e-04
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
P	1.614e-06	+	0.000e+00	=	1.614e-06
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.957e-05	+	0.000e+00	=	1.957e-05

Solution 2: 20BH

	Input		Delta		Input+Delta
pH	7.000e+00	+	0.000e+00	=	7.000e+00

APPENDIX 11 Cont.
 SELECTED OUTPUT FOR INVERSE MODELLING CALCULATION

Alkalinity	3.289e-04	+	1.053e-04	=	4.342e-04
C(-4)	0.000e+00	+	0.000e+00	=	0.000e+00
C(4)	3.934e-04	+	0.000e+00	=	3.934e-04
Ca	8.035e-04	+	-2.571e-04	=	5.464e-04
Cl	1.040e-03	+	3.328e-04	=	1.373e-03
H(0)	0.000e+00	+	0.000e+00	=	0.000e+00
K	2.558e-05	+	0.000e+00	=	2.558e-05
Mg	2.633e-04	+	-8.425e-05	=	1.790e-04
N(-3)	4.570e-04	+	-1.297e-04	=	3.272e-04
N(0)	0.000e+00	+	0.000e+00	=	0.000e+00
N(3)	2.856e-06	+	0.000e+00	=	2.856e-06
N(5)	4.427e-05	+	5.254e-06	=	4.952e-05
Na	1.305e-04	+	-4.176e-05	=	8.874e-05
O(0)	0.000e+00	+	0.000e+00	=	0.000e+00
P	1.614e-06	+	0.000e+00	=	1.614e-06
S(-2)	0.000e+00	+	0.000e+00	=	0.000e+00
S(6)	1.562e-05	+	0.000e+00	=	1.562e-05

Solution fractions:		Minimum	Maximum
Solution 1	1.113e+00	9.253e-01	1.279e+00
Solution 2	1.000e+00	1.000e+00	1.000e+00

Phase mole transfers:		Minimum	Maximum	
Anhydrite	3.128e+00	-2.074e+00	7.745e+00	CaSO4
Calcite	-7.555e-05	-2.087e-04	6.537e-05	CaCO3
CO2(g)	-4.232e-04	-9.655e-04	6.187e-05	CO2
Dolomite	3.027e-05	-4.670e-05	8.778e-05	CaMg(CO3)2
Gypsum	-3.128e+00	-7.745e+00	2.074e+00	CaSO4·2H2O
Halite	-3.711e-05	-1.022e-04	6.259e-05	NaCl
Hydroxyapatite	-6.065e-08	-5.404e-07	3.718e-07	Ca5(PO4)3OH
O2(g)	6.403e-06	-4.468e-05	6.772e-05	O2
Sylvite	-3.134e-05	-6.897e-05	1.576e-06	KCl

Redox mole transfers:	
N(-3)	2.326e-06
N(3)	3.500e-06
O(0)	1.281e-05

Sum of residuals (epsilons in documentation):	1.004e+01
Sum of delta/uncertainty limit:	9.655e+00
Maximum fractional error in element concentration:	3.200e-01

=====

APPENDIX 12
RESULTS OF INPUT AND CALCULATED OUTPUT OF LEACHATE TRANSPORT MODEL

Input file: C:\Users\BLESSING OCHELEBE\documents\leachate transport99.pqi
 Output file: C:\Users\BLESSING OCHELEBE\Documents\leachate transport99.pqo
 Database file: C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.12-12704\database\phreeqc.dat

 Reading data base.

SOLUTION_MASTER_SPECIES
 SOLUTION_SPECIES
 PHASES
 EXCHANGE_MASTER_SPECIES
 EXCHANGE_SPECIES
 SURFACE_MASTER_SPECIES
 SURFACE_SPECIES
 RATES
 END

 Reading input data for simulation 1.

DATABASE C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.12-12704\database\phreeqc.dat

SURFACE_MASTER_SPECIES
 Surf SurfOH
 Hfo_w Hfo_wOH
 SURFACE_SPECIES
 SurfOH = SurfOH
 log_k 0.0
 Hfo_wOH = Hfo_wOH
 log_k 0
 SOLUTION 1 leachate
 pH 7.85
 pe 4.0
 temp 25.
 units mg/l
 Ca 1064
 Mg 212.8
 Na 97.6
 Cl 829.5 charge
 C(4) 210
 S(6) 133.9
 Mn 15.23
 Pb 0.413
 Cd 0.4
 N(5) 135.0
 N(-3) 211.5

END

 Reading input data for simulation 2.

USE solution 1
 EQUILIBRIUM_PHASES 1
 Dolomite 0.0 1.6
 Calcite 0.0 0.1
 SAVE solution 1
 SELECTED_OUTPUT
 file ex14.sel
 reset false
 step
 USER_PUNCH
 heading mg/l_Ca mg/l_Mg mg/l_Na mg/l_S(6) mg/l_Mn ug/l_Pb ug/l_Cd
 ug/l_N(5) mg/l_N(-3) pH
 10 PUNCH TOT("Ca"), TOT("Mg"), TOT("Na"), TOT("S(6)"), TOT("Mn"),
 TOT("Pb")*1e3, TOT("Cd")*1e3, TOT("N(5)")*1e3, TOT("N(-3)") -LA("H+")
 END

APPENDIX 12 Cont.
RESULTS OF INPUT AND CALCULATED OUTPUT OF LEACHATE TRANSPORT MODEL

Beginning of batch-reaction calculations.

Reaction step 1.

Using solution 1. leachate
Using pure phase assemblage 1.

-----Phase assemblage-----

Phase	SI	log IAP	log K(T, P)	Moles in assemblage		
				Initial	Final	Delta
Calcite	0.00	-8.48	-8.48	1.000e-01	1.113e-01	1.133e-02
Dolomite	0.00	-17.09	-17.09	1.600e+00	1.593e+00	-7.315e-03

-----Solution composition-----

Elements	Molality	Moles
C	6.747e-03	6.751e-03
Ca	2.260e-02	2.261e-02
Cd	3.567e-06	3.569e-06
Cl	7.427e-02	7.431e-02
Mg	1.608e-02	1.609e-02
Mn	2.779e-04	2.780e-04
N	2.480e-02	2.481e-02
Na	4.255e-03	4.258e-03
Pb	1.998e-06	1.999e-06
S	1.397e-03	1.398e-03

Reading input data for simulation 3.

```

PRINT
      selected_output false
EXCHANGE 1
      equilibrate with solution 1
      X      1.0
SURFACE 1
      equilibrate solution 1
      SurfOH      0.07      600.      30.
END
    
```

Beginning of initial exchange-composition calculations.

Exchange 1.

X 1.000e+00 mol

Species	Moles	Equiv- alents	Equivalent Fraction	Log Gamma
CaX2	3.411e-01	6.823e-01	6.823e-01	-0.429
MgX2	1.523e-01	3.047e-01	3.047e-01	-0.409
NaX	9.443e-03	9.443e-03	9.443e-03	-0.110
MnX2	1.787e-03	3.574e-03	3.574e-03	-0.418
CdX2	1.398e-05	2.796e-05	2.796e-05	-0.450
PbX2	9.715e-06	1.943e-05	1.943e-05	-0.450

Beginning of initial surface-composition calculations.

Surface 1.

Diffuse Double Layer Surface-Complexation Model

APPENDIX 12 Cont.
RESULTS OF INPUT AND CALCULATED OUTPUT OF LEACHATE TRANSPORT MODEL

Surf

0.000e+00 Surface charge, eq
 0.000e+00 sigma, C/m²
 0.000e+00 psi, V
 -0.000e+00 $-F \cdot \text{psi} / RT$
 1.000e+00 $\exp(-F \cdot \text{psi} / RT)$
 6.000e+02 specific area, m²/g
 1.800e+04 m² for 3.000e+01 g

Surf

Species	Moles	Mole Fraction	Molality	Log Molality
SurfOH	7.000e-02	1.000	6.996e-02	-1.155

 End of simulation.

 Reading input data for simulation 4.

SOLUTION 0 20 x precipitation

pH 4.9
 pe 4.0
 temp 25.
 units mg/l
 Ca 32.2
 Mg 6.4
 Na 3.0
 Cl 36.87
 C(4) 24.00
 S(6) 1.5
 Mn 0.38
 Pb 0.01
 Cd 0.05
 N(5) 0.62
 N(-3) 6.4

EQUILIBRIUM_PHASES 0

Dolomite	0.0	1.6
Calcite	0.0	0.1
CO2(g)	-1.5	10.

SAVE solution 0

END

 Beginning of initial solution calculations.

Initial solution 0. 20 x precipitation

-----Solution composition-----

Elements	Molality	Moles
C(4)	3.934e-04	3.934e-04
Ca	8.035e-04	8.035e-04
Cd	4.449e-07	4.449e-07
Cl	1.040e-03	1.040e-03
Mg	2.633e-04	2.633e-04
Mn	6.918e-06	6.918e-06
N(-3)	4.570e-04	4.570e-04
N(5)	4.427e-05	4.427e-05
Na	1.305e-04	1.305e-04
Pb	4.827e-08	4.827e-08
S(6)	1.562e-05	1.562e-05

APPENDIX 12 Cont.
RESULTS OF INPUT AND CALCULATED OUTPUT OF LEACHATE TRANSPORT MODEL

Beginning of batch-reaction calculations.

Reaction step 1.

Using solution 0. 20 x precipitation
Using pure phase assemblage 0.

-----Phase assemblage-----

Phase	SI	log IAP	log K(T, P)	Moles in assemblage		
				Initial	Final	Delta
CO2(g)	-1.50	-2.97	-1.47	1.000e+01	9.997e+00	-3.451e-03
Calcite	0.00	-8.48	-8.48	1.000e-01	9.994e-02	-6.172e-05
Dolomite	0.00	-17.09	-17.09	1.600e+00	1.599e+00	-1.386e-03

-----Solution composition-----

Elements	Molality	Moles
C	6.679e-03	6.679e-03
Ca	2.252e-03	2.251e-03
Cd	4.449e-07	4.449e-07
Cl	1.040e-03	1.040e-03
Mg	1.650e-03	1.650e-03
Mn	6.918e-06	6.918e-06
N	5.013e-04	5.012e-04
Na	1.305e-04	1.305e-04
Pb	4.827e-08	4.827e-08
S	1.562e-05	1.562e-05

Reading input data for simulation 5.

```

PRINT
    selected_output true
    status false

ADVECTION
    cells 1
    shifts 200
    print_frequency 200

USER_GRAPH 1 161-20BH
    -headings PV S(6) (mg/l) Ca(mg/l) Mg(mg/l) Na(mg/l) Mn(mg/l) Pb(ug/l)
Cd(ug/l) N(5) (ug/l) N(-3) (mg/l) pH
    -chart_title "Chemical Evolution of leachate in the aquifer"
    -axis_titles "Pore volumes or shift number" "Log(Concentration, in
mg/l)" "pH"
    -axis_scale x_axis 0 200
    -axis_scale y_axis 1e-6 100 auto auto Log
    10 GRAPH_X STEP_NO
    20 GRAPH_Y TOT("Ca"), TOT("Mg"), TOT("Na"), TOT("S(6)"), TOT("Mn"),
TOT("Pb")*1e3, TOT("Cd")*1e3, TOT("N(5)")*1e3, TOT("N(-3)")
    30 GRAPH_SY -LA("H+")

END
    
```

Beginning of advection calculations.

```

Beginning of advection time step 1, cumulative pore volumes 1.000000.
Beginning of advection time step 2, cumulative pore volumes 2.000000.
Beginning of advection time step 3, cumulative pore volumes 3.000000.
Beginning of advection time step 4, cumulative pore volumes 4.000000.
Beginning of advection time step 5, cumulative pore volumes 5.000000.
Beginning of advection time step 6, cumulative pore volumes 6.000000.
Beginning of advection time step 7, cumulative pore volumes 7.000000.
Beginning of advection time step 8, cumulative pore volumes 8.000000.
    
```

APPENDIX 12 Cont.

RESULTS OF INPUT AND CALCULATED OUTPUT OF LEACHATE TRANSPORT MODEL

Beginning of advection time step 9, cumulative pore volumes 9.000000.
 Beginning of advection time step 10, cumulative pore volumes 10.000000.
 Beginning of advection time step 11, cumulative pore volumes 11.000000.
 Beginning of advection time step 12, cumulative pore volumes 12.000000.
 Beginning of advection time step 13, cumulative pore volumes 13.000000.
 Beginning of advection time step 14, cumulative pore volumes 14.000000.
 Beginning of advection time step 15, cumulative pore volumes 15.000000.
 Beginning of advection time step 16, cumulative pore volumes 16.000000.
 Beginning of advection time step 17, cumulative pore volumes 17.000000.
 Beginning of advection time step 18, cumulative pore volumes 18.000000.
 Beginning of advection time step 19, cumulative pore volumes 19.000000.
 Beginning of advection time step 20, cumulative pore volumes 20.000000.
 Beginning of advection time step 21, cumulative pore volumes 21.000000.
 Beginning of advection time step 22, cumulative pore volumes 22.000000.
 Beginning of advection time step 23, cumulative pore volumes 23.000000.
 Beginning of advection time step 24, cumulative pore volumes 24.000000.
 Beginning of advection time step 25, cumulative pore volumes 25.000000.

Beginning of advection time step 165, cumulative pore volumes 165.000000.
 Beginning of advection time step 166, cumulative pore volumes 166.000000.
 Beginning of advection time step 167, cumulative pore volumes 167.000000.
 Beginning of advection time step 168, cumulative pore volumes 168.000000.
 Beginning of advection time step 169, cumulative pore volumes 169.000000.
 Beginning of advection time step 170, cumulative pore volumes 170.000000.
 Beginning of advection time step 171, cumulative pore volumes 171.000000.
 Beginning of advection time step 172, cumulative pore volumes 172.000000.
 Beginning of advection time step 173, cumulative pore volumes 173.000000.
 Beginning of advection time step 174, cumulative pore volumes 174.000000.
 Beginning of advection time step 175, cumulative pore volumes 175.000000.
 Beginning of advection time step 176, cumulative pore volumes 176.000000.
 Beginning of advection time step 177, cumulative pore volumes 177.000000.
 Beginning of advection time step 178, cumulative pore volumes 178.000000.
 Beginning of advection time step 179, cumulative pore volumes 179.000000.
 Beginning of advection time step 180, cumulative pore volumes 180.000000.
 Beginning of advection time step 181, cumulative pore volumes 181.000000.
 Beginning of advection time step 182, cumulative pore volumes 182.000000.
 Beginning of advection time step 183, cumulative pore volumes 183.000000.
 Beginning of advection time step 184, cumulative pore volumes 184.000000.
 Beginning of advection time step 185, cumulative pore volumes 185.000000.
 Beginning of advection time step 186, cumulative pore volumes 186.000000.
 Beginning of advection time step 187, cumulative pore volumes 187.000000.
 Beginning of advection time step 188, cumulative pore volumes 188.000000.
 Beginning of advection time step 189, cumulative pore volumes 189.000000.
 Beginning of advection time step 190, cumulative pore volumes 190.000000.
 Beginning of advection time step 191, cumulative pore volumes 191.000000.
 Beginning of advection time step 192, cumulative pore volumes 192.000000.
 Beginning of advection time step 193, cumulative pore volumes 193.000000.
 Beginning of advection time step 194, cumulative pore volumes 194.000000.
 Beginning of advection time step 195, cumulative pore volumes 195.000000.
 Beginning of advection time step 196, cumulative pore volumes 196.000000.
 Beginning of advection time step 197, cumulative pore volumes 197.000000.
 Beginning of advection time step 198, cumulative pore volumes 198.000000.
 Beginning of advection time step 199, cumulative pore volumes 199.000000.
 Beginning of advection time step 200, cumulative pore volumes 200.000000.

Cell 1.

Using solution 1. Solution after simulation 4.
 Using exchange 1. Exchange assemblage after simulation 5.
 Using surface 1.
 Using pure phase assemblage 1. Pure-phase assemblage after simulation 5.

-----Phase assemblage-----

Phase	SI	log IAP	log K(T, P)	Moles in assemblage		
				Initial	Final	Delta
Calcite	0.00	-8.48	-8.48	1.080e-01	1.080e-01	-1.745e-07
Dolomite	0.00	-17.09	-17.09	1.596e+00	1.596e+00	4.444e-10

-----Surface composition-----

APPENDIX 12 Cont.
RESULTS OF INPUT AND CALCULATED OUTPUT OF LEACHATE TRANSPORT MODEL

Diffuse Double Layer Surface-Complexation Model

Surf
 0.000e+00 Surface charge, eq
 0.000e+00 sigma, C/m²
 0.000e+00 psi, V
 -0.000e+00 -F*psi/RT
 1.000e+00 exp(-F*psi/RT)
 6.000e+02 specific area, m²/g
 1.800e+04 m² for 3.000e+01 g

Surf
 7.000e-02 moles

Species	Moles	Mole Fraction	Molality	Log Molality
SurfOH	7.000e-02	1.000	7.000e-02	-1.155

-----Exchange composition-----

X 1.000e+00 mol

Species	Moles	Equiv- alents	Equivalent Fraction	Log Gamma
CaX2	3.376e-01	6.752e-01	6.752e-01	-0.181
MgX2	1.567e-01	3.134e-01	3.134e-01	-0.178
NH4X	9.644e-03	9.644e-03	9.644e-03	-0.049
NaX	9.191e-04	9.191e-04	9.191e-04	-0.046
MnX2	4.374e-04	8.748e-04	8.748e-04	-0.178
PbX2	8.175e-10	1.635e-09	1.635e-09	-0.187
CdX2	2.060e-10	4.120e-10	4.120e-10	-0.187

-----Solution composition-----

Elements	Molality	Moles
C	6.679e-03	6.679e-03
Ca	2.251e-03	2.251e-03
Cd	4.449e-07	4.449e-07
Cl	1.040e-03	1.040e-03
Mg	1.649e-03	1.649e-03
Mn	7.676e-06	7.675e-06
N	5.011e-04	5.011e-04
Na	1.305e-04	1.305e-04
Pb	4.827e-08	4.827e-08
S	1.562e-05	1.562e-05

 End of simulation.

 Reading input data for simulation 6.

 End of Run after 0.797 Seconds.
