IMPACT OF TOPOGRAPHY ON DISTRIBUTION OF SOILS FORMED FROM BASEMENT COMPLEX ROCKS IN PART OF KUBANNI BASIN, NORTHERN NIGERIA

BY

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A DISSERTATION SUBMITED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (SOIL SCIENCE)

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DECLARATION

I declare that the work in the dissertation entitled 'Impact of topography on distribution of soils formed from basement complex rocks in part of kubanni basin of northern Nigeria' has been performed by me in the Department of Soil Science under the supervision of Dr. W.B. Malgwi, Prof. B.A. Raji, and Prof. J.O. Ogunwole.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

Tardoo DavidAGAKU	…………………………………......	……………………..
Name of student	Signature	Date

CERTIFICATION

This dissertation entitled "IMPACT OF TOPOGRAPHY ON DISTRIBUTION OF SOILS FORMED FROM BASEMENT COMPLEX ROCKS IN PART OF KUBANNI BASIN OF NORTHERN NIGERIA" by Tardoo David AGAKU meets the regulations governing the award of the degree of MASTER OF SCIENCE of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The present study illustrates the effect of topography on soil formation and distribution on basement complex rocks of Northern Guinea Savanna of Nigeria. Six landforms were identified through the processing of satellite images namely; Tableland with very high relief, irregular plains with some moderate relief, smooth plains with some moderate relief, flat or nearly flat plains, irregular plains with low relief and the flood plains. The associated soil units on these plains were units KB1, KB2, KB3, KB4, KB5, and KB6. Soils of KB1 were associated with the Tableland, KB2, KB3, KB4 and KB5 were associated with the undulating plains and KB6 with the flood plains. A total of 46 samples were collected from 12 profile pits across the soil units except for soil unit KB1 which were skeletal dominated with rock outcrops and shallow soils. The Tablelands were very shallow soils, undulating plains were very deep (> 150 cm) while the flood plains were deep soils. The soils of the undulating plains were imperfectly drained to well drained with a surface soil colour ranging from very dark grey (10YR 3/1) to dark yellowish brown (10YR 3/4) while the flood plain was very poorly drained as evidenced by dark yellowish brown (10YR 4/4) to dark grey brown (10YR 4/2) surface soil colour. Blocky structure was dominant within the undulating plains while the soils of KB6 were predominantly structureless. The dominant particle size fraction across all soil units was clay at both surface and sub-surface. Bulk density was low, less than 1.85 g/cm^3 at surface of all soil units. The pH was rated slightly acidic to moderately acidic in water (5.60 to 6.50) and strong acidic in $CaCl_2$ (5.1 to 5.50), across the surface of all soil unit. Exchangeable acidity values at both surface and sub-surface across the soil units were low (0.01 to 0.20 dSm). Ca was medium to high (1.3 to 8.00 cmol(+) kg^{-1}), Na was medium to high (0.15 to 0.60 cmol(+) kg^{-1}) and Mg were low to

medium (0.06 to 0.68 cmol(+) kg^{-1}) while K was low (0.03 to 0.15 cmol(+) kg^{-1}) for the surface of the undulating plains. For the flood plain, Ca was medium (3.20 to 4.76 cmol(+) kg^{-1}) Na was high (0.45 to 0.60 cmol(+) kg^{-1}), Mg and K were medium (0.51 to 0.59 and 0.25 to 0.30 cmol(+) kg^{-1} respectively). Generally the basic cations were higher in the flood plain than the undulating plains. Organic carbon and total nitrogen were all low less than (10 g/kg) and 1.5 g/kg respectively across soil units while available phosphorous was low to medium (3.15 to 16.80 mg/kg) across all soil units but generally, they were all higher in the flood plains than the undulating plains. The base saturation was generally high (> 50% NH_4AOc and >70% ECEC) across all soil units.

According to the USDA/FAO classification, the soils of unit KB1 were classified as Typic Ustorthens/Regosols, KB2 p2, p3 were classified as Typic Plinthustalfs/Eutric plinthosols, KB2 p1, p4, KB3 p2, KB4 p1 and KB5 were classified as Typic Ustipsammers/Eutric Arenosols, KB3 p1 was classified as Typic Epiaqualfs/Gleyic Gleysols, and that of KB4 p2 was classified as Typic Haplustalfs/Vetic Lixisols, while those of unit KB6 were classified as Typic Epiaquepts/Stagnic Stagnosols. The undulating plains were more promising landforms than the other landforms for agricultural production, on the other hand the Tableland with very high relief are least promising for agricultural production.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 The background of the study

The term soil can be defined as the upper most part of the earth crust that supports plant growth. Soil has properties determined by the integrated effects of climate and living organisms acting upon parent materials as conditioned by relief over a long period of time.

Soils are formed as a result of weathering of rocks or materials deposited by water bodies, gravity or wind. Topography is one of the five fundamental soil forming factors (Jenny, 1941; Amundsen *et al.*, 1994).

The term topography and relief has no generally accepted definition by both geomorphologists' and Physiographers. However the terms are used synonymously to denote configuration of the land surface. The terms commonly used to explain topography are: level or flat, undulating, rolling, hilly and mountainous. (Jenny, 1941).

Topography as a soil forming factor has dominant influence in determining differences among set of soils and their nutrients status. In a given landscape, soils formed as a result of topography gives rise to soil catena or toposequenceBrady and Weil,(1999). They occur as sequence of soils with close relationship with positions in the landscape which may differ in both their morphological, chemical and fertility statusBrady and Weil (1999). Soil properties vary in vertical and lateral directions as a function of the landscape position, soil forming factors and processes. A soil therefore forms an integral part of the land surface and any variations in geomorphology which may influence hydrologic processes will influence the pedogenic processes through the effect of differential distribution of water, sediments and dissolved materials (Ovales and Collins, 1986; Young and Hammer, 2000; Brunner *etal.,* 2004). Soils properties on a toposequence differ due to degree of erosion, and deposition of both sediment and chemical constituents of the soil Krasilnikov *et al.*,(2005) and their development.

The effect of topography is more pronounced on young soils developed on hills with steep slope because the rate of soil development equal the rate of soil removal, than on old and level ground (Birkeland, 1999; Fisher and Binkley, 2000). The direction of the slope (i.e. the aspect) influences the amount and intensity of solar radiation to which a location is exposed and subsequently the temperature regime, which affects soil biological and chemical processes as well as evaporation. This can influence the degree of soil development. The slope determines not only the intensity of such processes as erosion and sediment redistribution, but also local drainage capacity. Topographical features such as curvature, slope class, slope length, and upslope area influence the hydrological conditions of a location and the soil properties(Fisher and Binkley, 2000).

1.2 **Topography and River basin**

The topography of a given area may have unique characteristics of landforms. An area of land drained by a river and its tributaries or an area characterized byrunoff being conveyed by a singular outlet is known as a river basin (drainage). River basins are used as a model in agriculturaldevelopment; that is why a part of theKubanni basin is chosen as a study area.

1.3 **Statement of problem:**

The permeability of soil is controlled by its texture and structure. Continuous tillage increases the risk of erosion on slopes by causing excess water runoff which cannot infiltrate, to flowMiller *et al.*,(1988). Soil properties such as soil thickness, soil available water and soil pH along the slope are known to affect crop yield Miller *et al.*,(1988). The volume of soil affects the quantity and quality of available nutrients, water holding capacity, pore space and rooting depth, while the soil available water affect the choice of cropping. A particular landscape (landform) may be more promising than the others for agricultural production.

The occurrences of different landforms in any given area may have different soils and their capability/suitability potentials for crop production may also vary. Similarly, a particular landform may need special land use management due to erosion, deposition and soil quality.This researchis tailored to help in providing proper information on the role of topography on land quality of the study area. This will assist famers and the Government in improving agricultural production in the study area.

1.4 **Justification:**

Various relationships are found depending on topographic positions and other factors affecting soil genesis but with a trend confirming that the movement of material within specific toposequence will control soil properties. Therefore, a hillslope sequence could be used to understand the variations of soil chemical properties in order to establish relationship between specific topographic positions and soil properties.

A proper understanding of the spatial variability of soils as it relates to topography of the area will allow better understanding of the landforms and their management and this will aid in the designing of proper soil conservation measures for improved crop production and also serve as a prerequisite for sound land use planning (Miller *et al.*, 1988; Dijikerman and Maidema, 1988).Study of the landscape units will give a better understanding of the genesis, characteristics and capability of soils formed and guidelines on how to use and conserved the soils for posterity.Topography as a soil-forming factor andas a tool for evaluating land capability has not received the due attention it deserves. It is this view that has influenced the choice of this research topic.

1.5 **The objectives of this study are therefore as follows;**

The main objective of this research is to characterize and evaluate the land capability of soils of part of Kubanni basin for agriculture.

The specific objectives are:

(i) To identify, characterize and determine the relationship between the different landforms and associated soil types in Kubanni basin of Northern Nigeria.

(ii) To classify the soil types using USDA Soil Taxonomy (Soil Survey Staff, 2010) and correlate with the Word Reference Base for Soil Resource 2014 (WRB).

(iii) To determine the land capability classification of the landforms identified in the study area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Factors of soil formation

The soils of any area are known to be a product of the interaction between five factors namely; parent material, living organism, climate, topography and time. Each of these factors has been widely discussed in soil studies as independent factors and in some cases, as they relate to soil formation Jenny, (1941). Existing information on such studies are summarized below:

2.1.1 Topography and Soil Development

Topography is one of the five fundamental elements of the soil forming factors Amundsen *et al.*,(1994); Jenny, (1941). Topography is central to the concept of soil catena Hook and Burke, (2000). The effect of topography is more pronounced on young and rolling topography than on old and level topographyBirkeland, (1999); Fisher and Binkley, (2000). Local slope determines not only the intensity of such processes as erosion and sediment redistribution, but also local drainage capacity. The various relationships were found to depend on the topographic positions and other factors affecting soil genesis and the movement of material within specific toposequence will control soil properties (Fisher and Binkley, 2000).

The topographic position of soil is among factors used to establish local soil classification that guides land use and management decisions Gobin *et al.*,(2000).Various researchers;(Onweremadu *et al.*, 2007;Birkeland 1999 and Hunkler and Schaetzi 1997) have shown that, the variation of soil properties bears a sensitive relationship with the angle of gradient and the length of slope. This is due to erosion and deposition processes operating along the slope, water percolation and runoff Ni and Zhang, (2007). Similarly the development of surface soil properties over inclined topography is related to gradient and to the position of the soil with respect to distance down slope (Aandahl, 1948; Acton, 1965; Moore *et al.,* 1993; Gessler *et al.,*1996 andKreznor *et al.*,1989) all observed that erosion phase, landscape segment, slope shape, slope gradient, and slope length affect the taxonomic placement of cultivated hill slope soils in northwest Illinois watershed when compared to uncultivated sites.

Each hillslope with a slope gradient is submissive to transport of soil particles. Erosion tends to be higher on convex sites with steep slopes compared to concave sites with low gradient. The soils at shoulders tend to be shallower due to erosion, whereas the soils on footslope and toeslope areas tend to be deeper due to deposition Kreznor *et al*(1989). The sediment transport is different for each soil particle size. The transport of coarse-sized particles (sand) is lowest, whereas the transport of fine soil particles (clay) and medium-sized particles (silt) is higher (Kreznor *et al.*,1989).

Clay particles form aggregates with organic material and iron and aluminum oxides, hence those aggregates are very stable and are less susceptible to sediment detachment. Coarse-sized particles are heavy and therefore also difficult to detach. Medium-sized particles (silt) are prone to erosion. If erosion occurs on a hillslope the silt content often is higher in the bottom soils compared to soils on the hillslope shoulder. Increasing the slope length allows water, which ran off the upper part of the slope to infiltrate in the lower part of the slope

Brubaker *et al*.,(1993) and to deposit eroded material carried in suspension. Brubaker *et al.* (1993) observed downslope increases of the amount of sand and silt parallel to decreases of clay and organic material content.On steep slopes, several geomorphic processes that may be active are debris avalanche, soil creep, slope wash and solution Graham and Buol,(1990). Soil creeps or hill creeps are the products of large boulders when they disintegrateSmyth and Montegomery, (1962) which add to accumulation of colluvium on lower slope position thus create a thin blanket of colluviums over most of the landscape Grahamand Buol,(1990). Soils developed in such materials tend to be loose because of their coarse texture as observed in Balogun series Smyth and Montgomery, (1962). Slope or hill wash has been defined by Young (1972) as the downslope transport of regolith materials through the effect of raindrop impact and overland water flow. Soils formed under this condition are made up of finer colluvial particles which accumulate in lower slope sites (Smyth and Montgomery, 1962).

Soil development in a highly unstable area is difficult, due to extremely active cutting down of valleys by streams, slopes steepness and high mobility. As a result, soils are immature and consist of little more than ill-sorted rock fragments. However on a relatively level ground soil formations are stable and pedogenesis take place over a considerable periodSparrow, (1965). Soils will therefore exhibit mature characteristics with well-developed horizons. As soon as the surface begins to grade into the waxing element, however, stability diminishes due to gravity-induced movement of material, until it is non-existent at the free faceSparrow, (1965). The soil movement on this waxing element takes many forms. At times it is seen as a progressive thinning of horizons while at others, it gives rise to small reverts which move down slope (Sparrow, 1965).

In general soils at the summit and backslope develop horizons faster. Soils on the shoulder develop more slowly because rainfall will run off this slope position faster, resulting into more soil erosion, and less leaching. At the footslope position the soils will collect sediment from upslope that can bury the horizons and slow down their development. This can lead to lithologic discontinuity. If sediment is minimal, then the increased water accumulating on the footslope will increase the leaching of mobile soil constituents and the degree of horizon development (Sparrow, 1965).

Topography also affects the amount of effective rainfall that infiltrates a given parcel of land. A steep slope will encourage runoff. A soil in a sloping location will experience less effective rainfall than that which one would measure in a rain gauge Sparrow(1965). Likewise, a low area may receive run-on water beyond the actual rainfall. Also, relief influences erosion. Soil horizons form from the top downwards. If the topsoil readily erodes away as it forms, the soil formation processes appear to have halted.

The extents of the changes in properties of the soil profile are determined by landscape position. Better moisture, greater vegetative growth and increased water infiltration and redistribution determine solum thickness, relative wetness of the soil profile and degree of horizon differentiation which increase towards lower slope positions (Sparrow, 1965).

2.1.2 **Climate and soil Formation**

The process of soil formation involves a number of climatic variables which include hydrological factors such as rainfall and the volume of leaching of mobile soil constituents, the period of year of in which the profile is wet, and the rise and fall of the water table and the temperature (Jones and Wild, 1975; Zonn, 1986).Ahn(1970), in one of his studies showed that as one goes northwards across the Savanna, profiles become shallower depending on the type of parent material. This trend was attributed to a declining weathering intensity as mean annual rainfall decreases to a greater exposure to soil erosion as the vegetation becomes sparser.

Climate is also known to influence, to a large extent the mineralogy of the soil. It has been observed that during prolonged and intensive weathering under high rainfall and temperature, losses of silica in soils are proportionally greater than those of the sesquioxides Ahn, (1970). Consequently, Kaolinite predominates in the Ferrallitic and Ferruginous soils of the Savannas while 2:1 lattice silicates are usually found in soils of the semi-arid regions Ojanuga, (1979). In sub-humid areas with a longer dry season, valleys have also been found to contain 2:1 clays (Greenland, 1981).

Some studies have also related the development of argillic B horizons to climate. For example Sys (1967), observed that textural B horizons develop more easily under dry sub-humid or semi-arid tropical climate, and actually argillic horizons are not very common under humid tropical and equatorial climates. He then attributed the greater development of the argillic horizon in the dry zones of the tropics to the rise in pH and a temporary mobilization of clay usually resulting from the sudden wetting of a dry soil (Kapalge, 1976).

Most tropical soils are characterized by reddish or yellowish color. Some investigators have explained that the intensity of coloration, and sometimes the color itself varies spatially depending on the class of slope. The red and yellow colors of the iron rich soils are commonly known to reflect the moisture conditions in a soil profile of the uplands. The yellow colors are caused by the presence of hydrated forms of iron oxide as a result of lower slope degree while the typical red soils are characterized by hematite, reflecting an oxidized state in the soil especially soils of the land upland plains (Kapalge, 1976).

2.1.3 **Vegetation and soil Formation**

Pedologists have long been interested in the contrast between soils formed under different vegetation types such as prairie/savanna and forest and under transitions between them (Jones and Beavers, 1964; White and Riecken, 1955). A study carried out by Daniels, *et al*.,(1962) showed that soil properties under prairie ecosystem varied from those under forest on uniform parent materials in the north central region of united State of America.

Soil pH values were higher for the surface soils under deciduous forest than under prairie, each recording pH values of 6.5 and 5.1 respectively. However base saturation of 90% was recorded under prairie and 80% under deciduous forest contrasting the observation by Sys (1967) that base saturation values were higher in the humus layer under forest than under Savanna in the Congo.

A similar trend which revealed a greater quantity of nutrients cycled through the vegetation in the forest zone than in the Southern Guinea Savanna of some West African soils was also observed by Nye and Greenland (1960). A probable explanation for the above is that tree roots penetrate more deeply than those of grasses in less weathered materials they are able to return more bases to the soil.

The clay contents of soils have also been found to vary under different vegetation cover. A clay content of 28% was recorded under prairie while 21% was recorded under deciduous forest in Iowa (Daniels *et al*, 1962).

For the effect of vegetation on the organic matter content of soils, Brady (1974) indicated that organic matter content of the grassland soils is generally much higher, especially in the surface horizons. This is explained in the terms of the interaction that develops among the natural vegetation, other soil organism, and the characteristics of soil. As a result of such interaction in soils developed under native grasslands, non-symbiotic nitrogen fixers (Azotobacter) tend to flourish, thus providing an opportunity for an increase in both the nitrogen and organic matter content of the soil. The higher organic matter according to Brady (1974), gives the soil a darker colour and higher moisture and cation holding capacities as compared to the forest soil.

Vegetation cover reduces natural erosion rates, thereby slowing down the rate of mineral surface removal Sys, (1967). It is obvious that the nature and number of organism living in the soil will play a vital role in the kind of soil developed.

2.1.4 **Parent Materials and Soil Formation**

Parent materials have been described by Fitzpatrick (1980) as consisting of mineral material or organic matter or a mixture of both. Organic matter is usually composed predominantly of unconsolidated, dead and decaying plant remains. Mineral material, which is the most widespread type of parent material, comprises of a large number of different rock forming minerals and can either be in a consolidated or unconsolidated state.

The influence of parent material has been obscured by prolonged pedogenesis such that in some cases, it may be very difficult to decide what the parent material of a soil actually was Jones and Wild, (1975). Even so, it has been possible and very useful to relate the properties, classification as well as the agricultural potentials of West African soils to their apparent parent material. For example, Jenny (1965) delineated the soils of Upper Volta according to the geological formation upon which they were found: fertile brown soils, high in clay and mineral reserves were found on pre-cambrian Birrimian formations (amphibolites, shales, dolerites and diorites), while fertile, heavy, base-rich soils were found on alluvium. He found that sandy soils were of the only medium to low fertililty on granite and sandstones in the area.

A relationship between soil texture and parent material has been widely recognized in Nigeria Jones (1973); Jones and Wild, (1975). Higgins (1965) found that even under different bio-climatic zones, soils developed from Basement Complex commonly recorded increase in clay content with depth. Their surface textures were commonly loamy sand to sand merging through loam to clay loam or sandy clay loam; with a structure at least weakly developed in the heavier textured horizons. This structure is commonly classified as moderate. Also, the chemical composition of rock appears to affect the type clay formed.

2.1.5 **Time and soil Formation**

Soil development in relation to time can be considered as occurring in three stages: (i) the immature or young stage, (ii) the mature stage and (iii) the senile stage. The immature or young stage is that characterized for organic matter accumulation in the surface soil and by little leaching or translocation of colloids. Only the A and C horizons are present and soil properties to a large extent have been inherited from the parent material. The mature stage is marked by the development of the B horizon while the senile stage is reached by the mature soil becoming highly differentiated so that large differences exist in the properties of the A and B horizons if sufficient time has elapsed (Forth, 1978).

Many studies relating to time as a factor of soil formation to soil properties have been based on the use of chronosequence, (Franzmeier and whiteside, 1963; Stevens and Walker, 1970; Adams and Walker, 1975a and b). A chronosequence, as defined by Jenny (1941, 1961) is an array of related soils in a geographic area that differ primarily as a result of time as a soil forming factor. Adams and Walker (1975) in their study of some chronosequence observed a degradation in absolute amounts of total nitrogen, oxidizable carbon, cation exchange capacity, Ca, Mg, K, Al, Fe and P as well as profile clay with increasing soil development.

Working on time as a factor in the genesis of soils developed in recent alluvium in Pennsylvania, Bilzi and Ciolkosz (1977) discovered that three of the four soils studied which were of the same chronological age (200-500 years) has experienced minimal morphological development than the fourth which was approximately 1,500 years older. These young soils had weak to moderate sub-angular blocky structure which, it was said may be due to the high silt and low clay content of the B horizon in one of the soils.

However, greater morphological development was very evident in the B horizon of the fourth soil. The B horizon of this soil which also happened to be the oldest had chroma as high as 6 indicating a significant oxidation while thin clay films present on prism faces and in pores indicate the possibility of some clay translocations. Boundary conditions between the horizons of these soils were also found to be more evidenced in the older soils than in the younger soils.

2.2 Topography and soil physical properties

Soils are essential natural resources with a board range of environmental functions. The study of the soil physical properties will lead to a proper understanding of the soil formation and its relationship with topography. Topography is central to the catena concept for soil development Hook and Burke, (2000), which is characterized by erosion and redistribution of sediments and soil material along slopes. The effect of topography is more pronounced on young and rolling soils than on old and level soils Birkeland, (1999); Fisher and Binkley, (2000). In addition, hydrologic response is also affected by many factors including land use and management practices; topographic positions, hillslope gradient, aspect, and variance; drainage patterns and density; surface deposits, soil texture, permeability, water storage capacity, soil hydrologic groups; and land cover in catchment.

Seibert *et al.,* (2007) reported that topography is also a major factor controlling both hydrological and soil processes at the landscape scale.The variability in soil properties in any landscape is an inherent natural phenomena conditioned by geological and pedological settings.

However, some of these variability's may also be induced by tillage and other soil management practices and are in many cases influenced by the factors like soil erosion and deposition. Among the soil properties concerned, soil texture is one of the important soil properties governing most of the physical, chemical and hydrological properties of soils. Variation in soil texture in the field at different slope degrees, directly contributes to the variation in nutrient storage and availability, water retention, availability and transport hence may influence the yield potential of any site. Warric and Gardner (1983) found a significant impact of this variability on soil performances and therefore the crop yield. Similarly, Tanji (1996) has shown that among the different soil physico-chemical properties measured, variability in soil texture component is a primary soil factor influencing crop yield (Reynolds 1970 ; Crave and Gascuel-Odoux 1997) found that variation in soil moisture content were directly related to the soil textural variability. Soil aggregation as influenced by higher clay content was the most important soil property influencing the soil loss by splash (Luk, 1979).

2.3 **Topography and soil chemical properties**

Understanding the soil chemical composition and its variation is essential for utilizing and managing the soils. However, a quantitative relationship between soil topography and its chemical constituents is not well established for a wide range of environments. This is due to the complex nature of such relationship owing to the sensitive impact of topography on the movement of soil material, which makes this relationship site specific. The question about the magnitude and pattern of variations in soil properties within specific landforms is given different views by researcherYoung and Hammer,(2000).Many researchers linked the pedogenic processes, which control soil properties, to the variation of geomorphic features and considered that soils could be differentiated by their location within the toposequence Huggett, (1975); Ovales and Collins, (1986). Other researchers took this relationship further by attempting to quantify the relationships between topographical parameters and soil properties. They found that variations in some soil chemical and mineralogical properties can be related to the slope steepness, length curvature and the relative location within a toposequence Aandahl, (1948; Acton, 1965; Ruhe and Walker, 1968, McKenzie and Austin, 1993; Moore *et al.,* 1993; Gessler *et al.,* 1995 and Gessler *et al.,* 2000).

However, various relationships were found depending on the topographic positions and other factors affecting soil genesis but with a trend confirming that the movement of material within specific toposequence will control soil properties. Therefore, a hillslope sequence could be used to understand the variations of soil chemical properties in order to establish relationship between specific topographic positions and soil properties.

Norton *at el.,* (2003) in a study of hill slope soils on the Colorado plateau reported that total organic carbon, nitrogen, and phosphorous concentrations in the surface horizons follow negative parabolic trend while inorganic nitrogen and available phosphorous concentration and total inorganic nitrogen and phosphorous ratios increased linearly from summit to toe slope. Consequently, they noted that these trends in soil properties when taken together, landform and vegetation data suggests that: one summit positions are relatively stable with immobilizing microbial environments, two, inorganic nutrients increase progressively down steep and erodible back slopes as inputs of forest litter are mixed with surface soil; and three, influx of mixed sediments and organic materials from back slopes maintains concentration of inorganic nutrients on foot slopes and toe slopes.

2.4 **Soil derived from the Nigerian Basement Complex rocks**

Theories had been put forward to explain the genesis of soils formed from rocks of the basement complex in the humid tropical zone of Nigeria Smyth and Montgomery (1962) observed that weathered rock materials from which the soils develop have a complicated history reflecting the influence of previous climatic variation, cycles of erosion and periods of intense soil forming activities. Distinct erosion phases in south western Nigeria and the superficial deposits of pediment and secondary sediment have been observed.

Ojanuga (1978) noted that multiple stratification of soil parent materials of varying Pedi sediments (over saprolite) and existence of inherited pedological features tend to indicate that cycles of erosion must have alternated repeatedly with cycles of pedogenesis. Cyclic changes in climate in West Africa were also reported by Thomas and Thorp (1985). Smyth and Montgomery (1962) reported that on a landscape shoulder, the soil properties reflect a combination of characteristics inherited during erosion evolution of the landscape.

This is as a result of pedologic processes acting on the present surface. The relative importance of these processes was considered to vary within the same landscape segments because different soil types have been noticed to be associated with different parts of the landscape. Ojo-Atere and Oladimeji, (1988) also reported from the study of upper slope soils that the surface horizons may be developed in transported material while the subsurface horizons may be derived from the underlying rock.

Basement complex rocks are subdivided into migmatite-gneiss complexes, the older meta-sediments; the older granites; and the younger granite alkaline ring complexes and volcanic rocksSmyth and Montgomery, (1962). The migmatite gneiss complex is the commonest rock type in the Nigerian Basement complex. It comprises of two main types of gneisses:

the biotite gneiss and the banded gneiss. The biotitic gneisses are more widespread and are normally fine-grained with strong foliation caused by the parallel arrangement of alternating dark and light minerals(Smyth and Montgomery, 1962).

The banded gneisses show alternating light-colored dark bands and exhibits intricate folding of their bands. The migmatite gneiss complex is the oldest basement rock.

Older granites are widespread throughout the Basement complex and occur as large circular masses within the schists and the older migmite-gneisss complexes. The older granite varies extensively in composition. The younger granite complexes in Nigeria are found mainly on the Jos Plateau, forming a distinctive group of intrusive and volcanic rocks that are bounded by ring dykes or ring faults. Other occurrences approximate a north-south belt towards the middle Benue in the south where the ages are younger(Smyth and Montgomery, 1962).

2.5 **Soil classification**

Soils developed on basement complex rocks vary greatly in their properties resulting in a wide range of classification; According to Harpstead, (1973) the most dominant soils particularly in the Guinea savanna are the less leached slightly acid Alfisols derived from pre-Cambrian crystalline Basement Complex rocks. He described the soils as being shallow, coarse textured and yellowish grey or yellowish brown in the surface layer and has red or reddish brown subsurface horizons with higher clay content. The dominant clay mineral was reported to be kaolinite while organic matter and nitrogen contents are generally low Esu and Ojanuga (1985) in the study of Alfisols in Basement Complex areas of Kaduna state reported that the soils had weak surface soil aggregates, ochric epipedons and argillic diagnostic horizons. In addition the soils were noted to have high available potassium content, but low available phosphorus.

The soils according to Ogunwole *et. al.,*(2001) are classified as Typic Haplustalf, which developed on deeply weathered pre-Cambrian Basement complex but overlain by Aeolian drift of varying thickness.

Soils of Zaria plains which developed on the basement complex; the basalts within the Northern Guinea savanna zones of Nigeria were found to vary from Dystropept, Haplustalfs, Kandiustalfs, to plinthustulfs (Kparmwang, 1993).

One common feature of the basement complex rocks irrespective of zone is the occurrence of plinthite at variable depth, which necessitates their classification as plinthustults (Esu, 1987; Mosugu, 1989; Kparmwang, 1993).

2.6 **Land capability Classification**

The capability classification is one of a number of interpretive groupings made primarily for agricultural purposes. As with all interpretive groupingsthe capability classification begins with the individual soil-mapping units,which are building stones of the system USDA, (1961). In this classification the soils are grouped according to their potentialities and limitations forsustained production of the common cultivated crops that do not requirespecialized site conditioning or site treatment. Non-arable soils (soils unsuitablefor longtime sustained use for cultivated crops) are grouped accordingto their potentialities and limitations for the production of permanentvegetation and according to their risks of soil damage if mismanagedUSDA, (1961).This includes limitation to use, soil management requirement, slope, soil texture, drainage conditions, soil depth, effects of past erosion, water holding capacities and stoniness.

The individual mapping units on soil maps show the location and extentof the different kinds of soilUSDA, (1961). One can make the greatest number of precisestatements and predictions about the use and management of the individualmapping units shown on the soil map. The capability grouping of soils isdesigned soas to; (1) help landowners and other users interpret the soil maps, (2) introduce users to the detail of the soil map itself, and (3) makepossible broad generalizations based on soil potentialities, limitations in use,and management problems (USDA, 1961).

The capability classification provides three major categories of soil groupings:

(1)Capability class (2) Capability subclass, and (3) Capability unit.

Capability classes are groups of capability subclasses or capability units that have the same relative degree of hazard or limitation. The risks of soil damage or limitation in use become progressively greater from class I to class VIII.

The capability classes are useful as a means of introducing the map user to link up more detailed information on the soil map.

The classes show the location, amount, and general suitability of the soils for agricultural use. Only information concerning general agricultural limitations in soil use is obtained at the capability class level.

The sub-classes show the type of limitation encountered in the classes. Four kinds of limitations are used in the sub-class and are indicated by a subscript letter such as “e” for erosion hazard, “s” for soil properties such as root zone, water table, stoniness, salinity, soil structure and hard pan. While letter “c” denotes soils with climatic problems and “w” representing excess wetness.

The capability unit condenses and simplifies soils information for planning individual tracts of land, field by field. Capability units with the class and subclass furnish information about the degree of limitation, kind of conservation problems and the management practices needed

2.7 **Soils of the basement complex rocks and fertility status.**

Soils derived from Basement Complex in the south Eastern zone of Nigeria are generally low in fertility, acidic, with low CEC, low base saturation and are deficient in available phosphorus Enwzor *et al.*,(1988). Eshett (1985) reported that the main type of clay in crest and middle slope physiographic positions was kaolinite while kaolinite and smectite occurred in the valley-bottom Eshett *et al.*, (1990) studied soils on toposequence in Northern Cross River state and observed that the soils were moderately weathered, with strong to medium acidity while CEC varied from low to medium. In addition the soils were observed to show a mixed mineralogy consisting of kaolinite (predominant), goethite, and quartz while smectite occurred in small amounts in the valley bottom area.

The soils of the basement complex vary a lot in soil characteristics therefore understanding of the slope characteristics and spatial distribution is of great importance for sustainable management of the soils.

2.8 Landscape Evolution of the Kubanni River Basin

The Kubanni river basin is situated within the Zaria plain located within the broad land region commonly known as the "High Plain of Hausaland". The High plain is bounded in the south by the Nupe plain and in the north by the Sokoto plain and the Chad basin (Malgwi., 1979).

According to Malgwi, (1979). The High pain is divided into three main land areas by two watersheds or divides whose focal point is situated near Funtua. One of the watersheds runs east to west near Funtua and has a flat laterite capped surfaces. The watersheds by the east-west divide or demarcate the southern and the northern part of the high plain. The other divides run from the north-east from Funtua separating the Sokoto plain to the north-west from the Chad basin to the north-east of Funtua.

The landforms of the area consist of inselbergs, mesas, plains as well as valleys which are recognized presently on the high plain due to the complex past erosion history of the High plain. It is believed that deep weathering of bedrock occurred in the past creating a substratum of residua which was subsequently modified by several cycles of erosion.

The High plain consists of gently sloping coalesced plains with scattered inselbergs. One good example is that of the Kufena inselberg near Wusasa within Zaria, a major landform in the study area. The High plain has become more rugged with many outcrops of granites, granitic gneisses or quartizite hills and granite whale backs(Malgwi, 1979).

The gently undulating plains beneath the inselbergs are the flat topped or tabular surface usually rising up to 4 to 15m above the lower lying surfaces from which they are separated by distinct scarpsKing (1962). These tabular surfaces are known as mesas. They occupy the crestal area of the interfluves and are capped by laterites. They are remnants of earlier extensive laterite-capped surfaces which were removed by erosion. They occur as isolated ridge in the High plain (Malgwi, 1979).

The Zaria landscape is characterized by the occurrence of a superficial deposit which often overlies the residua or colluvial materials. The deposit is thought to be of Aeolian origin and it was described by Higgins (1963) as drift material. This drift covers a large area of the plain formingloess plain covering a total area of 4403m^{2}Malgwi, (1979). The loess has a high fine sand and silt content.

Although the origin of the loess has not been established, Higgins and Tomlinson(1963) have assigned these materials to be products of Aeolian drift brought into the area in a similar manner to that of present day harmmattan dust.

Based on the above account, it appears that the present landscape has been formed by at least two major cycles creating at least two distinct surfaces at different levels beneath the inselbergs. Late Quaternary incision of the lower lying surface has created valleys which may have laterites at the valley sides. Where the incisions are severe the flood plains (fadamas) were formed. The parent materials of this area are so complex since they compose of residua, colluvial deposit and aeilian superficial deposit.

Theories have been put forward by different people in order to explain the land evolution of the High plain. According to King (1962) plain is a pediplain formed by the coalescence of pediments produced by the retreat of scarps as conditioned by lithology. Example is the

Kufena inselberg which were exhumed following the removal of residua as the scarps retreated.

Thomas (1965) and Thorp (1967) proposed the hypothesis of the landscape formation as etch-planation; a process of deep weathering and the formation of a weathering front beneath the weathered residua. The present inselbergs of the plains were therefore exposed at the surface owing to the removal of the residual overburden by erosion. The uplift of the landscape is thought to have provided the initial stripping of the overburden residua followed by the dissection of river.

The mesas represent iron oxide rich residua which are more resistant to erosion due to the hardening effect on exposure to the atmosphere. The result of the extensive undulating plains beneath the mesas is as a consequence of the weak surface that was more easily eroded than the mesas.

According to Thorp (1970) landform evolution follows the following sequence;

i. An early channel incision and the beginning of the removal of decomposed rocks
ii. Channel aggradations culminating in the pediment gravel and Aeolian drift.
iii. Renewed channel incision and regolith erosion
iv. Formation of the younger alluvial flood plain and
v. Gullying and slight channel incision.

2.9 **River basin and it importance to Agriculture development**

River basins are cradles of civilization and cultural heritageOgbeide and Uyigue,(2004). Ancient and modern communities have depended on them for livelihood, commerce and habitat.

However, land clearance and poor agricultural techniques particularly on marginal lands on hill slopes in the upper parts of the river basin rapidly lead to erosion and siltation of the water courses. As the need for crops intensifies, especially for grain, agricultural methods become more advanced and pressures are placed upon the aquatic system to the detriment of fisheries. The capacity of the unmodified floodplain for agricultural production is rapidly attained(Ogbeideand Uyigue, 2004).

Throughout much of the tropical world, the flood plains of rivers are used for dry season cultivationOgbeideand Uyigue,(2004). At its most primitive, this consists merely in planting floating rice on the plain, although attacks by fish on the growing plants quickly force the farmers to construct simple bunds Ogbeideand Uyigue,(2004). However, with the increase in demand for rice, many farmers have adopted a system of double cropping.

This is detrimental to the fishery as the fish have less time to grow between cropping. In addition, further maximum rice production can only be achieved through the use of insecticides to control insect pests and allegedly this too harms the fish resident in the rice fields (Ogbeideand Uyigue, 2004).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Physical environment of the study area

3.1.1 Site location;

The study area is part of Kubanni River basin, which is located within the Central High Plains of Northern Nigeria. The study area is within Latitude 11° 06.625’’N and 11°05.375’’N and longitude 007°41.608”E and 007°39.680”E, with an elevation above sea level ranging from 610 to 770 meters.

3.1.2 Landforms of Zaria and its environs

Several landforms are found in Zaria, such as the plains, inselbergs, valleys and gullies.

The plains on which Zaria is situated are part of the vast, gently undulating plains scenery which extends almost unbroken from Sokoto to Agades (Niger Republic). Such plains are characteristics of Africa plains as a whole. (Mortimore, 1970).

Within a range of 75 km reading from Zaria the plains vary in height from 545.5 to 712.1 Meters reflecting both regional slope to the south and a local relief of 30.3 to 45.5 MetersMortimore, (1970). Rising above the plains are hill features of two kinds; rock inselbergs and lateritic ironstones-capped mesas. The inselbergs vary considerably in dimension and shapes from the prominent land mark of Kufena to inconspicuous whale back. Inselbergs are distinctively shaped hills or bare rock. They belong to the general category of residual hills. They are associated most commonly with porphyritic massive granite and granite gneiss (Mortimore, 1970).

In Zaria there are three main groups of inselbergs-Farakwai, Hange, and Dubi, but prominent hills also occur in Zaria city and elsewhere (Mortimore, 1970).

Their sizes ranged from 3.0 to 3.6 Meters high and 6.1 to 9.1 Meters diameter to 151.5 Meters high and a quarter mile long covering an area of 1/3 square mile. These sizes depend on the volume of massive granite bounded by the major joints which divide such rocks into compartments (Mortimore, 1970).

The shapes of the inselbergs are quiet variable but the common according to Mortimore, (1970) is a convex or dome shape which can be almost perfectly symmetrical or hardly apparent within a pile of rectangular joint blocks.

At the north of Zaria in the vicinity of the regional watershed, valleys are wide, shallow and not incised; whilst towards Kaduna and the dissection zone further south-west, valleys tend to become deeper and slightly incised.

However, this general pattern has many exceptions; the Zaria-jos road crosses the headwater zone of valley which clearly shows an incised and re-illuviated character Mortimore, (1970). Westward beyond Maska, alleviated valley bottoms are singularly flat, wide and level contrasting markedly with the dry interfluves (Mortimore, 1970).

According to Mortimore, (1970) there may be regional patterns of wraping, cryclical incision working upstream from the lower Kaduna and, climatic-hydrological changes within contexts of greater and lesser available valley relief.

Gullies in the immediate environs of Zaria are prominent within the valleys, it is especially pronounced in Saya and Kubanni valleys. In fact the high incidence of gullies here is responsible for the unusual characteristics of high stream frequency and sandy channels in these basins.

3.1.3**Climate**

Fifty (50) years meteorological data collected at the institute for Agricultural Research Samaru, from 1964 to 2013 are presented inTable 3.1.

The Kubanni catchment area lies within the tropical wet and dry climatic zone characterized by strong seasonality and temperature distribution. The study area experiences an average of five rainy months from June to October and seven dry months usually from November to May.

The mean annual and monthly rainfall presented in Table 3.1. The rainy season is associated with the South West wind which blows across Zaria area between April and October, while the dry season is associated with the harmattan wind, of particular note is the heavy dust deposit in this environment by harmattan wind between the months of December to February.

Table: 3.1 Monthly mean summary of some weather parameters in Zaria (1964-2013).

Months	Rainfall	Temp.(^{0}C)		Relative humidity (%)		Sunshine	Wind speed SPD	Potential Evaporation
	Mm	max	min	max	Min	hours	(km/day)	(mm/day)
January	0.00	39.54	21.63	19.85	15.94	7.78	152.46	6.84
February	0.29	43.33	24.76	17.03	13.34	8.31	146.16	8.24
March	3.22	46.31	27.76	23.37	16.41	7.53	133.17	9.16
April	36.39	46.89	32.06	45.95	28.38	7.45	161.27	8.51
May	111.19	44.12	30.83	66.52	46.43	7.70	175.39	6.8
June	148.35	41.01	29.35	74.37	59.81	7.23	174.02	5.25
July	222.08	38.73	29.15	81.11	67.83	5.98	166.60	4.51
August	272.42	38.16	28.50	82.35	71.99	5.63	119.96	4.24
September	180.31	39.76	29.14	77.64	69.05	6.79	90.25	4.34
October	50.31	41.89	27.40	61.74	47.44	8.15	76.37	5.34
November	4.24	41.65	22.95	28.58	23.70	8.98	90.42	5.72
December	0.10	40.40	21.50	46.66	37.19	8.53	110.95	6.82
Total	1,028	501.80	325.03	625.20	837.50	90.06	1597.02	75.80

Source: Institute for Agricultural
Research metrological station, Zaria.

The beginning of rainy season is marked by an increase in mean monthly rainfall of 36.39mm in April to 272.42mm in August, which indicate the peak of rainy season, with a sudden drop in mean monthly rainfall in October (50.31mm). The heaviest rainfall is recorded between the months of August to September.

(ii) **Relative humidity**

Data for the relative humidity of the study area from 1964 to 2013 are as shown in Table 3.1.Records for the relative humidity show that the mean monthly maximum relative humidity was higher (82.35 %) in the month of August which corresponds to the period of highest rainfall Table 3.1. The mean Monthly minimum relative humidity was lowest (17 to 23 %) during the harmattan period (January to March).

(iii) **Temperature**

The mean annual temperature of the study area was about 34^oC. Mean maxium temperature was highest (46^oC) in March/April before onset of rainfall and lowest (38^oC) in July/August in the peak of raining season. This high temperature may give raise to the speedily biochemical processes. It is an iso-hyperthermic soil temperature regime, because the temperature difference between the lowest and the highest is greater than 6^oC at 50cm depth.

(iv) **Sunshine hours**

The data for sunshine hours across the study area is shown in Table 3.1. From the record, the highest sunshine hoursranged (8.1 to 8.3 hours) from October to February while the minimum sunshine hours occurred between the months of August to September with values ranging from 5.98hours to 5.63 hours. These low sunshine hours occur during the period of the peak of rainy season.

3.1.4 The Geological evolution of Kubanni river basin

The Kubanni River basin is underlain by basement rocks of Precambrian age. They are mainly granites, gneisses, and schists. The Zaria crystalline rocks are part of the Nigerian Basement Complex Oyawoye (1965) showed that there is structural relationship between this basement Complex and the rest of the West African basement. This is partly due to the fact that the whole region was involved in a single set of orogenic episode, the Pan African orogeny, which left an imprint of structural similarity upon the rock units.

Granitic intrusions form a suite of batholiths (the Zaria Batholiths), part of which are the Kufena Hills. The gneisses are found as small belts within the granite intrusions, and are also found east and west of the Batholiths. The biotite gneiss extends westward to form a gradational boundary with the schist belt. The gneiss continues eastward to some extent and is occasionally broken up by the older granite (McCurry, 1970).

The thrusting imposed on the basement complex during the Pan African Orogeny movement is believed to have brought together rocks of different ages with different structural and metamorphic styles Grant, (1969). The metasediment probably belongs to the sedimentary and granitic facies that were formed in a geosynclinal trough which had earlier developed at the end of the Pan African Orogeny Tokarski, (1972). During the Pan African Orogeny, the sediments and igneous material, together with the former metamorphosed basement rocks behaved as one tectonic unit. Some of these metamorphosed rocks became assimilated into the granite intrusions that accompanied the last orogeny (Grant, 1969).

3.1.5 Vegetation

The Kubanni basin lies in natural zone known as the northern guinea savanna zone. The zone was characterized by savanna vegetation, woodland vegetation type characterized by large surface coverage with few scattered trees and shorter grasses with tuff and occasional gallery forest along the water courses Hore, (1970).Prominent trees in the area are the Isoberlina woodland, *Parkia biglobosa*, and *Terminalia species*, grasses like *Andropogon gayanus* and *Hyperrhenia spp*. are prominent Ogunwole *et al.*, (2004). Unfortunately, these characteristics of the vegetation cover are hardly preserved due to clearance for cultivation and other forms of intensive and extensive land use Butu and Iguisi,(2012). Therefore the present vegetation consists of parkland.

3.1.6 Land Use

The major type of land use in this area include arable and livestock farming, mining of iron, and quarrying around the rocky areas.

The major crops grown are millets, sorghum and maize on the upland. In the lower plain towards the fadama crops like yam, carrots, onions, rice, tomatoes, pepper and sugarcane are grown.

3.1.7 Drainage

The Kubanni River is one of the main tributaries of Galma River; it has its headwaters from Kampagi Hills and flows into the Galma River near Tudun Wada Zaria. The River is a seasonal stream flowing at full capacity during the raining season with pockets of uncovered water bodies in the river channel during the dry season.

Soils of the study area are drained from Tablelands with very high relief through the undulating plains into the flood plains. The Tablelands with very high relief are excessively drained. The undulating plains ranges from imperfectly drained to well drained soils while the flood plains are very poorly drained soils with its water table during the dry season at 120cm and the surface could be submerged during the peak of the rainy season for some period of time of about 2-3 months(Local Farmers Report, 2013).

The poorly drained nature of this flood plain is as a result of it being a receiver of materials and run-off from the upland. The uplands are well drained even during peak of the rainy season, theyare drained within hours. This well drained nature of the upland is as a result of it high relief compared to the fadama. It easily losses it materials and water due to it slope.

3.2 Field work

3.2.1 Pre-field work

Satellite images Landsat-7 (3Dimensional), Enhanced thematic Mapper (ETM) and Digital Elevation Model (DEM) of the study areawere acquired. The satellite imagery was used to generate landuse/land cover, while the DEM was used to generate a topographic map, drainage and landforms maps. Reports and other information available on the study area were collected and studied.

Six landforms were identified within the Kubanni basin. This include; Tablelands with very high relief, irregular plains with some moderate relief, smooth plains with some local relief, irregular plains with low relief and the flood plain. An area of 4.7km by length and 200m by width (94 ha.) was delineated to capture the six landforms within the basin in the study area. Across the selected area grids at 100m interval was created for soil observation points and uploaded into the GPS for field work.

A reconnaissance survey of the delineated area was carried out; this was for ground truthing and interpretation of the satellite and DEM, as well as to acquaint the surveyor with the area and to find access routes and for identification of sample points and creating soil legend.

3.2.2 Detailed field investigation

Soils were examined along the transverse at 100meters interval. Soil observations were carried out by augering at severe depth intervals unless an impenetrable layer was encountered. The samples collected at each sampling point were described regarding soil depth, colour, texture, consistence and inclusions. Soils with similar properties were grouped together as a soil mapping unit and a total of six soil mapping units were discovered and denoted as KB1, KB2, KB3, KB4, KB5, and KB6.

In each of the mapping unit two profiles were dug, described and sampled.The profiles were described regarding horizon thickness, soil structure, soil consistence, molting, texture, root, pores and other miscellaneous properties using USDA(2010).Soil samples were collected from each genetic horizon and a total of 46samples were collected from the 12 profile pits. And the soil map of the study area was produced.

3.2.3 Soil sampling

Two types of samples were collected, the undisturbed samples and the disturbed samples. The undisturbed sample were taken at each genetic horizon of the profile pits using cores and were used to determine bulk density, total porosity and available water holding capacity. The disturbed samples were taken using hand towel to collect soils from identified genetic horizon of each profile pit and were used to determine the physical and chemical properties of the soil.

3.3 Preparatory to Analysis

The disturbed soil samples collected from the field were air dried, crushed and sieved using a 2mm sieve to remove materials greater than 2mm (gravels). These less than 2mm particles were used for the following analyses;

3.3.1. Particle Size Analysis

Particle size distribution was determined by the method described by Gee and Bauder (1986). The gravel content was first determined by direct sieving, followed by weighing. Sand, silt and clay were determined by the Bouyoucos hydrometer using sodium hexametaphosphate as dispersant and determining the sizes and amount of particles settling by employing progressive time intervals.

3.3.2 Bulk density

Bulk density was determined by the method described by Blake and Hartge (1986). Undisturbed soil samples collected in 100 cm^3 – metal cylinders were dried to constant weight at 105 ^0C and the dry weight of the sample was dried by total volume of the sample.

$$\text{Bulk density } (gcm^{-3}) = \text{Weight of oven dry soil (g)} / \text{Volume of soil } (cm^3)$$

3.3.3 **Total Porosity (T.P)**

Total porosity was calculated using the method described by Ibitoye, (2008). A saturated undisturbed core soil samplewas weighed with the volume of core determined and oven dried at 105^{o}Cfor 24 hours. The total pore space is the volume of the water at soil saturation obtained from its mass using the following equation;

Total porosity (f) = $\frac{Total\ \ pore\ \ volume}{Bulk\ \ soil\ \ volume} \times 100$ where

Pore volume = $\frac{mass\ \ of\ \ water\ \ loss\ (weig\,ht\ at\ saturation\ \ -oven\ \ dried\ \ weig\,ht)}{Density\ \ of\ \ water\ \ (g/cm\,3)}$

3.3.4 **Available Water Capacity (AWC) and Water Retention Difference (WRD)**

The core samples were saturated overnight and put in the pressure plate for extractionof moisture content at different bars. Available water capacity (AWC) was by calculating the difference in moisture content at field capacity (-33kPa) and permanent wilting point (-1500kPa) from the formula below. Water retention difference (WRD) was also obtained by the formula below (USDA, NRCS, 1995).

AWC (%) = FC (%) – PWP (%)

Where AWC = Available water capacity

FC = field capacity

PWP = permanent wilting point

WRD (cm) = {<u>FC (%) – PWP (%)</u>} x (ℓ_b / ℓ_w) x D

100

Where ℓ_w = density of water

ℓ_b) = bulk density of soil

D = thickness of soil horizon in cm.

3.3.5 Soil pH

Soil pH was determined both in water, and 1*M* $CaCl_2$ solutions in a 1:2.5 soil solution ratio using a Pye Unicam model 290 MK pH meter as described by Agbenin (1995). Delta pH (ΔpH) values (pH) $CaCI_2$ – (pH) H_2Owere calculated.

3.3.6 Electrical conductivity (ECe)

Electrical conductivity was determined at a 1: 2.5 soil/water ratio using a Wheatstone bridge at 25°C.

3.3.7 Exchangeable bases

Ten grams of soil was leached for two hours with NH_4OAc at pH 7.0 into a 100 ml volumetric flask. The exchangeable bases (Ca, Mg, K and Na) were extracted with neutral (pH 7.0) ammonium acetate (NH_4OAc) solution by repeated extraction (Anderson and Ingram, 1993). Potassium and sodium were read from the undiluted extract on a Gallenkamp flame photometer, while calcium and magnesium in solution were read on a Pye Unicam Model Sp 192 atomic absorption spectrophotometer (AAS) at 423 and 485 mm wave length respectively.

3.3.8 Exchangeable acidity

Exchangeable acidity was determined using 1*M* KCl as described by Thomas (1982). Ten grams of soil was leached for two hours with 1 ml potassium chloride (KCl) into a 100 ml volumetric flask. Three drops of phenolphthalein indicator was added to 50 ml of the leacheate which was then titrated with 0.1*M* NaOH to the pink end point and back titrated with a few drops of 0.1*M* NaF was added and titration continued using 0.1*M* HCl till colourless end point which persisted for over 10 seconds was obtained. Exchangeable acidity was calculated from the milliequivalents of NaOH used.

3.3.9 Cation exchange capacity (CEC)

Cation exchange capacity (CEC) was determined by the neutral (pH 7.0) NH_4OAc saturation method (Anderson and Ingram, 1993).

3.3.10 Effective cation exchange capacity (ECEC)

Effective CEC was determined as the sum of total exchangeable bases by (NH_4OAc) and 1*M* KCI extractable acidity.

3.3.11 Base saturation (BS) percentage

Base saturation was calculated for both ECEC and CEC by dividing the total exchangeable bases (Ca, Mg, K and Na) by the effective CEC and the CEC obtained by the NH_4OAc procedure respectively as follows:

$$\% \text{ Base saturation} = \frac{\text{Total exchangeable bases}}{\text{ECEC or CEC}} \times 100$$

3.3.12 Exchangeable sodium percentage (ESP)

The exchangeable sodium percentage was calculated as the proportion of the CEC (NH_4OAc) occupied by sodium cations as follows.

$$\text{ESP} = \frac{\text{Exchangeable Sodium}}{\text{CEC } (\text{NH}_4\text{OAc})}\ x\ 100$$

3.3.13 Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio was calculated using the following formula as proposed by(Agbenin, 1995).

$$\text{SAR} = \frac{\text{Na}}{\frac{\sqrt{\text{Ca} + \text{Mg}}}{2}}$$

3.3.14 Organic carbon (OC)

The acid – dichromate wet oxidation method of Walkley and Black as described by Nelson and Sommers (1982) was used in the determination of organic carbon. The soil organic matter was digested with potassium dichromate ($K_2Cr_2O_7$) using concentrated sulphuric acid to increase temperature and hasten the reaction. One gram each of the finely ground air-dried soil sample was weighed into 250 ml Erlenmeyer flasks and 10 ml of 1*N* $K_2Cr_2O_7$ added. Then 20 ml concentrated sulphuric acid (H_2SO_4) was added and the content of each flask was allowed to stand for thirty minutes after which the mixture in it was diluted to 250 ml with distilled water. Excess dichromate was back-titrated with ferrous ammonium sulphate using barium diphenylamine sulphate as indicator.

3.3.15 Available phosphorus

Available phosphorus was determined by the Bray - 1 method Bray and Kurtz, (1945). Phosphorus extracting solution (7 ml) was added to 1 g of soil in a test-tube and shaken for about five minutes. The content of the test-tube was filtered into another test-tube. Then 1 ml of solution made of 5 ml of distilled water, 2 ml of ammonium molybdate, concentrated stanuous chloride and 33 ml water was added to the filtrate, shaken and allowed to develop colour. Phosphorus in solution was determined calorimetrically by the ascorbic acid method (Murphy and Riley, 1962).

3.3.16 Total nitrogen

Total nitrogen was determined by the regular Macro kjedahl method. One gram of soil was

Weighed into a digesting tube into which 20 ml of concentrated sulphuric acid was added and digested for two hours. The content of the tube was then emptied into a 250 ml volumetric flask and filled to mark. This was distilled after which 10 ml of the distillate was titrated with 0.01*M* H_2SO_4 to the end point. Potassium sulphate (K_2SO_4) was used as the catalyst(Bremmer and Mulvaney, 1982).

3.3.17 0.1*M* HCl extractable micronutrients (Cu, Zn, Mn and Fe).

The 0.1*M* HCl extraction method described by IITA (1979) was used in the determination of HCl extractable micronutrient. The micronutrient cations in solution was read on the AAS; Cu at 325 nm, Zn at 214 nm, Mn at 80 nm and Fe at 373.9 nm wavelengths.

3.4 Soil classification

The soil mapping units delineated in this study area were classified according to (USDA) Soil Taxonomy Soil Survey Staff, (2010) and the World Reference Base for Soil Resources (FAO-ISRIC-ISSS, 2014).

3.5 Land capability classification

The land capability classification for Kubanni study area was based on detailed soil survey investigation of the landforms. The United State Department for Agriculture (USDA) Soil survey Staff (1961) system was used as the criteria for land capability classification for the study area.The criteria for land capability classification for the study area are shown in Table 3.2.

3.6 **Statistical Analysis**

All data collected in the study will be subjected to statistical analysis of variance and correlation using SAS computer package (SAS, 2009).

Table 3.2: Description of land capability classes

Class	**Description**

Class I: Soils that have few limitations for very intensive cultivation (no sub-classes). They can be used for a wide range of crops, pasture, and woodland and wildlife reserves.

Class II: Soils that have moderate limitations that reduce the choice of plants or require moderate conservation practices.

Class III: Soils that have severe limitations that reduce the choice of plants require special conservation practices or both.

Class IV: Soils that have severe limitations that reduce the choice of plants require very careful management or both.

Class V: Soils that have little or no erosion hazard but have other limitations, impractical to remove, that limit their use primarily to pasture grasses, range grasses, woodland, wildlife, or aesthetic.

Class VI: Soils that have severe limitations that make them generally unsuited to cultivation and limit their use primarily to pasture, range, woodland wildlife or aesthetic.

Class VII: Soils that have very severe limitations that made them unsuited to cultivation and that restrict their use primarily to grazing, woodlands, wildlife or aesthetic.

Class VIII: Soils and land form that have limitations that preclude their use for commercial plants and restrict their use to wildlife, aesthetic, recreation, and or watersheds.

CHAPTER FOUR

4.0 RESULTS

4.1 Landforms in the study area

In the entire Kubanni basin, six different major landforms were identified. All these landforms were in the selected study area (Figure 4.1 &4.2). The landforms include; (i) Tablelands with very high relief (TLVHR), (ii)irregular plains with some moderate relief (IPSMR) (iii) smooth plains with some local relief (SPSLR)(iv)Flat or nearly flat plain (FLFP)and (v)irregular plains with low relief (IPLR)and (vi) the flood plains (FP). Cross profile of landforms in the study area is shown in Figure 4.3. These landforms were further reduced to three; Tableland with very high relief, undulating plains and the flood plain as shown in Figure 4.3.

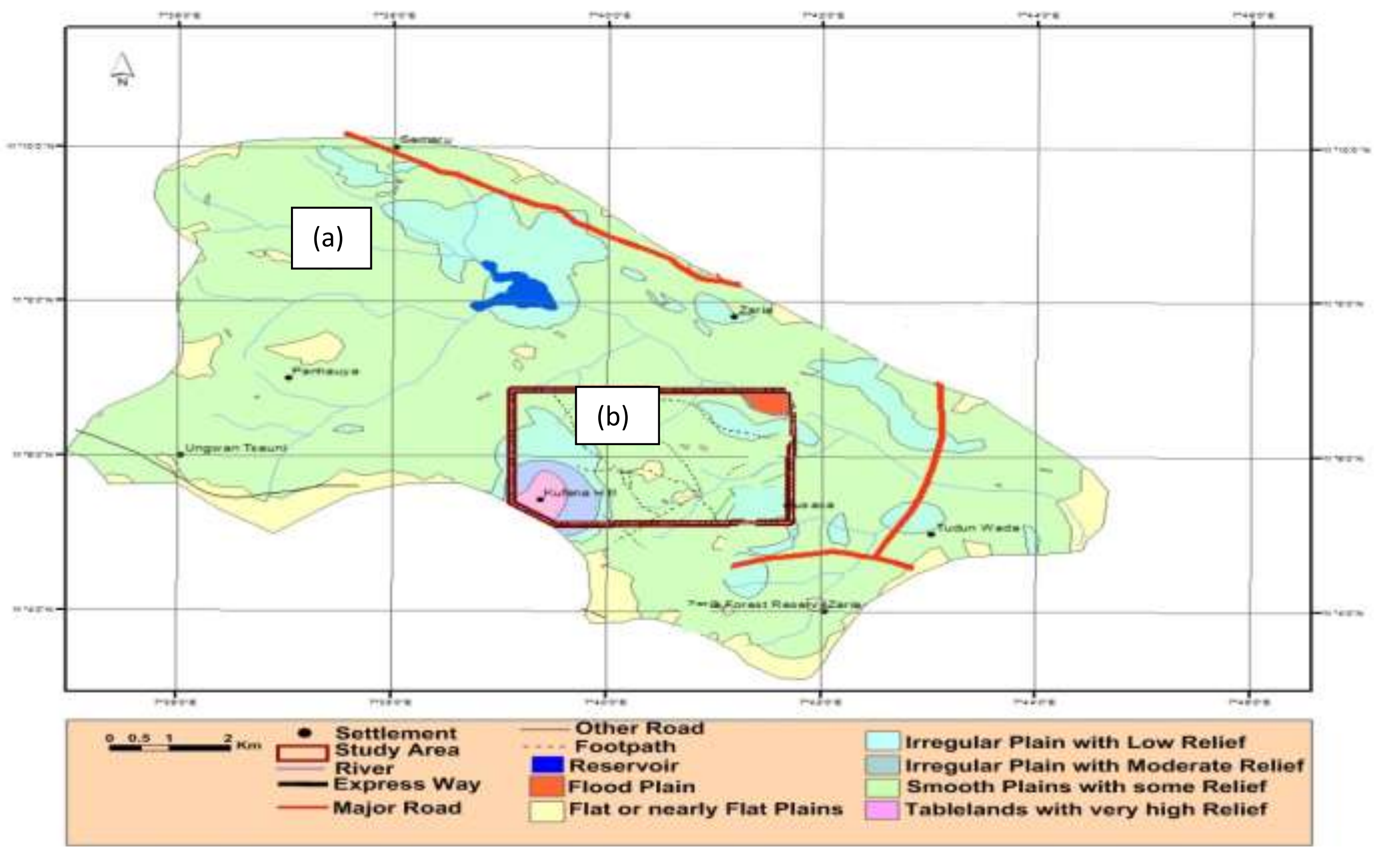

Figure 4.1:(a) map of Kubanni basin and its landforms, (b) landforms in the study area

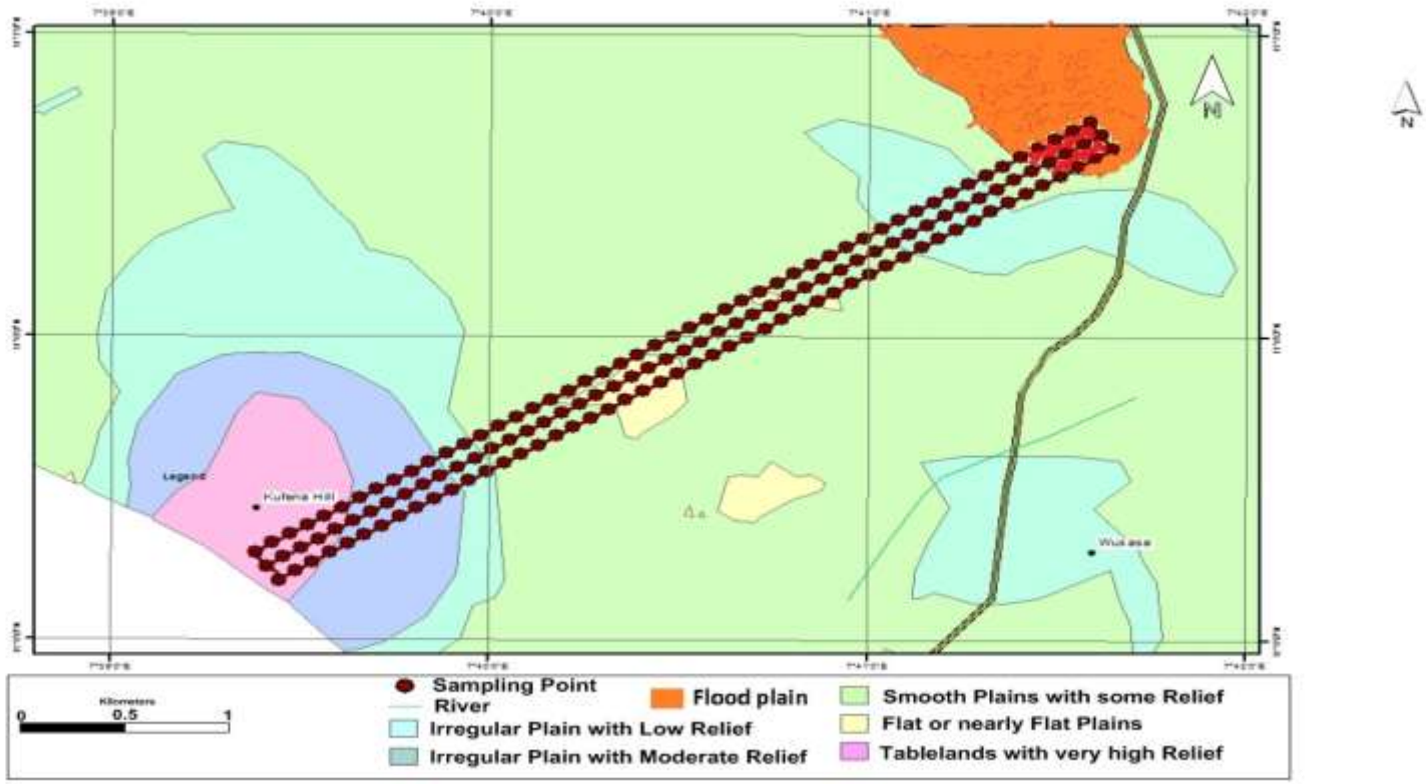

Figure 4.2: Field base map showing the transverses/soil observation points and landforms within the study area

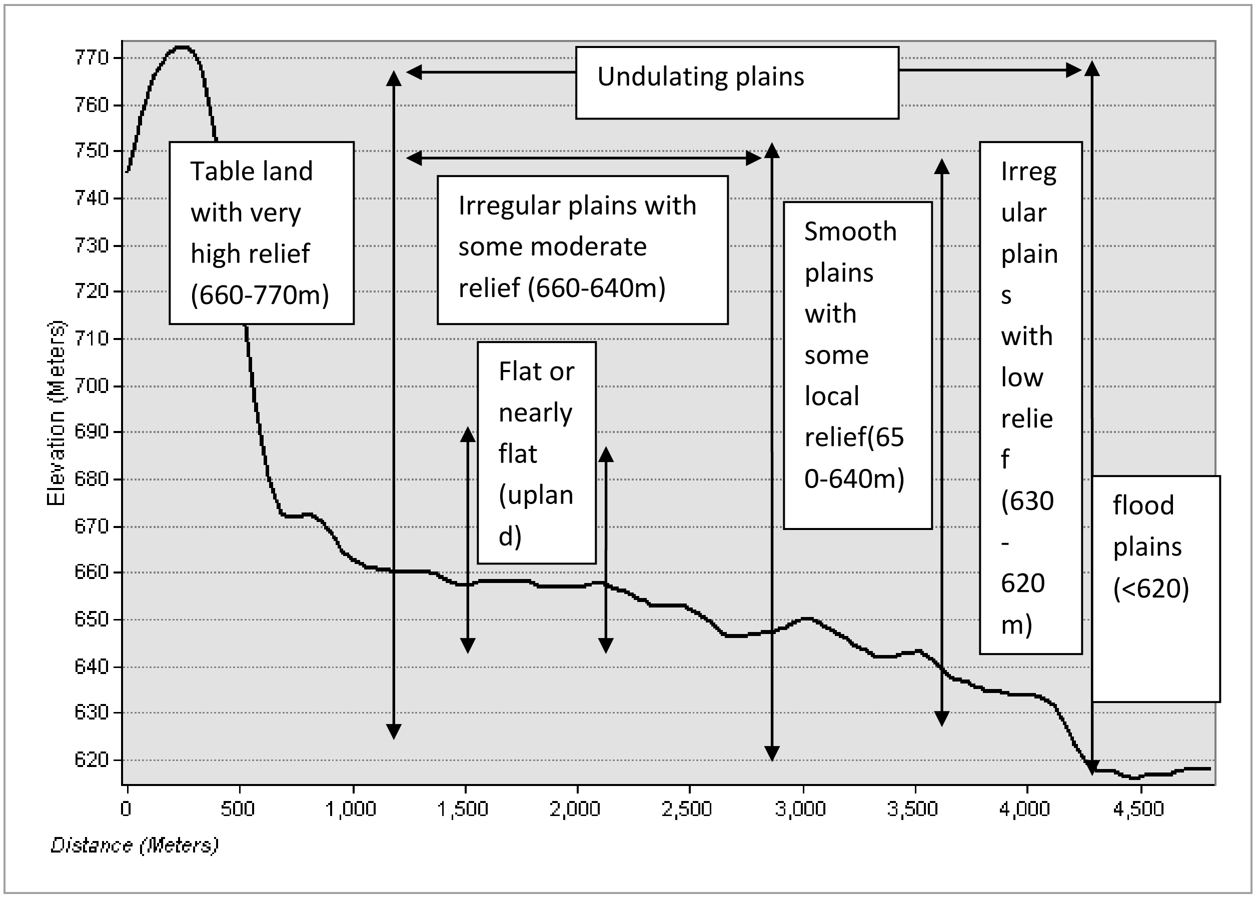

Figure 4.3: Cross profile of the middle transverse of the study area

The descriptions of the six Landforms identified in the study area are as follows;

(i) **Tablelands with very high relief (TLVHR):**

They are concave / dome in shape with a very high relative relief of about 660-770 m (Figure 4.3) with very steep slopes of 18-30 %. This landform is associated with hills and rock outcrops. This landform consists of rock outcrops and scattered rocks with pockets of very shallow soils as a result of excessive erosion activities. Excessive sheet erosion resulted in skeletal soil development. Vegetations around this landform are shrubs and scattered short trees.

(ii) **Irregular plains with some moderate relief (IPSMR):**

They are concave in shape, with moderate relative relief of about 640-660 m with a slope of 4-7 %. Soils of this landform were developed from sedimentary and colluvial parent materials. They are well drained, due to its high slope degrees. This landform has some surface ironstones and rock out crops which are in form of whaleback. Rill erosion is noticeable in part of this landform; materials eroded from this landform are deposited into the smooth plain with some local relief. It has parkland vegetation and it is intensively cultivated with crops like maize and millets.

(iii) **Smooth plains with some local relief (SPSLR):**

They are concave in shape, with a low relative relief of 640 – 650 m (Figure 4.3), and a slope of 2-4 %. This landform is highly undulating; made up of colluvial materials over sedimentary parent materials, with small depressions due to undulating nature of the plains which serve as collecting points. This resulted in imperfectly drained nature of the landform. Evidences of rill erosion were present and some rock boulders littering the surface were noticed. It has parkland vegetation and is intensively cultivated to crops like rice, vegetables, maize and millets.

(iv) **Irregular plains with low relief (IPLR):**

They are concave in shape, with a low relative relief of about 620 – 640 m (Figure 4.3), with a slope of < 0-2 %. This landform was seriously affected byrill and gully erosion which do not allow materials to settle in it but moved towards the flood plain due to more gentle slope towards it. It was well drained. The soils of this landform contain iron pan, which often underlain the soils and occurring on the surface giving soils variable depths. The high evidences of erosion and occurrence of flat iron pan in this landform make it impossible for crop cultivation.

(v) **Flat or nearly flat plain (FNFP):**

They are concave in shape with a low relative relief ranging between 650 and 660 m (Figure 4.3). It is made up of colluvial parent materials which are brought from the Tableland with very high relief (Figure 4.3). The FNFP has parkland vegetation and it is intensively cultivated with crops like maize and millets.

(vi) **Flood plain (FP):**

They are convex in shape, with a low relative relief of 600- 620 m, compared to that of the tablelands, with a very high relative relief of about 660-770 m (Figure 4.3). This landform is made up of both colluvial and alluvial deposits. The effect of erosion in this landform is very little due to its lowest position in the landscape. Sugarcane, rice and some vegetables are the common crops grown in it.

4.2 Soil mapping units delineated within the study area

Six soil mapping units were identified in the study area and are closely associated with the six landforms identified. These soil mapping units were denoted as; KB1, KB2, KB3, KB4, KB5 and KB6 and are shown in Figure 4.4.

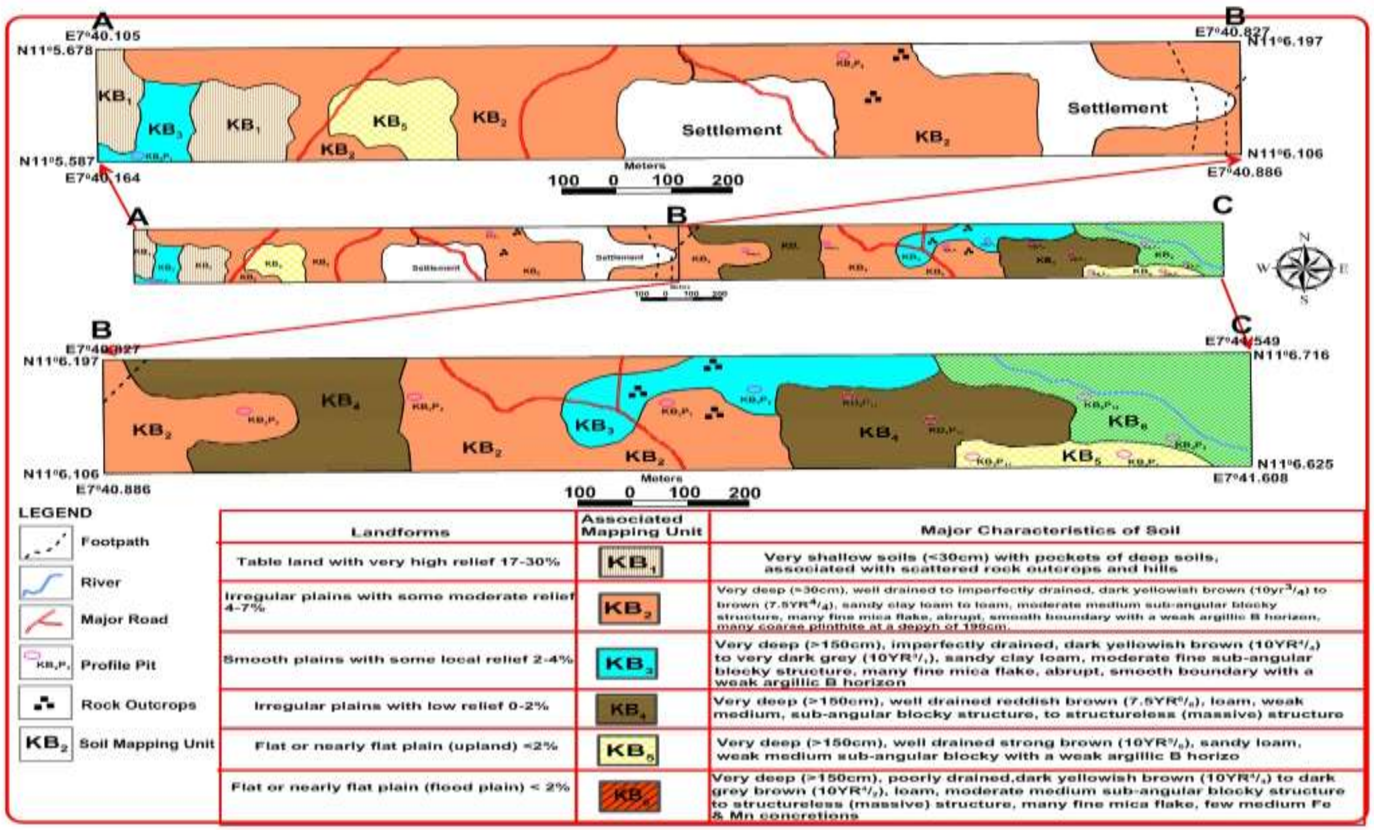

Figure 4.4: Soil map showing the available Landforms/soil units in the study area

The descriptions of the soil mapping units are presented as follows;

(i) **Soils of the mapping unit KB1:**

This soil mapping unit is associated with Tablelands with very high relief. This mapping unit was basically rock outcrop with very shallow pockets of soils. The soil unit was associated with hilly topography of rock outcrops and scattered rock on the surface. This soil mapping unit was associated with land with steep gradient with a slope of 18-30 %. As a result, high rate of erosion did not allow for deep soil to develop. This soil mapping unit can be considered as rock outcrop. No profile pit was cited in this mapping unit. This mapping unit is the second largest within the study area; covering a total of 15.80 ha.

(ii) **Soil mapping unit KB2:**

This mapping unit was associated with the irregular plains with some moderate relief, Soil mapping unit KB2 was the most extensive in the study area, covering 26.20 hectares (30.47 %). It had few scattered rock boulders on the surface. This soil mapping unit was associated with gentle slope resulting to rill and sheet erosion across the surface. Deposition within this mapping unit is due to materials eroded from the Tableland with very high relief. The soils were very deep (> 150 cm but < 200 cm). The soils were limited in depth by plinthite at the depths of 190cm, 190cm, 170cm, and 190cm for pedons KB2 p 1, KB2 p 2, KB2 p 3 and KB2 p 4 respectively.

(iii) **Soils of mapping unit KB3:**

This mapping unit was associated with the smooth plains with some local relief. It had a slope of 2-4 %. The soil unit has a gentle slope with undulating plains. Deposition within this mapping unit was due to materials eroded from the upland. The soil unit was very deep (> 150 cm). The occurrence of water Table at 190 cm of subsurface was a unique characteristic of this soil mapping unit.

(iv) **Soils of the mapping unit KB4:**

This mapping unit was associated with the irregular plains with some low relief. The unit had a steep slope (4-7 %) toward the upper slope. The soils were also very deep (> 150 cm) and had plinthites within 180 cm of soil surface. Gullies were a common feature of this unit.

(v) **Soil mapping unit KB5:**

This soil unit was associated with the flat or nearly flat plains (upland plain) with a slope less than 2 %. The soils were extremely deep (200 cm).

(vi) **Soils of mapping unit KB6:**

This soil unit was associated with the flood plains (fadama) with less than 2 % slope. The soils occupied the lowest position in the landscape in the study area. They serve as recipients of materials that were eroded from the uplands. The soils developed from thick colluvial-alluvial depositions giving rise to deep (> 100 cm) poorly drained soils with water table at 120cm. This water table could rise close to the surface or even above it during the rainy season.Extent of the landforms and their associated soil mapping units are shown in Table 4.1.

Table 4.1: Landforms/soil mapping units their extent and slope characteristics

	Associated landform	soil mapping unit	Slope degree	Extent of soil unit(ha)	Extent of landform unit (ha)	% Total area
	Tableland with very high relief	KB1	18-30%	15.80	15.80	18.37
	Irregular plain with some moderate relief	KB2	2-4 %	22.20	22.20	25.81
	Smooth plain with some local relief	KB3	2-4 %	12.00	12.00	13.95
	Irregular plain with low relief	KB4	4-7 %	15.10	15.10	17.56
	Flat or nearly flat plain	KB5	0-2%	10.90	10.90	12.67
	Flood plain	KB6	< 2%	10.00	10.00	11.63
Total	6	6		86	86	100

4.3 Soil morphological properties

Soils of the study area were generally deep to very deep ranging from 90 to 200 cm and the drainage ranges from excessively drained in soils of KB1 to very poorly drain in soils of KB6. In terms of structure there was no structural class for soils of KB1 because no profile pit was dug, the soils were within the rocky outcrops. The undulating plains had good structure of sub-angular blocky compared to the flood plains with structure less (massive) structure.

The summaries of soil morphological properties of the study area are shown in Tables 4.2.

Table :4.2Summary of Morphological properties of the landforms/ soil mapping units within the study area.

Landforms/soil units	Horizons	Depth	color (moist)	Texture	Structure	Consistency wet/moist/dry			Boundary	Features
IPSMR/KB2					Location:	Lat 11°06.405'N			Long 007°40.172' E	Altitude 651m
Profile p 1	Ap	0-14	10YR 3/4	scL	mmsbk	vsvp	fm	h	as	few fine roots, many micro-macro tubular and vesicular pores.
	Bt1	14-69	10YR 5/4	L	smsbk	sssp	vfr	s	cs	few fine roots, many micro-macro tubular and vesicular pores ,few clay cutans, common medium ant and termite holes, few Fe and Mn concretion.
	Bt2	69-124	5Y 5/2	L	mmsbk	sssp	vfr	s	ds	few micro-macro tubular pores, few fine ant holes, many Fe concretion, cracks both vertical and horizontal
	Cg	124-190	5Y 3/2	sL	Strless(m)	sssp	fm	h		few micro pores, cracks both vertical and horizontal.
IPSMR/KB2					Location:	Lat11°06.253' N			Longitude 007°40.942' E	Altitude 658m
Profile p2	Ap	0-20	10YR 4/4	cL	mmsbk	vsvp	fm	h	as	Few fine roots, many micro and few macro tubular/vesicular pores, few cracks both vertical and horizontal.
	Bt	20-67	7.5YR 4/6	cL	mmsbk	vsvp	fm	s	cs	Few fine-medium roots, many micro and few macro tubular pores, few coarse ant holes, common clay cutans, cracks both vertical and horizontal.
	Btg	67-140	5Y 5/2	L	wmsbk	vsvp	fm	s	as	Many fine Fe concretion, many micro and few macro pores, many medium ant holes, few cracks, few clay cutans. Presence of plinthite
	Btgv	140-190	5Y 5/2	sL	Strless(m)	sssp	vfr	l		Many fine Fe concretion, many micro and few macro pores, many medium ant holes, few cracks, few clay cutans. Presence of plinthite

IPSMR=irregular plains with some moderate relief

Table :4.2 Summary of Morphological properties of the landforms/soil mapping units within the study area. cont.

Landforms/soil units	Horizons	Depth	color (moist)	Texture	Structure	Consistency wet/moist/dry			Boundary	Features
IPSMR/KB2					Location:	Lat 11°06.167' N			Long 007°40.814' E	Altitude 665m
Profile p 3	Ap	0-15	7.5YR 4/4	L	mfsbk	vsvp	fm	s	as	few fine roots, many micro-macro tubular and vesicular pores, few Fe concretions.
	Bt	15-28	2.5YR 5/8	sL	wfsbk	vsvp	fm	s	cs	few medium roots, many micro-macro tubular and vesicular pores ,few clay cutans, few medium ant and termite holes, few Fe and Mn concretion.
	Btc	28-80	2.5YR 4/6	scL	wfsbk	sssp	vfr	s	ds	common micro-macro tubular pores, common fine ant holes, many Fe and Mn concretion.
	Cv	80-170	2.5YR 4/6	sL	Strless(m)	sssp	l	l		many micro and few macro pores, presence of plinthite.
IPSMR/KB2					Location:	Lat 11°05.902' N			Long 007°40.322' E	Altitude 673ml
Profile p 4	Ap	0-34	10YR 6/6	scL	wfsbk	nsnp	vfr	s	cs	common fine roots, many micro tubular pores, few ant holes.
	Bt	34-104	5YR 4/6	scL	scsbk	vsvp	fm	h	ds	Few fine roots, many micro-macro tubular/vesicular pores, many medium-coarse ant holes, common clay cutans, cracks both vertical and horizontal, many fine saprolite.
	B/C	104-190	10YR4/6	scL	strless(m)	vsvp	fm	vh		Many medium Fe concretion, many macro and few micro pores, few fine ant holes, few clay cutans, fine medium saprolite.

IPSMR=irregular plains with some moderate relief

Table :4.2Summary of Morphological properties of the landforms/ soil mapping units within the study area. cont.

Landforms/soil units	Horizons	Depth	color (moist)	Texture	Structure	Consistency wet/moist/dry			Boundary	Features
SPSLR/KB3					Location:	Latitude 11°06.413' N			Longitude 007°40.717' E	Altitude 685m
Profile p 1	Ap	0-45	10YR 3/1	scL	mfsbk	nsnp	vfr	s	as	many fine roots, many micro-macro tubular and vesicular pores, few fine ant holes many mica flakes, many fine saprolite.
	E	45-62	10YR6/2	sL	wfsbk	nsnp	vfr	s	as	Few fine roots, many micro-macro tubular and vesicular pores, many fine Fe concretion, many fine saprolite.
	Btg	62-130	10YR4/1	sc	mfsbk	sssp	fm	h	as	few fine roots, many medium Fe concretion, many micro-macro tubular and vesicular pores, few ant and termite holes, many clay cutans., vertical cracks
	Cg	130-190	5YR5/1	L	Strless(m)	vsvp	fm	vh		Common fine roots, Many mica flake., clay cutans, vertical cracks
SPSLR/KB3					Location:	Latitude 11°06.462' N			Longitude 007°41.256' E	Altitude 647m
Profile p 2	Ap	0-15	10YR 4/4	sL	mmsbk	sssp	vfr	s	as	Few fine roots, many micro-macro tubular pores, few ant holes.
	B	15-35	10YR 4/4	L	scsbk	sssp	fm	h	cs	Few fine roots, many micro tubular pores, few fine ant holes, few fine-medium Fe and Mn concretions
	Bc	35-75	10YR 5/2	scL	Strless(m)	sssp	fm	l	ds	few fine roots, common micro and macro pores, few medium ant holes,many Fe and Mn concretion.
	Cg	75-200	5Y 5/1	sL	Strless(m)	sssp	fm	l		Many coarse saprolite.

SPSLR=smooth plains with some local relief

Table :4.2 Summary of Morphological properties of the landforms/soil mapping units within the study area. cont.

Landforms/soil units	Horizons	Depth	color (moist)	Texture	Structure	Consistency wet/moist/dry			Boundary	Features
IPLR/KB4					Location:	Lat 11°06.529' N			Long 007°41.398' E	Altitude 635m
Profile p 1	Ap	0-10	7.5YR5/6	L	wmsbk	sssp	vfr	s	cs	many fine-medium roots, many micro-macro tubular and vesicular pores, few fine saprolite.
	B	10-65	5YR4/6	L	mmsbk	sssp	fm	s	cs	Common fine roots, many micro and few macro tubular and vesicular pores, few ant and termite holes.
	C	65-90	2.5YR6/2	scL	Strless(m)	sssp	fm	h		common medium Fe and Mn concretion, many fine micro and few coarse macro pores.
IPLR/KB4					Location:	Lat 11°06.482' N			Long 007°41.333' E	Altitude 634m
Profile p 2	A	0-35	7.5YR5/8	scL	wmsbk	sssp	vfr	s	as	few fine roots, few micro tubular pores, few coarse ant holes, few fine saprolite.
	C	35-104	5Y5/2	scL	Strless(m)	sssp	fm	h		few micro-macro tubular/vesicular pores, many medium saprolite.

IPLR=irregular plains with low relief

Table : 4.2 Summary of Morphological properties of the landforms/soil mapping units within the study area

Landforms/soil units	Horizons	Depth	color (moist)	Texture	Structure	Consistency wet/moist/dry			Boundary	Features
FNFP(upland)/KB5				Location:	Lat 11°06.581' N			Long 007°41.505' E		Altitude 636m
Profile p 1	Ap	0-14	10YR 4/3	sL	mmsbk	nsnp	vfr	s	cs	many fine roots, few micro tubular pores.
	B1	14-36	10YR 4/6	L	smsbk	nsnp	vfr	s	cs	Common fine roots, many micro-macro tubular pores ,few ant termite holes, cracks.
	B2	36-107	10YR 5/4	siL	smsbk	sssp	vfr	s	cs	many medium Fe concretion, many micro-macro tubular pores few ant holes.
	B3	107-200	10YR 7/2	siL	wmsbk	sssp	vfr	s	cs	Many coarse Fe concretions, many fine micro tubular pores.
FNFP(upland)/KB5				Location:	Lat 11°06.588' N			Long 007°41.457' E		Altitude 636m
Profile p2	Ap	0-5	10YR 4/3	sL	mmsbk	nsnp	vfr	s	cs	Few fine roots, few micro tubular pores.
	B1	5-33	10YR 4/6	L	smsbk	nsnp	vfr	s	cs	Common fine roots, few fine micro tubular and vesicular pores, few Vertical cracks.
	B2	33-132	10YR 5/4	L	mmsbk	sssp	vfr	s	cs	Many Fe/few Mn concretion, many micro and macro tubular and vesicular Pores, few coarse ant and termites holes.
	B3	132-200	10YR 7/2	siL	wmsbk	sssp	vfr	s	cs	Many coarse Mn concretions, Few micro tubular and vesicular pores.

FNFP=flat or nearly flat plains

Table 4.2: Morphological properties of the soil mapping units within the study area. cont.

Landforms/soil units	Horizons	Depth	color (moist)	Texture	Structure	Consistency wet/moist/dry	Boundary	Features
FP/KB6					Location:	Latitude 11o06.626' N	Longitude 007o40.531' E	Altitude 630m above sea level (asl)
Profile p 1	Ap	0-36	10YR 4/2	L	Strless(m)	sssp fm h	cs	many fine-medium roots, many micro tubular pores, cracks both vertical and horizontal, few fine clay cutans, few ant holes,
	Bt	36-82	10YR 6/6	siL	Strless(m)	sssp fmvh	cs	many fine-medium roots, many micro-macro tubular pores ,few ant and termite holes, many mica flake, few Mn concretion.
	Btg	82-95	10YR 7/2	sL	Strless(m)	nsnp vfr s	ci	Many fine roots, many mica flake, many micro tubular pore
	C	95-110	7.5YR 5/6	sL	Strless(m)	nsnp l s	cs	Common fine roots, Many mica flake.
	2A	110-120	10YR 6/1	L	Strless(m)	nsnp fm s		Many common mica flake
FP/KB6					Location:	Latitude 11o06.593' N	Longitude 007o41.441' E	Altitude 632m above sea level (asl)
Profile p 2	Ap	0-10	10YR 4/4	L	mmsbk	sssp fm h	cw	Many medium roots, few micro tubular pores.
	B	010-73	10YR 5/4	L	Strless(m)	sssp fm h	ds	Few medium-coarse roots, many micro tubular pores, few medium ant holes
	Bt	73-93	10YR 4/2	L	Strless(m)	sssp fm h	cs	Many fine roots, Very few micro pores, few medium Fe concretion
	Btg	93-104	10YR 5/1	siL	Strless(m)	sssp fm s	as	Few fine roots, Few micro pores, few mica flake
	C	104-120	5YR 5/6	s	Strless(m)	nsnp l s		

FNFP=flat or nearly flat plains,**Texture:** L-loam, SL-sandy loam, SCL-sandy clay loam, Sc- sandy clay,SiL-silt loam, CL-clay
Structure: Wfsbk-weak,fine,subangular blocky, Msmsbk-moderately strong medium subangular blocky, Scsbk-strong,coarse subangular blocky, Strless(m)-structureless (massive),**Consistence:wet (stickiness):** ns-none sticky, ss-slightly sticky,s-sticky, vs- very sticky, **Wet (plasticity):** np-none plastic, sp-slightly plastic,p- plastic, vp- very plastic, **Moist:**fr-friable, vfr-very friable, fm-firm,vfm-very firm,L-loose,**Dry:** s- soft, sh-slightly hard,h-hard,vh-very hard,
Boundary: Distinctness (thickness): a-abrupt (< 2 cm), c-clear (2-5 cm), g-gradual (5-15 cm), d-diffuse (> 15 cm), **Topography:** s-smooth, w-weavy, i-irregular,b-broken.

4.3.1 Soil physical properties

The summary of the physical properties are shown in Table 4.3 and 4.4.

(a) Particle size distribution across landforms/soil units.

The particle size distribution across the soil units was dominated by the clay fraction. In the surface horizons clay content ranged from 250gkg^{-1} to 710gkg^{-1}with a mean of (480gkg^{-1}), 590gkg^{-1} to 610gkg^{-1}(600gkg^{-1}), 510gkg^{-1} to 570gkg^{-1}(540gkg^{-1}), 530gkg^{-1} to 570gkg^{-1} (550 gkg^{-1}) for soil units KB2, KB3, KB4, and soil unit KB5 in that order which are all of the undulating plains and 370gkg^{-1} to 420gkg^{-1} (395gkg^{-1}) for that of the flood plain associated with soil unit KB6.

The corresponding values of clay fraction for the sub-surface horizons of pedons ranges from 410gkg^{-1} to 710gkg^{-1}with a mean of (560 gkg^{-1}), 470gkg^{-1} to 610gkg^{-1}(540 gkg^{-1}), 410gkg^{-1} to 650gkg^{-1} (530 gkg^{-1}), 270gkg^{-1} to 410gkg^{-1} (340 gkg^{-1}) which are all of the undulating plains and 410 to 910 (660 gkg^{-1}) for the flood plain respectively.

Generally clay fractions were higher inthe surface horizons of soil units KB2 p1, p4, KB3 p2, KB4 p1, and KB5 p1 and p2 and in the subsurface it higher in KB2 p2, p3, KB3 p1, KB4 p2 and KB6 p1 and p2 Table 4.2. Second to clay fraction was sand fraction with its surface values ranging from 390 gkg^{-1} to 230 gkg^{-1}with a mean of (310 gkg^{-1}), 270 gkg^{-1} to 190 gkg^{-1} (230 gkg^{-1}), 210 gkg^{-1} to 130 gkg^{-1} (170 gkg^{-1}), 130 gkg^{-1} to 190 gkg^{-1} (160 gkg^{-1}) for soil units KB2, KB3, KB4, and soil unit KB5 in that order which are all of the undulating plains and 150 gkg^{-1} to 190 gkg^{-1} (170 gkg^{-1}) for flood plain which is associated with soil unit KB6.

Table 4.3: physical parameters of landforms/soil units within the study area.

Landforms/soil units	Horizon	Depth (cm)	Sand	Silt	Clay	silt:clay ratio	Textural class
			Particle size distribution within the study area				
			← gkg^{-1} →				
IPSMR/KB2				Location:	Lat11^{o}06.405' N	Long 007^{o}40.172' E	Altitude 651m
Profile p1	Ap	0-14	230	160	610	0.26	sandy clay
	Bt1	14-69	230	280	490	0.57	loam
	Bt2	69-190	230	280	510	0.55	loam
	Cg	190-214	70	320	610	0.52	sandy loam
IPSMR/KB2				Location:	Lat11^{o}06.253' N	Long007^{o}40.942' E	Altitude 658m
profile p2	Ap	0-20	390	360	250	1.44	Clay Loam
	Bt	20-67	290	300	410	0.73	Clay Loam
	Btg	67-140	270	300	430	0.70	Loam
	Btgv	140-190	90	320	590	0.54	Sandy Loam
IPSMR/KB2				Location:	Lat 11^{o}06.167' N	Long 007^{o}40.814' E	Altitude 665m
profile p3	Ap	0-15	250	300	450	0.67	Loam
	Bt	15-28	70	380	550	0.69	Sandy Loam
	Btc	28-80	210	240	550	0.44	Sandy Clay Loam
	Cv	80-170	70	220	710	0.31	Sandy Loam
IPSMR/KB2				Location:	Lat 11^{o}05.902' N	Long 007^{o}40.322' E	Altitude 673m
profile p4	Ap	0-34	250	40	710	0.06	Sandy Clay Loam
	Bt	34-104	270	240	490	0.49	Sandy Clay Loam
	B/C	104-190	310	240	450	0.53	Sandy Clay Loam
SPSLR/KB3				Location:	Lat 11^{o}06.413' N	Long 007^{o}40.717' E	Altitude 685m
profile p1	Ap	0-45	270	120	610	0.20	Sandy Clay Loam
	E	45-62	130	260	610	0.43	Sandy Loam
	Btg	62-130	390	140	470	0.30	Sandy Clay
	Cg	130-190	90	400	510	0.78	Loam
SPSLR/KB3				Location:	Lat11^{o}06.462' N	Long 007^{o}41.256' E	Altitude 647m
Profile p2	Ap	0-15	190	220	590	0.37	Sandy Loam
	B	15-35	210	300	490	0.61	Loam
	Bc	35-75	270	160	570	0.28	Sandy Clay Loam
	Cg	75-200	50	380	570	0.67	Sandy Loam

IPSMR=irregular plains with some moderate relief,SPSLR=smooth plains with some local relief

Table 4.3: physical parameters of landforms/soil units within the study area cont.

Landforms/soil units	Horizon	Depth (cm)	Sand	Silt	Clay	silt:clay ratio	Textural class
		Particle size distribution within the study area					
			←	gkg^{-1}	→		
IPLR/KB4	Location:	Lat 11°06.529' N		Long 007°41.398' E		Altitude 635m	
profile p1	A	0-10	130	360	510	0.71	Loam
	B	010-65	270	320	410	0.78	Loam
	C	65-90	250	100	650	0.15	Sandy Clay Loam
IPLR/KB4	Location:	Lat 11°06.482' N		Long 007°41.333' E		Altitude 634m	
profile p2	A	0-35	210	220	570	0.39	Sandy Clay Loam
	B	35-180	230	160	610	0.26	Sandy Clay Loam
FNFP/KB5	Location:	Lat 11°06.581' N		Long 007°41.505' E		Altitude 636m	
Profile p1	Ap	0-14	130	300	570	0.53	sandy loam
	B1	14-36	250	340	410	0.83	loam
	B2	36-107	170	560	270	2.07	silt loam
	B3	107-200	90	520	390	1.33	silt loam
FNFP/KB5	Location:	Lat 11°06.588' N		Long 007°41.457' E		Altitude 636m	
Profile p2	Ap	0-5	190	280	530	0.53	sandy loam
	B1	5-33	230	380	390	0.97	loam
	B2	33-132	270	320	410	0.78	loam
	B3	132-200	70	520	410	1.27	silt loam
FNFP/KB6	Location:	Lat 11°06.626' N		Long 007°40.531' E		Altitude 630m	
profile p1	AP	0-36	150	480	370	1.30	Loam
	Bt	36-82	90	500	410	1.22	Silt Loam
	Btg	82-95	110	300	590	0.51	Sandy Loam
	C	95-110	130	120	750	0.16	Sandy Loam
	2A	110-120	110	480	410	1.17	Loam
FNFP/KB6	Location:	Lat 11°06.593' N		Long 007°41.441' E		Altitude 632m	
profile p2	Ap	0-10	190	400	420	0.95	Loam
	B	10-73	190	340	470	0.72	Loam
	Bt	73-93	150	360	490	0.73	Loam
	Btg	93-104	90	500	410	1.22	Silt Loam
	C	104-120	50	40	910	0.04	Sand

IPLR=irregular plains with low relief,FP=flood plains

In the same order, the corresponding values for the sub-surface horizons ranged from 70gkg^{-1} to 310gkg^{-1}with a mean of (190gkg^{-1}), 50gkg^{-1} to 390gkg^{-1}(220 gkg^{-1}), 20gkg^{-1} to 270gkg^{-1} (250gkg^{-1}), 70gkg^{-1} to 270gkg^{-1} (170 gkg^{-1}) and 50gkg^{-1} to 150gkg^{-1} (100gkg^{-1}). Sand fractions were higher in surface horizons than the subsurface horizons of soil units KB2 p1, p2, p3 and KB3 p1, KB4 p2 KB5 p2 and in KB6 but the reverse was the case for soil units KB2 p4, KB3 p2, KB4 p1 and KB5 p1. This irregular distribution trend within profiles implies that sedimentation was the process of soil formation in this study area.

The third most dominant fraction was the Silt with it surface horizon values ranging from 360 gkg^{-1} to 40 gkg^{-1} with a mean of (200 gkg^{-1}), 120 gkg^{-1} to 220 gkg^{-1} (170 gkg^{-1}), 220 gkg^{-1} to 360 gkg^{-1} (290 gkg^{-1}), 280 gkg^{-1} to 300 gkg^{-1} (290 gkg^{-1}),for soil units KB2, KB3, KB4, and soil unit KB5 which are all of the undulating plains and 400 gkg^{-1} to 480 gkg^{-1} (440 gkg^{-1}) for flood plain which is associated with soil unit KB6.

Similarly the corresponding values for the sub-surface horizons ranged from 220gkg^{-1} to 380gkg^{-1} (300gkg^{-1}), 140gkg^{-1} to 400gkg^{-1} (270gkg^{-1}), 100gkg^{-1} to 320gkg^{-1} (210gkg^{-1}), 320 to 520gkg^{-1} (420gkg^{-1}) and 40gkg^{-1} to 500gkg^{-1} (270gkg^{-1}).

The silt content was higher at the surface horizons of soil units KB2 p2, KB4 p1, p2 and KB6 p2 while in subsurface horizons it was higher in soil units KB2 p1, p3, p4, KB3 p1, p2, KB5 p1, p2 and in KB6 p1 (Table 4.3).

The values of the silt/clay ratio for surface horizons ranges from 0.06 to 1.44 with a mean of (0.75), 0.20 to 0.37 (0.29), 0.39 to 0.71 (0.55), 0.53 to 0.53 (0.53) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 0.95 to 1.30 (1.13), for flood plain which is associated with soil unit KB6.

In the same order, the corresponding values for the sub-surface horizons range from 0.31 to 0.73 (0.52), 0.28 to 0.78 (0.53), 0.15 to 0.78 (0.47), 2.07 to 0.78 (1.43) and 0.04 to 1.22 (0.63). The silt/clay ratio across the study area was lower than the value (< 0.75 and 1.5) proposed by Sombroek and Zonneveld (1971) Table 4.3.

b) Bulk density across Landforms/Soil units within the study area.

The data on bulk density is represented in table 4.4. The values of bulk density across the surface horizons of all soil units in the study area ranged from 1.44 g/cm^3 to 1.46 g/cm^{3}with a mean of (1.45 g/cm^3), 1.53 g/cm^3 to 1.60 g/cm^3 (1.57 g/cm^3), 1.46 g/cm^3 to 1.71 g/cm^3 (1.59 g/cm^3), 1.35 g/cm^3 to 1.42 g/cm^3 (1.39 g/cm^3) for soil units KB2, KB3 KB4, and KB5 in that order, which are all of the undulating plains and 1.15 g/cm^3 to 1.33 g/cm^3 (1.29 g/cm^3) for flood plain which is associated with soil unit KB6.

In the same order, the corresponding values for the sub-surface horizons ranged from 1.42 g/cm^3 to 2.05 g/cm^3 (1.74 g/cm^3), 0.92 g/cm^3 to 2.34 g/cm^3 (1.63 g/cm^3), 1.12 g/cm^3 to 1.37 g/cm^3 (1.25 g/cm^3), 0.92 g/cm^3 to 1.56 g/cm^3 (1.24 g/cm^3) and 1.30 g/cm^3 to 2.34 g/cm^3 (1.82g/cm^3). Bulk density at the surface horizon across all soil units was generally low, lower than 1.85 g/cm^3 as proposed by Malgwi (2007) except for soil unit KB4 (Table 4.4).

Table 4.4: Soil physical parameters of bulk density, total porosity and AWHC of the landforms within the study area

Landforms/soil units	Horizon	Depth (cm)	Bulk density(g/cm^3)	Total porosity(%)	AWHC (%)		
IPSMR/KB2			Location:	Lat 11°06.405' N	Long 007°40.172' E	Altitude 651m	
Profile pit 1	Ap	0-14	1.46	14.87	2.00		
	Bt1	14-69	1.75	18.64	8.00		
	Bt2	69-124	1.63	12.24	3.00		
	Cg	124-190	1.61	14.75	3.00		
IPSMR/KB2			Location:	Lat 11°06.253' N	Long 007°40.942' E	Altitude 658m	
Profile pit 2	Ap	0-20	1.45	5.72	13.00		
	Bt	20-67	1.45	12.92	13.00		
	Btg	67-140	1.67	16.58	11.00		
	Btgv	140-190	1.59	8.58	4.00		
IPSMR/KB2			Location:	Lat 11°06.167' N	Long 007°40.814' E	Altitude 665m	
profile pit 3	Ap	0-15	1.44	5.49	15.00		
	Bt	15-28	1.46	11.67	7.00		
	Btc	28-80	1.59	10.18	18.00		
	Cv	80-170	1.42	8.01	14.00		
IPSMR/KB2			Location:	Lat 11°05.902' N	Long 007°40.322' E	Altitude 673m	
profile pit 4	Ap	0-34	1.45	2.75	17.00		
	Bt	34-104	1.57	14.3	9.00		
	B/C	104-190	1.50	9.49	25.00		
SPSLR/KB3			Location:	Lat 11°06.413' N	Long 007°40.717' E	Altitude 685m	
profile pit 1	Ap	0-45	1.60	5.83	9.00		
	E	45-62	1.47	1.49	15.00		
	Btg	62-130	1.48	8.81	8.00		
	Cg	130-190	1.66	11.67	25.00		
SPSLR/KB3			Location:	Lat 11°06.462' N	Long 007°41.256' E	Altitude 647m	
Profile pit 2	Ap	0-15	1.53	13.73	2.00		
	B	15-35	1.58	14.87	5.00		
	Bc	35-75	1.65	12.35	6.00		
	Cg	75-200	1.50	10.75	3.00		

IPSMR=irregular plains with some moderate relief
SPSLR=smooth plains with some local relief

Table 4.4: Soil physical parameters of bulk density, total porosity and AWHC of the landforms within the study area

Landforms/soil units	Horizon	Depth (cm)	Bulk density(g/cm3)	Total porosity(%)	AWHC (%)
IPLR/KB4			Location:	Lat 11^{o}06.529' N Long 007^{o}41.398' E	Altitude 635m
Profile pit 1	A	0-10	1.46	9.72	10.00
	B	10-65	1.32	8.58	7.00
	C	65-90	1.37	9.38	4.00
IPLR/KB4			Location:	Lat 11^{o}06.482' N Long 007^{o}41.333' E	Altitude 634m
Profile pit 2	A	0-35	1.71	11.09	13.00
	B	35-180	1.21	4.23	19.00
FNFP(upland)/KB5			Location:	Lat 11^{o}06.581' N Long 007^{o}41.505' E	Altitude 636m
Profile pit 1	Ap	0-14	1.35	10.41	1.00
	B1	14-36	1.43	19.40	15.00
	B2	36-107	1.56	16.81	25.00
	B3	107-200	1.52	18.87	12.00
FNFP(upland)/KB5			Location:	Lat 11^{o}06.588' N Long 007^{o}41.457' E	Altitude 636m
Profile pit 2	Ap	0-5	1.42	13.27	17.00
	B1	5-33	1.46	12.47	16.00
	B2	33-132	1.29	10.52	17.00
	B3	132-200	1.48	26.31	10.00
FP/KB6			Location:	Lat 11^{o}06.626' N Long 007^{o}40.531' E	Altitude 630m
Profile pit 1	AP	0-36	1.33	31.11	4.00
	Bt	36-82	1.59	24.59	9.00
	Btg	82-95	1.84	30.54	33.00
	C	95-110	1.80	18.53	6.00
	2A	110-12(	1.58	35.00	13.00
FP/KB6			Location:	Lat 11^{o}06.593' N Long 007^{o}41.441' E	Altitude 632m
Profile pit 2	Ap	0-10	1.15	16.93	19.00
	B	10-73	1.52	10.98	7.00
	Bt	73-93	1.54	27.79	12.00
	Btg	93-104	1.49	34.66	10.00
	C	104-12(	1.30	11.44	13.00

IPLR=irregular plains with low relief
FNFP=flat or nearly flat plains

FP=flood plain

c) **Impact of topography on total porosity across the landforms in the study area**

The value for total porosity across the study area for surface horizons ranged from 14.87% to 2.75% with a mean of (8.81%), 13.73% to 5.83% (9.78%), 11.09% to 9.72% (10.41%), 10.41% to 13.27% (11.84%) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 16.93% to 31.11% (24.02%)for flood plain which is associated with soil unit KB6.

In the same order, the subsurface horizons ranges from 18.64% to 8.01% (13.33%), 14.87% to 1.49% (8.18%), 9.38% to 4.23% (6.81%), 10.52% to 67.25% (38.89%)and 11.44% to 35.00% (23.22 %). Soils of unit KB2, KB3, KB4 and KB6 were rated poor soils (< 30%) as proposed by Kachinkii (1965) while soils of KB5 were rated unsatisfactory soil (<40%).

d) **Impact of topography on soil available water holding capacity (AWHC) across landforms/Soil units in the study area**

The available water holding capacity (AWHC) across the soil units varies from 2% to 17% with a mean of (9.5 %), 2% to 9% (5.5 %), 10% to 13% (11.5%), 1% to 17% (9.0%) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 4% to 19% (11.5%) for flood plain which is associated with soil unit KB6.

In the same order, the subsurface horizons ranged from 3% to 25% (14%), 3% to 25% (14%), 4% to 19% (11.5%), 10% to 25% (17.5%) and 6% to 33% (19.5%). Available water holding capacity was higher in the surface horizons of soil units KB4 p1 and KB6 p2while in the subsurface horizons it was higher in KB2, KB3, KB4 p2, KB5 and KB6 p1. Table 4.4. It was positively correlated with CEC Table 4.5.

Table 4.5 : Correlation matrix for physio-chemical properties.

	Sand	Silt	Clay	pd	AWHC	$pH(H_2O)$	$pH(CaCl_2)$	TEB	TEA	CEC	CEC clay	ECEC	OC	TN	AP	Ec
Silt	-0.38**															
Clay	-0.32	-0.76***														
pd	-0.1	-0.13	0.2													
AWHC	0.06	0.12	0.17*	-0.03												
$pH(H_2O)$	-0.04	-0.01	0.04	0.29*	-0.02											
$pH(CaCl_2)$	-0.01	0.09	-0.08	0.27*	-0.12	0.6***										
TEB	0.21	-0.02	-0.12	0.11	-0.31*	0.36*	0.59***									
TEA	-0.02	0.25	-0.24	-0.01	-0.04	-0.42**	-0.54***	-0.26*								
CEC	0.11	0.09	0.16**	-0.07	0.25*	0.41**	0.58***	0.66***	-0.19							
CEC clay	0.2	0.3*	-0.45**	-0.08	-0.09	0.38*	0.49***	0.55***	-0.04	0.9***						
ECEC	0.21	0.01	-0.16	0.12	-0.32*	0.32*	0.53***	0.99**	-0.13	0.65***	0.56***					
OC	0.21	0.02	-0.17**	-0.25*	-0.15	-0.15	0.09	0.16	-0.12	0.06	-0.14	0.15				
TN	0.16	0.17	-0.29*	0.02	-0.25	0.03	0.4**	0.31*	-0.2	0.35*	0.22	0.29*	0.72***			
AP	0.08	-0.23	0.18	-0.13	-0.2	-0.15	0.19	0.24	-0.13	0.11	-0.13	0.23	0.56***	0.42		
Ec	-0.1	0.07	0.01	-0.1	-0.28*	-0.15	0.5***	0.35*	-0.28*	0.36*	0.22	0.32*	0.37*	0.37	0.57	

Significance level: ***=p 0.05, **= p 0.01, ***= p 0.001**

4.3.2 **Impact of Landforms/Soil units on Soil Chemical properties**

a) Impact of Topography on soil reaction (pH) across Landforms/Soil units.

The data for pH across soil units is shown in Table 4.5. The values of the soil pH (H_20) across the surface horizons of all soil units in the study area ranged from 5.85 to 6.38 with a mean of (6.12), 5.83 to 6.50 (6.20), 6.09 to 6.24 (6.17), 6.13 to 6.36 (6.25)for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 5.60 to 5.70 (5.65)for flood plain/KB6.

In the same order, thepH of subsurface horizons ranges from 5.56 to 6.55 (6.21), 6.02 to 6.56 (6.34), 5.84 to6.09 (5.97), 5.57 to pH 6.30 (5.94) and 5.50 to 6.50 (6.0).

The soil pH ($CaCl_2$) for surface horizons, the value ranged from4.02 to 5.40 with a mean of (4.71), 4.92 to 4.97 (4.95), 4.03 to 4.55 (4.29), 4.80 to 5.20 (5.00) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 4.89 to 5.04 (4.97) for flood plain/KB6.

In the same order thepH ($CaCl_2$) of subsurface horizons ranges from 4.33 to 5.68 (5.01), 4.72 to 5.52 (5.12), 3.73 to 4.37 (4.05), 4.52 to 4.98 (4.75) and 4.11 to 5.25 (4.68). Generally, soil reaction (pH) was moderate to slightly acidic across the undulating plains, while the flood plain which is associated with soil unit KB6 was moderately acidic at the surface and very strong acidic to slightly acidic at the sub-surface.

Table 4.6: some chemical properties of landforms/soil units within the study area

Landforms/soil units	Horizon	Depth (cm)	pH 1:2.5			Exchangeable bases mg/kg								
			H20	CaCl2	Δ pH	Ca	Mg		Na	TEB	Al+H	Ec	SAR	ESP
						← cmol(+)kg-1 →						← dS/m →		%
IPSMR/KB2				Location:	Latitude 11°06.405' N		Longitude 007°40.172' E		Altitude 651m asl					
Profile p1	Ap	0-14	6.00	5.40	-0.60	8.00	0.68	0.15	0.44	9.27	0.20	0.20	0.09	4.44
	Bt1	14-69	6.50	5.59	-1.21	7.98	0.82	0.11	0.42	9.33	0.20	0.05	0.14	3.34
	Bt2	69-124	6.55	5.68	-1.17	4.85	0.51	0.08	0.53	5.97	0.20	0.07	0.23	5.31
	Cg	124-190	6.45	5.52	-1.23	6.78	0.66	0.08	0.43	7.95	0.20	0.05	0.16	4.49
IPSMR/KB2				Location:	Latitude 11°06.253' N		Longitude 007°40.942' E		Altitude 658m asl					
profile p2	Ap	0-20	6.38	5.22	-1.16	3.43	0.33	0.07	0.35	4.18	0.20	0.05	0.18	5.04
	Bt	20-67	6.38	5.17	-1.21	5.05	0.91	0.10	0.56	6.62	0.40	0.05	0.23	4.56
	Btg	67-140	6.45	5.35	-1.10	6.49	0.75	0.11	0.37	7.72	0.40	0.05	0.14	3.51
	Btgv	140-190	6.55	5.30	-1.30	3.86	0.65	0.10	0.42	5.03	0.20	0.09	0.20	4.75

IPSMR=irregular plains with some moderate relief

Table 4.6: some chemical properties of landforms/soil units within the study area

Landforms/soil units	Horizon	Depth (cm)	pH 1:2.5 H20	pH 1:2.5 CaCl2	Δ pH	Ca	Mg	k	Na	TEB	Al+H	Ec	SAR	ESP
						Exchangeable bases cmol(+)kg^{-1}								
						←		cmol(+)kg^{-1}		→		← dS/m →		%
IPSMR/KB2				Location:	Latitude 11°06.167' N		Longitude 007°40.814' E		Altitude 665 m asl					
profile p3	Ap	0-15	6.12	5.20	-0.92	2.34	0.32	0.13	0.33	3.12	0.20	0.05	0.20	6.01
	Bt	15-28	6.17	4.54	-1.63	2.88	0.51	0.18	0.30	3.87	0.20	0.04	0.16	2.96
	Btc	28-80	6.63	4.54	-2.09	2.59	0.44	0.24	0.39	3.66	0.20	0.03	0.22	7.99
	Cv	80-170	6.50	4.58	-1.92	2.40	0.39	0.30	0.34	3.43	0.20	0.01	0.20	5.56
IPSMR/KB2				Location:	Latitude 11°05.902' N		Longitude 007°40.322' E		Altitude 673 m asl					
profile p4	Ap	0-34	5.85	4.02	-1.83	2.11	0.06	0.04	0.37	2.58	0.60	0.03	0.25	11.07
	Bt	34-104	5.56	4.33	-1.23	3.92	0.56	0.10	0.38	4.96	0.40	0.03	0.18	3.65
	B/C	104-190	6.14	4.45	-1.69	3.30	0.30	0.18	0.30	4.08	0.20	0.01	0.15	6.82

IPSMR=irregular plains with some moderate relief

Table 4.6: some chemical properties of landforms/soil units within the study area

Landforms/mapping units	Horizon	Depth (cm)	pH 1:2.5 H20	CaCl2	Δ pH	Ca	Mg	k	Na	TEB	Al+H	Ec	SAR	ESP
					Exchangeable bases cmol(+)kg^{-1}	←		Cmol(+)kg^{-1}			→	← dS/m →		%
SPSLR/KB3 profile			Location:	Latitude 11^{o}06.413' N	Longitude 007^{o}40.717' E				Altitude 685 m asl					
p1	Ap	0-45	6.50	4.97	-1.53	5.26	0.21	0.03	0.46	5.96	0.20	0.04	0.20	4.52
	E	45-62	6.40	5.50	-0.90	1.82	0.02	0.08	0.30	2.22	0.20	0.09	0.22	2.62
	Btg	62-130	6.56	5.45	-1.21	4.20	0.63	0.36	0.53	5.72	0.20	0.06	0.24	3.02
	Cg	130-190	6.63	5.52	-1.11	4.20	1.46	0.08	0.43	6.17	0.20	0.06	0.13	3.88
SPSLR/KB3 profile			Location:	Latitude 11^{o}06.462' N		Longitude 007^{o}41.256' E			Altitude 647 m asl					
p2	Ap	0-15	5.83	4.92	-0.91	3.01	0.28	0.06	0.43	3.78	0.20	0.10	0.23	5.47
	B	15-35	6.02	4.72	-1.30	4.46	0.27	0.07	0.56	5.36	0.80	0.01	0.26	6.55
	Bc	35-75	6.45	5.00	-1.45	4.02	0.21	0.05	0.43	4.71	0.40	0.03	0.21	10.15
	Cg	75-200	6.37	5.06	-1.31	6.11	0.55	0.07	0.49	7.22	0.40	0.03	0.19	3.84

SPSLR= smooth plains with some local relief

Table 4.6: some chemical properties of landforms/soil units within the study area

Landforms/mapping units	Horizon	Depth (cm)	pH 1:2.5 H20	CaCl2	Δ pH	Ca	Mg	k	Na	TEB	Al+H	Ec dS/m	SAR	ESP %
					Exchangeable bases $cmolkg^{-1}$	←		$Cmolkg^{-1}$		→				
IPLR/KB4			Location:	Latitude 11°06.529' N	Longitude 007°41.398' E				Altitude 635m asl					
profile p1	A	0-10	6.24	4.55	-1.69	2.80	0.28	0.14	0.26	3.48	0.20	0.03	0.15	2.72
	B	010-65	5.84	3.73	-2.11	2.30	0.12	0.06	0.42	2.90	0.60	0.01	0.27	8.19
	C	65-90	6.09	4.12	-1.97	3.00	0.30	0.16	0.41	3.87	0.20	0.01	0.22	10.00
IPLR/KB4			Location:	Latitude 11°06.482' N	Longitude 007°41.333' E				Altitude 634m asl					
profile p2	A	0-35	6.09	4.03	-2.06	1.30	0.30	0.12	0.15	1.87	0.80	0.01	0.28	5.36
	B	35-180	6.06	4.37	-1.69	2.50	0.35	0.14	0.32	3.31	0.20	0.01	0.16	8.94

IPLR= irregular plains with low relief

Table 4.6: some chemical properties of landforms/soil units within the study area

Landforms/mapping units	Horizon	Depth (cm)	pH 1:2.5 H20	CaCl2	Δ pH	Ca	Mg	k	Na	TEB	Al+H	Ec dS/m	SAR	ESP %
					Exchangeable bases cmolkg^{-1}	←	Cmolkg^{-1}		→			←	→	
FNFP/KB5 profile			Location:	Latitude 11°06.581' N	Longitude 007°40.505' E				Altitude 636 m asl					
p1	AP	0-14	6.13	4.8	-1.33	2.22	0.22	0.14	0.37	2.95	0.2	0.08	0.24	7.48
	B1	14-36	6.19	4.97	-1.22	3.1	0.34	0.08	0.43	3.95	0.2	0.07	0.23	4.89
	B2	36-107	6.04	4.89	-1.15	3.07	0.46	0.05	0.5	4.08	0.2	0.07	0.27	10.97
	B3	107-200	6.02	4.85	-1.17	2.82	0.26	0.04	0.49	3.61	0.4	0.08	0.28	6.67
FNFP/KB5 profile			Location:	Latitude 11°06.588' N	Longitude 007°41.457' E				Altitude 636 m asl					
p2	Ap	0-5	6.36	5.2	-1.16	2.94	0.32	0.15	0.42	3.83	0.2	0.06	0.23	4.75
	B1	5-33	6.3	4.68	-1.62	2.58	0.37	0.05	0.49	3.49	0.6	0.02	0.28	10.37
	B2	33-132	6.3	4.52	-1.78	2.85	0.35	0.06	0.47	3.73	0.6	0.02	0.26	6.02
	B3	132-200	5.57	4.76	-0.81	2.01	0.2	0.1	0.48	2.79	0.4	0.02	0.24	15.00

FNFP= flat or nearly flat plains

Table 4.6: some chemical properties of landforms/soil units within the study area

Landforms/ mapping units	Horizon	Depth (cm)	pH 1:2.5 H20	pH 1:2.5 CaCl2	Δ pH	Exchangeable bases cmolkg^{-1} Ca	Mg	k	Na	TEB Cmolkg^{-1}	Al+H	Ec dS/m	SAR	ESP %
FP/KB6 Profile p1	Location: Latitude 11°06.626' N				Longitude 007°40.531' E					Altitude 630 m asl				
	Ap	0-36	5.7	5.04	-1.36	3.2	0.51	0.3	0.45	4.46	0.4	0.06	0.16	5.65
	Bt	36-82	6.44	5.25	-1.39	3.58	0.18	0.05	0.39	4.20	0.2	0.05	0.20	4.77
	Btg	82-95	6.48	4.98	-1.5	1.81	0.11	0.04	0.07	2.03	0.2	0.01	0.05	1.39
	C	95-110	6.44	5.05	-1.49	1.67	0.1	0.03	0.3	2.10	0.2	0.06	0.22	6.57
	2A	110-120	5.5	4.11	-1.39	1.3	0.06	0.04	0.25	1.65	1.2	0.05	0.22	4.20
FP/KB6 Profile p2	Location: Latitude 11°06.593' N				Longitude 007°41.441' E					Altitude 632 m asl				
	Ap	0-10	5.6	4.89	-1.61	4.76	0.59	0.25	0.6	6.20	0.2	0.1	0.26	5.61
	B	10-73	6.5	4.73	-1.97	3.53	0.69	0.07	0.12	4.41	0.2	0.08	0.06	1.47
	Bt	73-93	6.48	5.1	-1.88	2.88	0.4	0.05	0.1	3.43	9.2	0.09	0.06	1.30
	Btg	93-104	6.5	4.12	-2.4	2.39	0.22	0.06	0.43	3.10	1	0.06	0.27	5.12
	C	104-120	6.1	4.51	-1.59	1.54	0.11	0.02	0.32	1.99	0.2	0.06	0.25	7.15

FP=flood plains

ΔpH across all soil units were negative for both surface and subsurface horizons and it was less than – 0.5 the value proposed by (Uehara and Gillman 1981).

b) **Impact of Topography on Salinity/Sodicity across the Landform/Soil units**

Summary of Electrical conductivity (Ece) across the soil units are shown in Table 4.6.

Electrical conductivity (ECe) is a good indicator of the degree of salinity of the soil. The ECe of the surface horizons ranged from 0.03 $dSm^{-1}$to 0.2 dSm^{-1} with a mean of (0.12 dSm^{-1}), 0.04dSm^{-1} to 0.1dSm^{-1}(0.07dSm^{-1}), 0.01dSm^{-1} to 0.03dSm^{-1} (0.02dSm^{-1}), 0.06$dSm^{-1}$to 0.08dSm^{-1} (0.10 dSm^{-1}) for soil units KB2, KB3, KB4, and KB5 respectively which are all of the undulating plains and 0.06dSm^{-1} to 0.10dSm^{-1} (0.08 dSm^{-1}) of flood plain/KB6.

In the same order, the subsurface horizons ranges from 0.01dSm^{-1} to 0.07dSm^{-1} (0.04 dSm^{-1}), 0.01dSm^{-1} to 0.09dSm^{-1} (0.05 dSm^{-1}), 0.01dSm^{-1} to 0.01dSm^{-1} (0.01 dSm^{-1}), 0.02 to 0.08 (0.05 dSm^{-1}) and 0.01dSm^{-1} to 0.09 dSm^{-1} (0.05 dSm^{-1}).

Electrical conductivity (Ece) across all the soil units were below the critical limits of 4 dSm-1 to be defined as saline soil (FAO 1993).

c) **Impact of Topography on exchangeable acidity across Landforms/Soil units**

The surface values of exchangeable acidity across the soil units ranged from 0.20 $cmolkg^{-1}$ to 0.60 $cmol(+)kg^{-1}$ with a mean of (0.4 $cmol(+)kg^{-1}$), 0.20$cmol(+)kg^{-1}$ to 0.20$cmol(+)kg^{-1}$ (0.20$cmol(+)kg^{-1}$), 0.20 $cmol(+)kg^{-1}$ to 0.80 $cmol(+)kg^{-1}$ (0.5 $cmol(+)kg^{-1}$), 0.20 $cmol(+)kg^{-1}$ to 0.20 $cmol(+)kg^{-1}$ (0.20 $cmol(+)kg^{-1}$),for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 0.20 cmol(+)kg^{-1} to 0.40 cmol(+)kg^{-1}(0.3 cmol(+)kg^{-1}) of the flood plain associated with soil unit KB6.

In the same order, the subsurface horizons ranged from 0.20 cmol(+)kg^{-1} to 0.40 cmol(+)kg^{-1} (0.3 cmol(+)kg^{-1}), 0.20 cmol(+)kg^{-1} to 0.80 cmol(+)kg^{-1} (0.5 cmol(+)kg^{-1}), 0.20 cmol(+)kg^{-1} to 0.60 cmol(+)kg^{-1} (0.4 cmol(+)kg^{-1}), 0.20 cmol(+)kg^{-1} to 0.60 cmol(+)kg^{-1} (0.4 cmol(+)kg^{-1}) and 0.20 cmol(+)kg^{-1} to 1.20 cmol(+)kg^{-1} (0.7 cmol(+)kg^{-1}).

The exchangeable acidity was low (less than 1.0 cmol(+)kg^{-1}) across the surface horizons of all soil units Table 4.6.

d) **Impact of topography on exchangeable bases across the landforms**

i) **Exchangeable Calcium (Ca)**

The data for the exchangeable bases across soil units is shown in Table 4.6

The exchangeable bases across landforms show that Exchangeable calcium (Ca) was the dominant cation on the exchangeable sites. The surface values for Ca ranged from 2.11 cmol(+)kg^{-1} to 8.00 cmol(+)kg^{-1} with a mean of (5.01 cmol(+)kg^{-1}), 3.01cmol(+)kg^{-1}to 5.26 cmol(+)kg^{-1}(4.14 cmol(+)kg^{-1}), 1.30 cmol(+)kg^{-1}to 2.80 cmol(+)kg^{-1}(2.05 cmol(+)kg^{-1}), 2.22 cmol(+)kg^{-1} to 2.94 cmol(+)kg^{-1} (2.58 cmol(+)kg^{-1}) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 3.20 cmol(+)kg^{-1}to 4.76 cmol(+)kg^{-1}(3.49 cmol(+)kg^{-1}) for flood plain which is associated with soil unit KB6 respectively.

In the same order, the subsurface horizons ranged from 2.40 cmol(+)kg^{-1}to 7.98 cmol(+)kg^{-1} (5.19 cmol(+)kg^{-1}), 1.82 cmol(+)kg^{-1}to 6.11 cmol(+)kg^{-1}(3.97 cmol(+)kg^{-1}), 2.50 cmol(+)kg^{-}

^{1}to 3.00 cmol(+)kg^{-1}(2.65 cmol(+)kg^{-1}), 2.01 cmol(+)kg^{-1} to 3.10 cmol(+)kg^{-1} (2.56 cmol(+)kg^{-1}) and 1.30 cmol(+)kg^{-1} to 3.58 cmol(+)kg^{-1} (2.44 cmol(+)kg^{-1}).

Calcium was rated low to high across soils of the undulating plains and medium in soils of the flood plain Table 4.6.

ii) **Exchangeable Sodium (Na)**

Exchangeable sodium was the second most dominant basic cation in the study area. The values of exchangeable sodium across the surface horizons of the landforms ranged from 0.33 cmol(+)kg^{-1} to 0.44 cmol(+)kg^{-1}with a mean value of (0.39 cmol(+)kg^{-1}), 0.43 cmol(+)kg^{-1} to 0.46 cmol(+)kg^{-1} (0.45 cmol(+)kg^{-1}), 0.15 cmol(+)kg^{-1} to 0.26 cmol(+)kg^{-1}(0.21 cmol(+)kg^{-1}), 0.37cmol(+)kg^{-1} to 0.42cmol(+)kg^{-1} (0.39cmol(+)kg^{-1}) for soil units KB2, KB3, KB4 and KB5 in that order, which are all of the undulating plains and 0.07 cmol(+)kg^{-1} to 0.60 cmol(+)kg^{-1} (0.49 cmol(+)kg^{-1}) for the flood plain associated with soil unit KB6 respectively.

In the same order, the subsurface horizons ranged from 0.30 cmol(+)kg^{-1} to 0.56 cmol(+)kg^{-1}(0.43 cmol(+)kg^{-1}), 0.30 cmol(+)kg^{-1} to 0.56 cmol(+)kg^{-1} (0.43 cmol(+)kg^{-1}), 0.32 cmol(+)kg^{-1}to 0.41 cmol(+)kg^{-1} (0.37 cmol(+)kg^{-1}), 0.43 cmol(+)kg^{-1} to 0.50 cmol(+)kg^{-1} (0.47 cmol(+)kg^{-1}) and 0.07 cmol(+)kg^{-1} to 0.43 cmol(+)kg^{-1} (0.25 cmol(+)kg^{-1}).

The surface values of Na was rated low in soil unit KB4 and low to high in KB6 and high in soil units KB2, KB3 and KB5 Table 4.6.

iii) **The exchangeable Magnesium**

The exchangeable Magnesium (Mg) content was the third dominant cation in the exchange site. It content across the surface horizons of the soil units ranged from 0.06 cmol(+)kg^{-1}to 0.68 cmol(+)kg^{-1}with a mean of (0.37 cmol(+)kg^{-1}), 0.21 cmol(+)kg^{-1} to 0.28 cmol(+)kg^{-1}(0.25 cmol(+)kg^{-1}), 0.28 cmol(+)kg^{-1}to 0.30 cmol(+)kg^{-1} (0.29 cmol(+)kg^{-1}), 0.22 cmol(+)kg^{-1} to 0.32 cmol(+)kg^{-1} (0.27 cmol(+)kg^{-1}) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 0.51 cmol(+)kg^{-1} to 0.59 cmol(+)kg^{-1} (0.55 cmol(+)kg^{-1}) of the flood plain associated with soil unit KB6.

In the same order, the subsurface horizons ranged from 0.30 cmol(+)kg^{-1} to 0.91 cmol(+)kg^{-1} (0.61 cmol(+)kg^{-1}), 0.02 cmol(+)kg^{-1} to 1.46 cmol(+)kg^{-1} (074 cmol(+)kg^{-1}), 0.12 cmol(+)kg^{-1} to 0.35 cmol(+)kg^{-1}(0.24 cmol(+)kg^{-1}), 0.20 cmol(+)kg^{-1} to 0.46 cmol(+)kg^{-1} (0.33 cmol(+)kg^{-1}) and 0.06 cmol(+)kg^{-1} to 0.69 cmol(+)kg^{-1} (0.38 cmol(+)kg^{-1}).

Exchangeable Mg across the surface and subsurface horizons within the study area was rated low to medium across all soil units Table 4.6.

iv) **Exchangeable potassium (K)**

Exchangeable K was the least dominant in the exchange site. The surface K value ranged from 0.04 cmol(+)kg^{-1} to 0.15 cmol(+)kg^{-1} with a mean (0.09 cmol(+)kg^{-1}), 0.03cmol(+)kg^{-1} to 0.06cmol(+)kg^{-1} (0.05 cmol(+)kg^{-1}), 0.12cmol(+)kg^{-1} to 0.14cmol(+)kg^{-1} (0.13 cmol(+)kg^{-1}), 0.14 cmol(+)kg^{-1} to 0.15 cmol(+)kg^{-1} (0.15 cmol(+)kg^{-1})for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 0.25 cmol(+)kg^{-1} to 0.30 cmol(+)kg^{-1} (0.28 cmol(+)kg^{-1}) for the flood plain/KB6.

In the same order, the subsurface horizons ranged from 0.08 cmol(+)kg^{-1} to 0.18 cmol(+)kg^{-1} (0.13 cmol(+)kg^{-1}), 0.05 cmol(+)kg^{-1} to 0.36 cmol(+)kg^{-1} (0.21 cmol(+)kg^{-1}), 0.06 cmol(+)kg^{-1} to 0.16 cmol(+)kg^{-1} (0.10 cmol(+)kg^{-1}), 0.04 cmol(+)kg^{-1} to 0.10 cmol(+)kg^{-1} (0.07 cmol(+)kg^{-1}) and 0.02 to 0.07 cmol(+)kg^{-1} (0.05 cmol(+)kg^{-1}).

Generally, potassium (K) was rated low at surface horizons of undulating plains and medium at the flood plain. At the subsurface it was rated low across all landforms.

e) **Impact of topography on cation exchange capacity (CEC) across the landforms**

The data for cation exchange capacity (CEC) is shown in Table 4.7, surface values of the CEC across soil units ranged from 3.30 cmol(+)kg^{-1} to 10.00 cmol(+)kg^{-1} with a mean of (6.65 cmol(+)kg^{-1}), 7.80 cmol(+)kg^{-1} to 10.20 cmolkg^{-1}(9.00 cmol(+)kg^{-1}), 2.80 cmol(+)kg^{-1} to 9.60 cmol(+)kg^{-1} (6.20 cmol(+)kg^{-1}), 5.00 cmol(+)kg^{-1} to 8.80 cmol(+)kg^{-1} (6.90 cmol(+)kg^{-1}) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 8.00 cmol(+)kg^{-1} to 10.70 cmol(+)kg^{-1} (9.35 cmol(+)kg^{-1}) of the flood plains associated with soil unit KB6.

Table 4.7: showing CEC, ECEC and BS of the landforms/soil units within the study area

Landforms/soil units	Horizon	Depth (cm)	CEC NH$_4$oAc cmol(+)kg^{-1}	ECEC	BS NH$_4$OAc %	BS ECEC
			Latitude	Longitude		
IPSMR/KB2		Location:	11^{o}06.405' N	007^{o}40.172' E	Altitude 651 m	
Profile p1	Ap	0-14	10.00	9.47	92.75	97.89
	Bt1	14-69	12.50	9.53	74.67	97.90
	Bt2	69-124	10.00	6.17	59.67	96.76
	Cg	124-190	9.50	8.15	83.65	97.54
			Latitude	Longitude		
IPSMR/KB2		Location:	11^{o}06.253' N	007^{o}40.942' E	Altitude 658m asl	
profile p2	Ap	0-20	6.90	4.38	60.51	95.43
	Bt	20-67	12.20	7.02	54.25	94.30
	Btg	67-140	10.40	8.11	74.16	95.07
	Btgv	140-190	8.80	5.23	57.18	96.18
			Latitude	Longitude		
IPSMR/KB2		Location:	11^{o}06.167' N	007^{o}40.814' E	Altitude 665m asl	
profile p3	Ap	0-15	5.50	3.31	56.58	93.96
	Bt	15-28	10.00	4.07	38.72	95.09
	Btc	28-80	4.90	3.85	74.58	94.81
	Cv	80-170	6.10	3.64	56.36	94.50
			Latitude	Longitude		
IPSMR/KB2		Location:	11^{o}05.902' N	007^{o}40.322' E	Altitude 673m asl	
profile p4	Ap	0-34	3.30	3.17	77.98	81.09
	Bt	34-104	10.50	5.36	47.2	92.53
	B/C	104-190	4.40	4.28	92.82	95.33
			Latitude	Longitude		
SPSLR/KB3		Location:	11^{o}06.413' N	007^{o}40.717' E	Altitude 685m asl	
profile p1	Ap	0-45	10.20	6.15	58.35	96.75
	E	45-62	11.30	2.41	19.56	91.70
	Btg	62-130	17.60	5.92	32.53	96.62
	Cg	130-190	11.00	6.36	56.04	96.86
			Latitude	Longitude		
SPSLR/KB3		Location:	11^{o}06.462' N	007^{o}41.256' E	Altitude 647m asl	
profile p2	Ap	0-15	7.80	3.98	48.5	94.98
	B	15-35	8.50	6.15	62.98	87.00
	Bc	35-75	4.20	5.10	119.98	92.16
	Cg	75-200	12.70	7.62	56.83	94.75

IPSMR=irregular plains with some moderate relief

SPSLR=smooth plains with some local relief

Table 4.7: showing CEC, ECEC and BS of the landforms/ soil units within the study area

Landforms/ mapping units	Horizon	Depth (cm)	CEC NH$_4$oAc cmol(+)kg^{-1} ⟵	ECEC ⟶	BS NH$_4$OAc % ⟵	BS ECEC ⟶
IPLR/KB4		Location:	Latitude 11^{o}06.529' N	Longitude 007^{o}41.398' E	Altitude 635m asl	
profile p1	A	0-10	9.60	3.68	36.22	94.56
	B	010-65	5.10	3.50	56.91	82.87
	C	65-90	4.10	4.07	94.48	95.05
IPLR/KB4		Location:	Latitude 11^{o}06.482' N	Longitude 007^{o}41.333' E	Altitude 634m	
profile p2	A	0-35	2.80	2.67	66.79	70.04
	B	35-180	3.60	3.51	91.94	94.30
FNFP/KB5		Location:	Latitude 11^{o}06.581' N	Longitude 007^{o}40.505' E	Altitude 636m asl	
profile p1	Ap	0-14	5.00	3.21	60.21	93.77
	B1	14-36	8.90	4.15	44.4	95.18
	B2	36-107	4.60	4.28	88.8	95.33
	B3	107-200	7.30	4.01	49.41	90.02
FNFP/KB5		Location:	Latitude 11^{o}06.588' N	Longitude 007^{o}41.457' E	Altitude 636m	
profile p2	Ap	0-5	8.80	4.07	43.94	95.08
	B1	5-33	4.70	4.09	74.20	85.32
	B2	33-132	7.80	4.33	47.82	86.14
	B3	132-200	3.20	3.19	87.26	87.46
Flood/KB6		Location:	Latitude 11^{o}06.626' N	Longitude 007^{o}40.531' E	Altitude 630 m	
profile p1	AP	0-36	8.00	4.63	52.87	91.36
	Bt	36-82	8.20	4.39	51.15	95.45
	Btg	82-95	5.00	2.23	40.66	91.04
	C	95-110	4.50	2.30	46.58	91.29
	2A	110-120	6.00	2.85	27.46	57.86
FNFP(flood)/KB6		Location:	Latitude 11^{o}06.593' N	Longitude 007^{o}41.441' E	Altitude 632m asl	
profile p2	Ap	0-10	10.70	6.30	57.03	96.83
	B	10-73	8.50	4.61	51.89	95.66
	Bt	73-93	8.00	3.62	42.80	94.48
	Btg	93-104	8.50	4.10	36.52	75.63
	C	104-120	4.50	2.19	44.26	90.88

IPLR=irregular plains with low relief
FNFP=flat or nearly flat plains

In the same order, the subsurface horizons ranged from 4.40 cmol(+)kg^{-1} to 12.50 cmol(+)kg^{-1} (8.45 cmol(+)kg^{-1}), 4.20 cmol(+)kg^{-1} to 17.60 cmol(+)kg^{-1} (10.90 cmol(+)kg^{-1}), 3.60 cmol(+)kg^{-1} to 5.10 cmol(+)kg^{-1} (4.35 cmol(+)kg^{-1}), 3.20 cmol(+)kg^{-1} to 8.90

cmol(+)kg^{-1} (6.05 cmol(+)kg^{-1}) and 4.50 cmol(+)kg^{-1} to 8.50 cmol(+)kg^{-1} (6.50 cmol(+)kg^{-1}).Cation exchange capacity (CEC-NH_4OAc) across all soil units were rated low to medium > (6 cmol(+)kg^{-1} but < 12cmol(+)kg^{-1}) at surface horizons and low to high at subsurface horizons of soil unit KB2, KB3 and KB5 but low in soil unit KB4 while in soil unit KB6 it was low to medium Table 4.7.

f) **Impact of topography on soil base saturation across landforms**

The data for base saturation across soil units is shown in Table 4.7. The values of BS (NH_4OAc) for surface horizons ranged from 56.58 % to 92.72 % with a mean of (74.65 %), 48.50 % to 58.35 % (53.43 %), 36.22 % to 66.79 % (51.51 %), 43.94 % to 60.21 % (52.08 %) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 52.87 % to 57.03 % (54.95 %) of the flood plain associated with soil unit KB6.

In the same order, the values for the sub-surface horizons ranged from 47.20 % to 92.82 % (70.01 %), 19.56 % to 98.98 % (59.27 %), 56.91 % to 94.48 % (65.50 %), 44.40 % to 88.80 % (66.60 %) and 27.46 % to 51.89 % (39.68 %).

The base saturation (NH_4AOc) was low to high at surface of undulating plains and low to medium in flood plain associated with soil unit KB6.

The BS (ECEC) values for surface horizons ranged from 81.09% to 97.89% with a mean of (89.49%), 94.98% to 96.75% (95.87%), 70.04% to 94.56% (82.30%), 93.77% to 95.08% (94.43%) for soil units KB2, KB3, KB4, and KB5 respectively which are all of the undulating plains and 91.36% to 96.83% (94.10%) of the flood plains which is associated with soil unit KB6.

The corresponding values for the sub-surface horizons ranged from 92.53% to 97.90% (95.23%), 91.70% to 96.86% (94.28%), 82.87% to 94.30% (88.59%), 85.32% to 95.33% (90.33%) and 57.86 % to 95.66 % (76.76 %). The ECEC in surface horizons across soil units was moderate to high in KB2 andKB4 but high inKB3 andKB6.

g) **Impact of topography on organic carbon (O.C) across landforms**

The data for O.C is shown in Table 4.8. The surface values of O.C across the soil units ranged from 5.09 gkg^{-1} to 9.56 gkg^{-1} with a mean of (7.33 gkg^{-1}), 5.7 gkg^{-1} to 8.55 gkg^{-1} (7.13 gkg^{-1}), 1.83 gkg^{-1} to 6.31 gkg^{-1} (4.1 gkg^{-1}), 3.66 gkg^{-1} to 5.49 gkg^{-1} (4.58 gkg^{-1}) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 8.95 gkg^{-1} to 9.16 gkg^{-1} (9.06 gkg^{-1}) of the flood plain associated with soil unit KB6.

In the same order, the subsurface horizons ranged from 0.61gkg^{-1} to 3.26gkg^{-1} (1.94 gkg^{-1}), 0.41gkg^{-1} to 3.66gkg^{-1} (2.06 gkg^{-1}), 0.41 gkg^{-1} to 3.46 gkg^{-1} (1.9 gkg^{-1}), 0.81gkg^{-1} to 3.26 gkg^{-1} (2.04) and 0.41gkg^{-1} to 2.44gkg^{-1} (1.43gkg^{-1}).Organic carbon across all soil units was low (less than 10 gkg^{-1}) at both surface and subsurface horizons Table 4.8.

Table 4.8: organic carbon, total nitrogen and available phosphorous of the landforms/soil units of the study area

Landforms/mapping units	Horizon	Depth (cm)	OC (g/kg)	TN (g/kg)	C/N ratio	AP (mg/Kg)
IPSMR/KB2	Location:	Latitude 11°06.405' N	Longitude 007°40.172' E	Altitude 651 m asl		
Profile p1	Ap	0-14	9.56	0.98	9.76	16.08
	Bt1	14-69	2.65	0.77	3.44	4.38
	Bt2	69-124	1.42	0.49	2.91	3.68
	Cg	124-190	1.42	0.49	2.91	3.85
IPSMR/KB2	Location:	Latitude 11°06.253' N	Longitude 007°40.942' E	Altitude 658 m asl		
profile p2	Ap	0-20	7.73	0.98	7.89	4.73
	Bt	20-67	2.65	0.70	3.78	2.98
	Btg	67-140	2.03	0.56	3.63	2.98
	Btgv	140-190	0.61	0.63	0.97	3.15
IPSMR/KB2	Location:	Latitude 11°06.167' N	Longitude 007°40.814' E	Altitude 665 m asl		
profile p3	Ap	0-15	6.10	0.70	8.72	4.20
	Bt	15-28	3.26	0.77	4.23	2.63
	Btc	28-80	1.83	0.42	4.36	2.98
	Cv	80-170	3.05	0.28	10.9	2.98
IPSMR/KB2	Location:	Latitude 11°05.902' N	Longitude 007°40.322' E	Altitude 673 m asl		
profile p4	Ap	0-34	5.09	0.49	10.38	10.33
	Bt	34-104	1.42	0.56	2.54	2.98
	B/C	104-190	0.81	0.28	2.91	2.80
SPSLR/KB3	Location:	Latitude 11°06.413' N	Longitude 007°40.717' E	Altitude 685 m asl		
profile p1	Ap	0-45	5.70	0.91	6.26	16.8
	E	45-62	1.22	0.49	2.49	8.40
	Btg	62-130	0.81	0.70	1.16	4.55
	Cg	130-190	0.81	0.49	1.66	4.20
SPSLR/KB3	Location:	Latitude 11°06.462' N	Longitude 007°41.256' E	Altitude 647 m asl		
profile p2	Ap	0-15	8.55	0.91	9.39	5.78
	B	15-35	3.66	0.84	4.36	4.38
	Bc	35-75	1.83	0.49	3.74	3.85
	Cg	75-200	0.41	0.35	1.16	4.90

IPSMR= irregular plains with some moderate relief

SPSLR= smooth plains with some local relief

Table 4.8: organic carbon, total nitrogen and available phosphorous of the landforms/ soil units of the study area

	Horizon	Depth (cm)	OC ← g/kg	TN →	C/N ratio	AP mg/Kg
Landforms/mapping units						
IRPLR/KB4	Latitude 11°06.529' N	Longitude 007°41.398' E	Altitude 635 m			
profile p1	A	0-10	6.31	0.84	7.51	3.85
	B	010-65	3.46	0.28	12.35	3.33
	C	65-90	0.41	0.35	1.16	3.33
IRPLR/KB4	Latitude 11°06.482' N	Longitude 007°41.333' E		Altitude 634 m		
profile p2	A	0-35	1.83	0.35	5.23	3.15
	B	35-180	0.41	0.35	1.16	2.10
FNFP/KB5	Latitude 11°06.581' N		Longitude 007°41.505' E		Altitude 636 m asl	
Profilep1	Ap	0-14	5.49	0.70	7.85	16.10
	B1	14-36	2.65	0.56	4.72	10.50
	B2	36-107	2.44	0.63	3.88	3.68
	B3	107-200	0.81	0.56	1.45	3.33
FNFP/KB5	Latitude 11°06.588' N		Longitude 007°41.457' E		Altitude 636 m asl	
Profile p2	Ap	0-5	3.66	0.63	5.81	6.13
	B1	5-33	3.26	0.14	23.26	4.38
	B2	33-132	2.24	0.49	4.57	4.03
	B3	132-200	1.42	0.49	2.91	3.68
FP/KB6	Latitude 11°06.626' N		Longitude 007°40.531' E		Altitude 630 m asl	
Profile p1	AP	0-36	9.16	1.54	5.95	8.23
	Bt	36-82	2.44	0.63	3.88	4.20
	Btg	82-95	2.44	0.70	3.49	7.53
	C	95-110	0.20	0.42	0.48	4.20
	2A	110-120	0.81	0.49	1.66	4.73
FP/KB6	Latitude 11°06.593' N		Longitude 007°41.441' E		Altitude 632 m asl	
Profile p2	Ap	0-10	8.95	0.70	12.79	6.13
	B	10-73	0.41	0.49	0.83	3.85
	Bt	73-93	1.02	0.49	2.08	2.80
	Btg	93-104	1.42	0.28	5.09	3.68
	C	104-120	0.81	0.14	5.81	3.85

IPLR= irregular plains with low relief

FP= flood plains

The C:N ratio across the surface horizons of all soil units ranged from 7.89 to 10.38 with a mean of (9.14), 6.26 to 9.39 (7.83), 5.23 to 7.51 (6.37), 5.81 to 7.85 (6.83)for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 5.95 to 12.79 (9.37) of the flood plain associated with soil unit KB6 respectively.

In the same order, the subsurface horizons ranged from 2.54 to 10.90 (6.72), 1.16 to 4.36 (2.76), 1.16 to 12.35 (6.76), 1.45 to 23.26 (12.36), and 0.48 to 5.81 (3.15).

h) The surface values of TN ranged from 0.49 gkg^{-1} to 0.98 gkg^{-1} with a mean of (0.74 gkg^{-1}), 0.91 gkg^{-1} to 0.91 gkg^{-1} (0.91 gkg^{-1}), 0.35 gkg^{-1} to 0.84 gkg^{-1} (0.60 gkg^{-1}), 0.63 gkg^{-1} to 0.70 gkg^{-1} (0.67 gkg^{-1}) for soil units KB2, KB3, KB4, and KB5 in the order, which are all of the undulating plains and 0.7 gkg^{-1} to 1.54 gkg^{-1} (1.1 gkg^{-1}) of the flood plain associated with soil unit KB6.

In the same order, the subsurface horizons ranged from 0.28 gkg^{-1} to 0.77 gkg^{-1} (0.53 gkg^{-1}), 0.35 gkg^{-1} to 0.84 gkg^{-1} (0.60 gkg^{-1}), 0.28 gkg^{-1} to 0.35 gkg^{-1} (0.32 gkg^{-1}), 0.14 gkg^{-1} to 0.63 gkg^{-1} (0.39 gkg^{-1}) and 0.14gkg^{-1} to 0.70gkg^{-1} (0.4 gkg^{-1}).Total nitrogen was rated low (< 1.5 gkg^{-1}) for surface horizons of undulating plains and low to medium at the flood plain (< 2 gkg^{-1}) while at the subsurface it was low across all soil units (Table 4.8).

i) **Impact of topography on available phosphorous (AP) across landforms**

The surface values of AP across soil units ranged from 4.20 $mgkg^{-1}$ to 16.08 $mgkg^{-1}$ with a mean of (10.14 $mgkg^{-1}$), 5.78 $mgkg^{-1}$ to 16.80 $mgkg^{-1}$ (11.29 $mgkg^{-1}$), 3.15 $mgkg^{-1}$ to 3.85 $mgkg^{-1}$ (3.5 $mgkg^{-1}$), 6.13 $mgkg^{-1}$ to 16.10 $mgkg^{-1}$ (11.12 $mgkg^{-1}$) for soil units KB2, KB3,KB4, and KB5 in that order, which are all of the undulating plains and 6.13mgkg^{-1} to 8.23mgkg^{-1} (7.18 mgkg^{-1}) of the flood plain associated with soil unit KB6 respectively.

In the same order, the subsurface horizons ranged from 2.63mgkg^{-1} to 4.38mgkg^{-1} (3.51 mgkg^{-1}), 3.85mgkg^{-1} to 8.40mgkg^{-1} (6.13 mgkg^{-1}), 2.10mgkg^{-1} to 3.33mgkg^{-1} (2.73mgkg^{-1}), 3.33mgkg^{-1} to 10.50mgkg^{-1} (6.92mgkg^{-1}) and 2.80mgkg^{-1} to 7.53mgkg^{-1} (5.17 mgkg^{-1}).Available phosphorous across soil units was rated low to medium (< 10-20 mgkg^{-1} according USDA 1993).

j) **Impact of topography on soil micro-nutrients across the landforms**

The data for micro-nutrients (Fe, Zn, Mn and Cu) across soil units are shown in Table 4.9

(i) **Extractable iron (Fe)**

The values of iron (Fe) across surface horizons ranged from 1.34 mgkg^{-1} to 4.86 mgkg^{-1} with a mean of 3.10 mgkg^{-1}, 3.75 mgkg^{-1} to 26.26 mgkg^{-1} (15.01 mgkg^{-1}), 1.02 mgkg^{-1} to 2.34 mgkg^{-1} (1.68 mgkg^{-1}), 2.95 mgkg^{-1} to 3.11 mgkg^{-1} (3.03 mgkg^{-1}) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 36.88 mgkg^{-1} to 49.85 mgkg^{-1} (43.36 mgkg^{-1}) for flood plain associated with soil unit KB6.

Table 4.9: Extracted micro-nutrients of the landforms/soil units of the study area

Landforms/soil units	Horizon	Depth (cm)	Fe	Zn	Mn	Cu
			←	Mg/kg	→	
IPSMR/KB2	Location:	Latitude 11°06.405' N		Longitude 007°40.172' E	Altitude 651m asl	
Profile p1	Ap	0-14	1.34	8.30	4.77	0.26
	Bt1	14-69	0.04	0.24	0.74	0.04
	Bt2	69-124	4.23	0.20	1.29	0.01
	Cg	124-190	6.87	0.28	1.70	0.00
IPSMR/KB2	Location:	Latitude 11°06.253' N		Longitude 007°40.942' E	Altitude 658m asl	
Profile p2	Ap	0-20	4.86	0.56	2.52	0.19
	Bt	20-67	2.64	0.56	1.08	0.08
	Btg	67-140	3.28	0.23	0.53	0.07
	Btgv	140-190	2.33	0.12	0.95	0.01
IPSMR/KB2	Location:	Latitude 11°06.167' N		Longitude 007°40.814' E	Altitude 665m asl	
profile p3	Ap	0-15	3.01	0.09	1.58	0.03
	Bt	15-28	1.58	0.16	0.55	0.05
	Btc	28-80	2.35	0.12	0.30	0.05
	Cv	80-170	2.02	0.15	0.27	0.04
IPSMR/KB2	Location:	Latitude 11°05.902' N		Longitude 007°40.322' E	Altitude 673m asl	
profile p4	Ap	0-34	2.78	0.12	1.45	0.00
	Bt	34-104	1.71	0.25	0.73	0.04
	B/C	104-190	3.46	0.32	0.99	0.01
SPSLR/KB3	Location:	Latitude 11°06.413' N		Longitude 007°40.717' E	Altitude 685m asl	
profile p1	Ap	0-45	26.26	0.42	1.70	0.11
	E	45-62	7.38	0.09	0.59	0.00
	Btg	62-130	3.17	0.10	0.77	0.00
	Cg	130-190	9.34	0.07	0.16	0.00
SPSLR/KB3	Location:	Latitude 11°06.462' N		Longitude 007°41.256' E	Altitude 647m asl	
profile p2	Ap	0-15	3.75	0.37	1.76	0.04
	B	15-35	3.11	0.22	0.90	0.05
	Bc	35-75	3.02	0.24	2.62	0.02
	Cg	75-200	4.47	0.24	0.82	0.00

IPSMR=irregular plains with some moderate relief

SPSLR= smooth plains with some local relief

Table 4.9: Extracted micro-nutrients of the landforms/ soil units of the study area

Landforms/ mapping units	Horizon	Depth (cm)	Fe	Zn	Mn	Cu
			Mg/kg			
IPLR/KB4	Location: Latitude 11°06.529' N Longitude 007°41.398' E Altitude 635m asl					
profile p1	A	0-10	2.34	0.25	1.85	0.06
	B	010-65	1.74	0.28	0.61	0.05
	C	65-90	2.82	0.19	1.83	0.01
IPLR/KB4	Location: Latitude 11°06.482' N Longitude 007°41.333' E Altitude 634 m asl					
profile p2	A	0-35	1.02	0.18	0.57	0.00
	B	35-180	1.70	0.30	1.16	0.00
FNFP/KB5	Location: Latitude 11°06.581' N Longitude 007°41.505' E Altitude 636m asl					
Profile p1	Ap	0-14	3.11	0.54	2.16	0.02
	B1	14-36	2.16	0.26	1.28	0.07
	B2	36-107	2.77	0.33	0.52	0.04
	B3	107-200	2.99	0.27	1.04	0.02
FNFP/KB5	Location: Latitude 11°06.588' N Longitude 007°41.457' E Altitude 636m asl					
Profile p2	Ap	0-5	2.95	0.43	1.71	0.00
	B1	5-33	2.16	0.24	1.33	0.08
	B2	33-132	1.69	0.12	1.41	0.02
	B3	132-200	2.10	0.11	1.75	0.05
FP/KB6	Location: Latitude 11°06.626' N Longitude 007°40.531' E Altitude 630m asl					
profile p1	AP	0-36	49.85	0.68	6.65	0.28
	Bt	36-82	21.72	0.24	3.09	0.16
	Btg	82-95	16.72	0.13	0.91	0.11
	C	95-110	8.76	0.09	1.04	0.01
	2A	110-120	54.07	0.16	1.94	0.13
FP/KB6	Location: Latitude 11°06.593' N Longitude 007°41.441' E Altitude 632m asl					
profile p2	Ap	0-10	36.88	0.39	6.63	0.12
	B	10-73	4.59	0.30	1.67	0.05
	Bt	73-93	5.90	0.46	1.56	0.05
	Btg	93-104	36.97	0.30	1.64	0.11

IPLR=irregular plains with low relief, FNFP= flar or nearly flat plains, FP= flood plains

The corresponding values for sub-surface horizons ranged from 0.04 $mgkg^{-1}$ to 6.87 $mgkg^{-1}$ (3.50 $mgkg^{-1}$), 3.02 $mgkg^{-1}$ to 9.34 $mgkg^{-1}$ (6.18 $mgkg^{-1}$), 1.70 $mgkg^{-1}$ to 2.82 $mgkg^{-1}$ (2.26 $mgkg^{-1}$), 1.69 $mgkg^{-1}$ to 2.99 $mgkg^{-1}$ (2.34 $mgkg^{-1}$) and 4.59 $mgkg^{-1}$ to 54.07 $mgkg^{-1}$ (29.33 $mgkg^{-1}$). Generally,iron (Fe) was low to high (> 4.5 $mgkg^{-1}$) across undulating plains and high in flood plains in both surface and sub-surface horizons.

ii) **Extractable manganese**

The surface values of Mn ranged from 1.45 $mgkg^{-1}$ to 4.77 $mgkg^{-1}$ with a mean of 3.11 $mgkg^{-1}$, 1.70 $mgkg^{-1}$ to 1.76 $mgkg^{-1}$ (1.73 $mgkg^{-1}$), 0.57 $mgkg^{-1}$ to 1.85 $mgkg^{-1}$ (1.21 $mgkg^{-1}$), 1.71 $mgkg^{-1}$ to 2.16 $mgkg^{-1}$ (1.94$mgkg^{-1}$)for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 6.63 $mgkg^{-1}$ to 6.65 $mgkg^{-1}$ (6.64 $mgkg^{-1}$) for flood plain/KB6.

The corresponding values for the sub-surface horizons ranged from 0.27 $mgkg^{-1}$ to 1.70 $mgkg^{-1}$ (0.99 $mgkg^{-1}$), 0.16 $mgkg^{-1}$ to 2.62 $mgkg^{-1}$ (1.39 $mgkg^{-1}$), 0.61 $mgkg^{-1}$ to 1.83 $mgkg^{-1}$ (1.22$mgkg^{-1}$), 0.52 $mgkg^{-1}$ to 1.75$mgkg^{-1}$ (1.14 $mgkg^{-1}$) and 0.55 $mgkg^{-1}$ to 3.09 $mgkg^{-1}$ (1.82 $mgkg^{-1}$). Extractable Mn was rated medium in surface horizons of soil units KB2, KB3, KB4, and KB5 and medium to high in soil unit KB6 Table 4.9.

iii) **Extractable zinc (Zn)**

The value of zinc (Zn) at the surface horizons ranged from 0.09 $mgkg^{-1}$ to 0.83 $mgkg^{-1}$ with a mean of 0.46 $mgkg^{-1}$, 0.37 $mgkg^{-1}$ to 0.42 $mgkg^{-1}$ (0.40 $mgkg^{-1}$), 0.02 $mgkg^{-1}$ to 0.25 $mgkg^{-1}$ (0.14 $mgkg^{-1}$), 0.43 $mgkg^{-1}$ to 0.54 $mgkg^{-1}$ (0.49 $mgkg^{-1}$) for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 0.39 $mgkg^{-1}$ to 0.68 $mgkg^{-1}$ (0.54 $mgkg^{-1}$) for flood plain/KB6.

The corresponding values for the sub-surface horizons ranged from 0.20 $mgkg^{-1}$ to 0.56 $mgkg^{-1}$ (0.38 $mgkg^{-1}$), 0.07 $mgkg^{-1}$ to 0.24 $mgkg^{-1}$ (0.16 $mgkg^{-1}$), 0.19 $mgkg^{-1}$ to 0.30 $mgkg^{-1}$(0.25 $mgkg^{-1}$), 0.11 $mgkg^{-1}$ to 0.33 $mgkg^{-1}$ (0.22 $mgkg^{-1}$) and 0.09 $mgkg^{-1}$ to 0.46 $mgkg^{-1}$ (0.28 $mgkg^{-1}$).Extractable zinc (Zn) was rated low (< 1$mgkg^{-1}$) across all soil units both in the surface and subsurface horizons.

Iv) **Extractablecopper (Cu)**

The values of Cu across surface horizon of all soil units ranged from 0.00 $mgkg^{-1}$ to 0.26 $mgkg^{-1}$ with a mean of 0.26$mgkg^{-1}$, 0.04 $mgkg^{-1}$ to 0.11 $mgkg^{-1}$ (0.08 $mgkg^{-1}$), 0.00 $mgkg^{-1}$ to 0.06 $mgkg^{-1}$ (0.06 $mgkg^{-1}$), 0.00 $mgkg^{-1}$ to 0.02 $mgkg^{-1}$ (0.02 $mgkg^{-1}$),for soil units KB2, KB3, KB4, and KB5 in that order, which are all of the undulating plains and 0.12 $mgkg^{-1}$ to 0.28 $mgkg^{-1}$ (0.20 $mgkg^{-1}$) for flood plain/KB6.

The corresponding values for the sub-surface horizons ranged from 0.00 $mgkg^{-1}$ to 0.08 $mgkg^{-1}$ (0.08 $mgkg^{-1}$), 0.00 $mgkg^{-1}$ to 0.05 $mgkg^{-1}$ (0.05 $mgkg^{-1}$), 0.00 $mgkg^{-1}$ to 0.05 $mgkg^{-1}$ (0.05 $mgkg^{-1}$), 0.02 $mgkg^{-1}$ to 0.08 $mgkg^{-1}$ (0.05$mgkg^{-1}$) and 0.00 $mgkg^{-1}$ to 0.16 $mgkg^{-1}$ (0.16 $mgkg^{-1}$). Extractable Cu was rated low (less than 0.2$mgkg^{-1}$) in surface horizons of soil units KB3, KB4 and KB5 and low to medium (0.2 to 1.0$mgkg^{-1}$) in KB2 and KB6Table 4.9.

4.4 Soil classification

The summaries of soil classification according to the USDA soil taxonomy and WRB for soil resource are shown in Table 5.0

4.5 Land capability classification

The criteria used for land capability classification in the study area and it summary are presented in Table 3.2 and 4.10 respectively. The land capability map of the study area is presented in Figure4.5.

Table 4.10: Land capability classification of the landforms in the study area

Landforms	Associated soil mapping units	Capability Classes	Major Limitation	Soil unit extent (ha)	% Total area
Irregular plains with some moderate relief and flat or nearly flat plain	KB2/KB5	II e,	Sheet erosion, moderate to strong sloping slope, moderate to structureless structure.	28.0	18.84
Flood plain (fadama)/Smooth plains with some local relief	KB6/KB3	III w, s	Water lodged during rainy season, moderate to structureless structure, stickiness, and hardness.	15.93	40.42
Tablelands with very high relief	KB1	VIII e, s	Hills and scattered rock outcrop with shallow depth.	15.93	18.52
Irregular plains with low relief	KB4	VI e, s	Gully erosions and ironstones	19.11	22.22

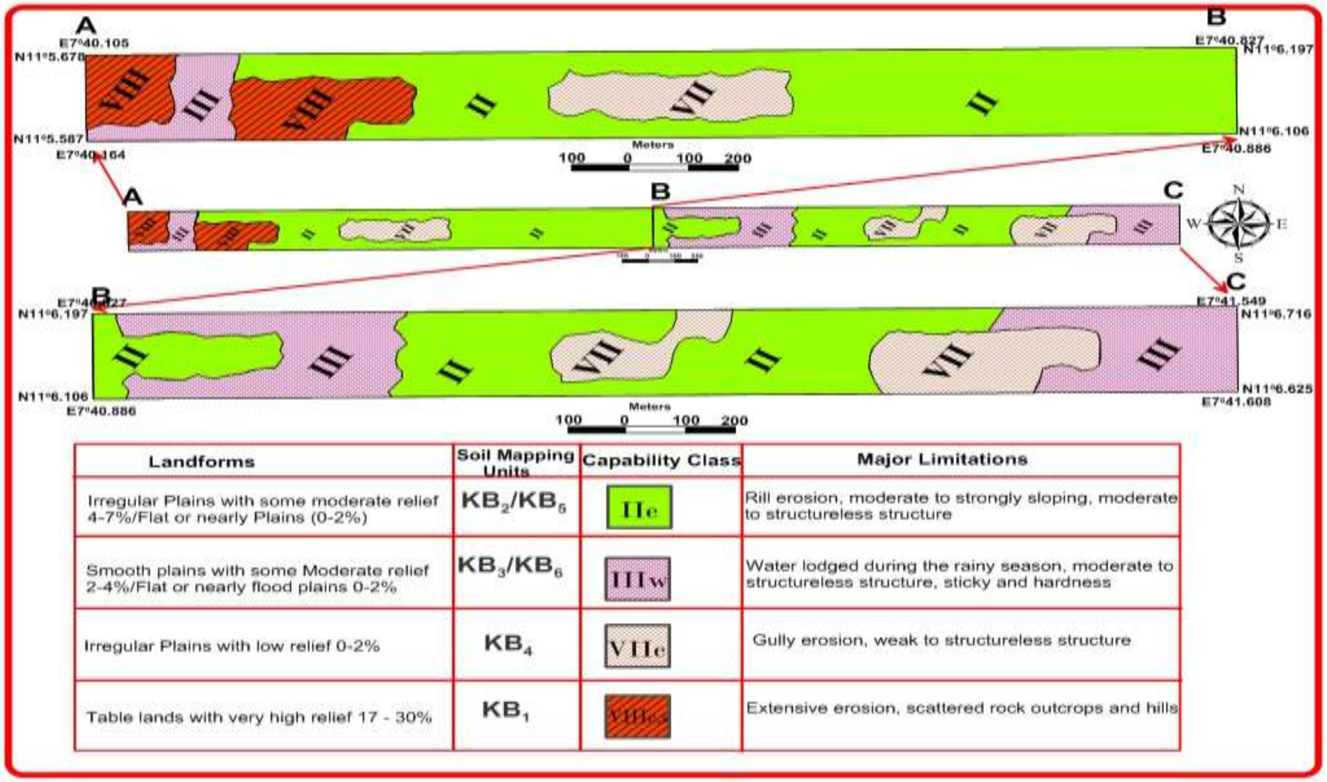

Figure 4.5:Map of land capability classification of the study area.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Relationship between landforms and soil properties

5.1.1 Soil morphological properties

Soil properties such as depth, drainage, color, structure, particle size, bulk density, total porosity and available water holding capacity were all considered anddiscussed. The summaries of morphological and physical properties are shown in Tables4.2, 4.3 and 4.4.

(a) Soil depth

The depth of soils varies with landforms and slope classes.The Tableland with very high relief occurred on very steep slope of 18-30 %. It was associated with soils of unit KB1, which were very shallow, with rocky outcrop, and scattered rocks on the surface such that profile pit could not be sited.

Below the Tableland with very high relative relief were series of undulating plains and the flood plains. The undulating plains include;irregular plains with some moderate relief which were associated with soil unit KB2; smooth plains with some local relief associated with soil unit KB3; irregular plains with low relief associated with KB4 and flat or nearly flat plains (upland plain) associated with KB5. The flood plains were associated with soil unit KB6.

The undulating plains were very deep soils (> 150 cm) while the flood plainwere deep soils. This depth is as a result of deep weathering and pedogenesis of saprolite and continuous accumulation of materials which were removed from the higher land above such as the Tableland and deposited across these landforms.Soils of the undulating plains were developed from soil parent materials derived from colluvial over saprolite while those of the flood plains were developed from parent material of colluvial-alluvial deposits.

(b) **Soil drainage and Soil colour**

The drainage status of landforms within the study area was closely related to the topography of the landscapes.

The Tableland with very high relative relief, associated with soil unit KB1 was excessively drained. This is because of its steep slope (18-30%) which resulted in excessive run-off at the expense of infiltration.Soils of the Tableland with very high relative relief associated with soil unit KB1 was not assigned with any colour because the soils were very shallow and no profile pit was sited on it.

Below the Tablelands with very high relief were series of undulating plains.The undulating plains includedirregular plains with some moderate relief which are associated with soil unit KB2; smooth plains with some local relief associate with soil unit KB3; irregular plains with low relief associated with KB4 and that of the flat or nearly flat plains associated with KB5. These plains were upland plains.

The undulating plains had drainage ranging from imperfectly drained to well drained with a surface colour ranging from very dark grey (10YR 3/1) to dark yellowish brown (10YR 3/4).The brown in colour could be attributed to high amount of heamatite in the soils (Ewulo, 2012) while the gray in colour could be attributed to poor drainage condition of the soils.The well drained upland undulating plains were due to vertical and lateral movement of water towards the flood plain as a result of the steep slope.

The imperfectly drainedparts of these undulating plains were due to local depressions that occurred within parts of the plains giving raise to the micro-basins. The colour was dominated with grey coloration of the horizons which is a clear indication that the soils were water saturated for a longer period than soils of the undulating plains. The depressions in this landform served as a water collecting point similar to that of the flood plain.

The drainage in the flood plain associated with soil unit KB6 was very poor.This is because it had nearly level(< 2%) slope. It had a surface colour of dark yellowish brown (10YR 4/4) to dark grey brown (10YR 4/2). The poor drainage of this landform is due to the landform being the lowest position in the landscape. As a result the water table stood at 120cm at the end of the dry season; which could rise to the surface at the peak of rainy season.As a consequence, the drainage status was poor and could be very poor at the peak of rainy season.

(c) **Soil structure**

Sub-angular blocky and massive structures were the dominant structures within the study area. A moderate medium sub-angular blocky structure was observed within the undulating plains.

The good structure observed in the undulating plains could be due to their well-drained nature in most parts of the plain.Within the undulating plains moderate medium sub-angular blocky structure dominated the irregular plains with some moderate relief and flat or nearly flat plains while a weak medium sub-angular blocky structure dominated the smooth plain with some local relief and the irregular plains with low relief.

The flood plain associated with soil unit KB6has a moderate medium sub-angular blocky to structureless (massive) structure. This poor structure observed in this landform may be as a result of poor drainage and youthfulness of the soil development.

(d) **Soil consistency**

Soil consistence comprises the attributes of soil minerals that are expressed by the degree and kind of cohesion and adhesion or by the degree of resistance to deformation or rapture.Soils of the undulating plains had consistencies which ranged from very sticky, very plastic, very firm and hard, to non-sticky, non-plastic, very friable and soft consistency at wet, moist, and dried respectively. This consistency is closely related to the clay content (Table 4.2) shows that clay is the dominant size fraction across the study area with the highest surface content recorded within parts of the undulating plains precisely in the surface of KB2 p4.

The non-sticky, non-plastic, very friable and soft consistency at wet, moist, and dry reflect to the fact that the undulating plains are upland soils which are well drained.Soils of the flood plain (KB6) were slightly sticky, slightly plastic, firm and hard at wet, moist and dry consistency respectively. The consistency of this landform is a proof of its higher clay content(Raji, 1995)as a result of clay deposits from the colluvial/alluvial materials.

(e) **Inclusions**

Roots were observed in all surface horizons of the undulating plains and at the flood plain. This property was common to all landforms and soil mapping units within the study area. The content of roots however decreased as depth increased.

Many micro-macro tubular and vesicular pores were common in all Ap horizon of all the landforms and mapping units of the undulating plains and flood plains. Similarly, common to few fine micro –macro pores, common fine to few fine ant holes were observed in all sub-surface horizonsof all the landforms and mapping units of the undulating plains and flood plains. Thisindicates some degree of faunal pedoturbation and soil development within the profiles.

Common to many few fine Fe/Mn concretions were also observed in sub-surface horizon of all the undulating plains and flood plains. The Fe/Mn concretions present in the flood plains might have been transported in from the upland plains into the flood plain.

Plinthite was only noticeable in the sub-surface horizon of irregular plain with some moderate reliefwhich is associated with soil unit KB2, and the irregular plain with low reliefwhich is associated with soil unit KB4. This may beas a result of high concentrations of Fe in soilsdue to the parent material or lateral movement and deposition of iron over time from the Tableland with very high relief, which might lead to its precipitation and accumulations that has given rise to formation of plinthite (laterite) (Ibrahim and Abubakar, 2013).

Commonto many mica-flakes were observed in the profiles of soil units KB3 and KB6. This is an indication of the Basement Complex parent materials. The mica-flake in the flood plain might have been laterally translocated from the upland into the flood plain. This is an indication that schist and gneisses were common rock in the area. The weatherable minerals (mica flakes) also indicate the youthfulness of the soil (Ayolagha and Opene, 2012).

Clay cutans were common among soils of units KB2, and KB3 but not in KB6. This shows that there was more soil development in the upland soil than in the flood plain soils.

5.2 Soil physical properties

(a) Impact of topography on particle size distribution across the landforms:

(i) Clay fraction

Clay fractions were higher in the surface horizons of soil units KB2 p1, p4, KB3 p2, KB4 p1, and KB5 p1 and p2 and in the subsurface it was higher in KB2 p2, p3, KB3 p1, KB4 p2 and KB6 p1 and p2 (Table 4.2) indicating clay eluviations from surface and illuviation in the sub-surface horizons. Highestsurface clay contentwas recorded in soil unit KB3 p1 (Table 4.2). This might be due to fine colluvial deposits on this soil unit.The soil unit was a depression receiving materials which were eroded from the upper slope.

Comparing the surface horizons and the subsurface horizons of the undulating plains with those of the flood plains statistically, it shows that clay content was significant ($p < 0.05$) in the surface horizons but not significant ($p > 0.05$) in the subsurface horizons Appendix B.Although statistically clay content was not significant in the subsurface horizons but the clay values shows that clay content was higher in the sub-surface of soil unit KB6 which is associated with the flood plain than other soil units, this might be due to clay deposits from the upland across the undulating plains into this soil unit.Another reason for the high clay content inthe subsurface might be due to alluvial deposits from the upstream.

However the trend of clay distribution with increase in depth was irregular across all soil units. The irregular distribution of clay in the profiles across the soil units suggested different period of colluvial-alluvial depositions rather than the deep weathered nature of the parent materials in situ. This finding is similar to that of Ebuchua and Ojobor,(2011). They also reported irregular trend of clay distribution within depth among the soils of the Niger-Delta region of Nigeria.

(ii) **Silt fraction**

The silt content was higher in the surface horizon of soil units KB2 p2, KB4 p1, p2, and KB6 p2 and in the subsurface it was higher in KB2 p1, p3, p4, KB3 p1, p2, KB5 p1, p2 and KB6 p1, p2. Generally silt content was higher in the subsurface horizons than the surface but statistically when comparing soils of the undulating plains with those of the flood plains at both surface and subsurface horizons it was significant ($p < 0.05$) in the surface horizons but not significant in the subsurface horizons Appendix B.

The highest value at surface and sub-surface was recorded in the flood plainwhich is associated with soil unit KB6(Table 4.3). This may be attributed to the fine sediments from alluvial and Aeolian deposits.The silt content further points to the Aeolian origin of the Upper soil parent material Maniyunda, (1999). The higher content of silt in the flood plainprofiles could be attributed to the fact that the flood plains, received fine colluvial-alluvial sediments from upper slope positions through erosion and from river Kubanni respectively. A similar finding was reported by Malgwi, (2001). He also reported high silt content in flood plains and attribute it to fluvial processes.

The soil unit with the lowest surface silt fraction was the KB3. This may be due to lateral translocation of silt or association of silt with clay in vertical translocation into the Bt horizon, since this landform show evidence of cutans.

(iii) **The silt/clay ratio**

Silt/ clay ratio across the study area were lower than the value (< 0.75 and 1.5) proposed by sombroek and zonneveld (1971).According to sombroek and zonneveld, (1971) the low value (< 0.75) indicate strong pedogenic weathering which might have taken place in situ. It also indicates old age of the surface deposit. Values between 0.75 and 1.5 indicate recent processes which may be fluviatile processes, while high values greater than 1.5 indicate recent pedogenic processes and may be Aeolian

Soils of the undulating plains had silt/clay ratio values less than0.75 This suggest a strong pedogenic weathering which might have taken place in situ across these landforms. Soils of the flood plainwhich is associated with soil unit KB6 had greater values than0.75 but less than 1.5 proposed by sombroek and zonneveld (1971), which suggests a recent process which may be fluviatile.

Although statistically silt/clay ratios were not significant at both surface and subsurface horizons of the undulating plains and flood plains it values shows that it was higher in the surface horizons than in the subsurface horizons and decreased with increase in profile depth (Table 4.3). This implies that the soils are more weathered in the subsurface than at the surface. This in line with reports of Yakubu,(2001) and Sharu *et, al.,* (2013) on soil of Sokoto state.

(iv) **Sand fraction**

The values of the sand fraction were higher in the surface horizons of soil units KB2 p2, p3, and KB6 p1 while in the subsurface it was higher in KB2 p1, p4, KB3, KB4, KB5 and KB6 p2. The highest surface value (390 gkg^{-1})was recorded at the undulating plains, specifically soil unit KB2(Table 4.3). However these values were far below 400 gkg^{-1} and 700 gkg^{-1} reported by (Mosugu, 1989; Zarafi, 1993; Maniyunda, 1999, and Shobayo, 2010),in their report on sand fractions within the Zaria region. The low values of sand within this soil unit may be that since the soils are very deep (> 150 cm) it shows that the soils are well weathered.

The soil unit with the lowest surface sand fraction was KB4. The low sand value within this soil unit may be due to the high intensities of gully erosion within this landform.

The low sand value at the sub-surface across all soil units may be due to the high clay content in depth due to high pedogenesis. However, sand has an irregular trend of distribution within the profiles, implying sedimentation as a process of soil formation in this area.

(b) **Impact of topography on soil bulk density across the landforms in the study area**

The bulk density was generally low (less than 1.6 to 1.85 g/cm3) USDA, (1993)in the surface horizons of all soil units. There was no significance ($p > 0.05$) difference at both surface and subsurface horizons of both the undulating plain and flood plains.The highest surface values were recorded in the undulating plain; specifically in soil unit KB4 p2. The high bulk density value record in this soil unit compared to any other soil unit was as a result of compaction due to high intensity of the gully erosion across this soil unit which has removedthe epipedons, exposing the sub-surface which is high in clay.

The bulk density ranged from low to moderate in the sub-surface of all soil units; statistically there were no significant difference ($p > 0.05$) across undulating and flood plains. This low to high bulk density values may be linked to the high clay content observed across their sub-surface and the massive structure within them and the eluviation of iron oxide and clay.

However it has an irregular trend of distribution within the profiles. A similar trend of distribution was also reported by some researchers; Raji (1995), Raji *et. al.,* (1996) and Maniyunda, (1999) who attributed it to compaction due to mechanical or animal traction.

Bulk density is therefore not a problem for the surface horizons of allsoil units. The low bulk density noticed in the surface of all soil units may be due to the moderately soil structure within them as earlier reported.

(c) Impact of topography on total porosity across the landforms in the study area

The distribution of total porosity across the soil units shows an irregular trend of distribution with increase in depth. This may be attributed to the variation in the structural development in the profiles. The low porosity at the sub-soils in all soil units may be due to the high clay content with improved aggregation. There has been no observed relationship between topography and total porosity.

The poor porosity on the surface of some of the pedons may be due to cultivation that usually creates high surface porosity but later collapse due to the break in inter-pores connection leading to hard surface caps on exposure to the action of rainfall.

In terms of porosity rating, soils of KB2, KB3, KB4and that of KB6were rated poor soils, (< 30%) while soils of KB5 were said to be unsatisfactory soil (< 40%) as proposed by Kachinkii (1965). The flood plain soilshad higher clay content especially in subsurface horizons and it is expected to be highly compacted because porosity is inversely related to bulk density, it show to have high porosity than all the other soil units reason for this may be due sedimentation.

According to Kachinkii (1965), best soils should have porosities of over 50%; good soils between 45-50%; satisfactory soils 40-45 %; unsatisfactory soils fewer than 40% and poor soils, below 30%.

(d) Impact of topography on soil available water holding capacity (AWHC) across landforms in the study area

The distribution of AWHC across the soil units was higher in the surface horizons of KB4 p1 and KB6 p2, when this two surface horizons were compared statistically, there were no significant ($p > 0.05$) difference between them. However, it showed that the subsurface horizons had higher AWHC than the surface horizons. This could be attributed to the higher clay content in the subsurface than the surface horizons. It the subsurface horizons the highest AWHCwas recorded in the flood plain soils with the value of 19.5% while the least was at the undulating plains specifically soil unit KB4 with a value of 11.5%. This high value of AWHC at the subsurface of the flood plain could be due to the high clay content recorded at the subsurface of this landform as earlier reported.

The AWHC was positively correlated with clay content ($r = 0.17$, $p =0.05$), there is also a positive correlation between AWHC and CEC ($r = 0.25$, $p = 0.05$) (Table 6) which is due to the relationship of CEC with clay which carries the charges.

5.3 The impact of Landforms on soil chemical properties

(a) Impact of topography on soil reaction (pH) across the landforms

The soil reaction (pH) was moderately (5.6 to 6.0) to slightly acidic (6.1 to 6.5) Malgwi, (2007) across the undulating plains, while the flood plainwhich is associated with soil unit KB6 was moderately acidic at the surface and strongly acidic (5.1 to 5.5) to slightly acidic inthe sub-surface. There was significance difference ($p < 0.05$) between the surface horizons of both landforms (Appendix B).

The high pH recorded in the flood plain over the undulating plainswas due to the enrichments of the flood plain with basic cations which weredeposited in the flood plains from the upland. This landform (flood plain) has the least slope of < 2%, therefore it serve as a collecting point.

The pH in $CaCl_2$ was lower than the pH in water. The results imply that some plant nutrient may be more readily available in water than in $CaCl_2$which show the actual soil situation in the field, it also implies that in water there is more of the H^+ than in $CaCl_2$ which triggers the reaction. The pH value of all the profiles falls within the normal range of 5.5-7.0 reported to be optimum for the release of plant nutrients (Sharu*et al.*, 2013).

The ∆pH values across the landforms were all negative for both surface and sub-surface horizons and were less than -0.5 implying that the soils had negative charges (zero point of charge) with dominance of clay minerals of variable charge.

Uehara and Gillman (1981) reported that ∆pH value of < -0.5 indicates a dominance of clay minerals with variable charges.

(b) **Impact of topography on salinity/sodicity across the landforms**

The electrical conductivity (ECe) of all soil units were below the critical limits of $4dSm^{-1}$ to be defined a saline soil (FAO, 1993). All the soils of thesoil units showed low ECe values ranging from 0.01 to 0.20 dSm^{-1}indicating non-saline nature of the soils. Generally the ECe decreased with increasing soil depth. There is no clear relationship between topography and salinity.

The values of Sodium absorption ratio across the landforms were low Table 4.6.The soils across all the soil unitswere non saline, or sodic as the electrical conductivity (ECe) of the saturation extract, SARand ESP were all low, far less than 4dsm^{-1}and 15 % indicative of salinity and sodicity. However the values decreased with increase in depth across all soil units but with a slight increase at the surface of soil unit KB6.This justifies the pH of this soil unit (flood plain) as earlier reported to be moderately acidic, since sodicity is pH dependents. Although soil unit KB6(flood plain) is expected to have higher soluble salt concentration but the values do not meet the requirement for grouping these soils as saline (FOA, 1993). These imply that salinization is not a significant pedogenic process across the landforms and the soilsdoes not contain appreciable amount of soluble salt that may hinder the growth of plants. This is similar to the finding of Egbuchua and Enujeke,(2013). He also reported low values of electrical conductivity(0.09 to 1.70dSm^{-1}) in their work onsome hydromorphic vertisols inLake Chad basins of Nigeria.However there is no clear relationship between the landforms and the Salinity and Sodicity.

(c) **Impact of topography on exchangeable bases across the landforms**

Calcium (Ca) is rated low (0 to 2) to high (greater than 5 cmol(+)kg^{-1} Malgwi (2007) across the undulating plains and medium (2 to 5cmol(+)kg^{-1}) in the flood plain (KB6) Table 4.6. Across undulating plains the rating was; medium to high at the surface of soil unit KB2 and KB3, low to medium in soil unit KB4 and medium in KB5. There were no significant difference ($p > 0.05$) between the surface horizons of the undulating and flood plains.

In the subsurface Ca was rated medium to high in soil unit KB2 and low to high in KB3, the Ca values were medium in KB4, KB5 and KB6. There were significance difference at ($p < 0.05$) between the subsurface horizons of the undulating and the flood plains.

Generally the distribution of Ca within the profile shows irregular distribution across all oil unitss. The low Ca values recorded in some of the profiles may be due to cation removal by plant uptake, low organic matter decomposition and erosion. This is in agreement with the report of Hussaini, (2011).He also reported low Ca values in soil and attributed it to plant uptake,low organic matter decomposition and erosion in his research on soils of theInstitutefor Agricultural Research Farm, Zaria, Nigeria.

The highest surface value of Ca (8.00 cmol(+)kg^{-1}) was recorded in undulating plains specifically in soil unit KB2 relief. This high value of Ca was recorded in KB2 over other soil units may be that Ca was brought in from soil unit KB1 (Tableland with very high relief).

The lowest (1.3cmol(+)kg^{-1}) surface Ca value was recorded in soil unit KB4. This low Ca value could be accounted for by intensities of gully erosion across this soil unit.

The dominance of Ca over the other cations in the study area may be due to the occurrence of exchange sites in soils which shows specific affinity for Ca (Esu, 1982).

(ii) **Exchangeable sodium (Na)**

The value of Na was rated high in soil unit KB2, KB3, KB5 and low in KB4 and low to high in KB6. There were no significance difference ($p > 0.05$) in the surface horizons of the undulating and flood plains but in the subsurface there was significance difference ($p < 0.05$) between the undulating and the flood plains Table 4.6.

The high rate of Na across most of the soil units may be attributed to the parent materials, which may be rich in Na bearing mineral. Although there was no clear trend in itsdistribution in the profile, generally the lower horizons had higher exchangeable sodium than surface horizons. This shows that most of the Na may have leached downward. This is similar to reports of Kparmwang, (1993) on basaltic soils of Northern guinea savanna of Nigeria and Raji, (1995) on ancient dune soils of Northern Nigeria. They also observed higher Na at the subsoil than the surface and attributed it to leaching.

Higher content of Na was recorded in soil unit KB6(flood plains). This high Na in this soil unit may have been brought in from the upland plains since Na is very soluble and mobile and this soil unit is the lowest position of all the soil units. Another reason may be that since this soil unit is saturated over some time it can cause capillary movement of water from the water table to the surface Malgwi, (2001), coupled with deteriorated structure of subsoil and poor drainage characteristicswhich could lead to Na build-up or vice versa.

The lowest Na value was recorded in the upland plains which might be due to continuous removal of the surface horizons of the uplands together with Na down slope into the flood plain.

(iii) **The exchangeable Magnesium**

The exchangeable Magnesium (Mg) was the third dominant cation in the exchange site.

Exchangeable Mg across the surface and subsurface horizons within the study area was rated low to medium acrossall soil units.

Generally Mg content increased with increase in soil depth and the trend of distribution in the profiles is similar to that of Ca, except that Mg was lower than Ca (Table 4.6). This is in line with other researcher's reports(Maniyunda, 1999; Hussaini, 2011; Shobayo, 2011). They also reported a general increase of Mg with increase in depth.

The content of Mg was higher in soil unit KB6(flood plain) than all other soil units. This shows that most of the bases must have been deposited in this soil unit from the upper slope. The lowest content of Mg was recorded in soil unit KB4. This low Mg in this soil unitcould be due to gully erosion that occurs across this soil unit.There were significantly differences ($p < 0.05$) between soils of the undulating and flood plains in both surface and subsurface horizons.

The level of Mg on the surface horizons shows no threat to the soil but it continued accumulation on the exchangeable complex may cause soil structural deterioration and lower water intake rate.

(iv) **Exchangeable potassium (K)**

Exchangeable K was the least dominant in the exchange site. The value of potassium (K) was rated low at surface horizons ofundulating plains and medium at the flood plain. In the subsurface horizons it was rated low across all soil units. Comparing the undulating plains with the flood plains statistically, there were significantly differences ($p < 0.05$) in both surface and subsurface horizons.

The values of K were high at surface of soil unit KB6(flood plains).This high value of K in the surface of soil unit KB6 may be due to high application of NPK fertilizer within this soil unit by farmers.Possibly it may also be due to continuous loss of surface soil from the undulating plains and its subsequent deposition in the flood plains.

The low value of K recorded across surface horizons of upland plainsmay be due to intensive cultivation of the field and it uptake by plant. Another reason may be due to continuous loss of the upland surface soil and nutrient through erosion.

(d) **Impact of topography on exchangeable acidity across landforms**

The exchangeable acidity was low (<1.0 cmol(+)kg^{-1}) across the surface horizons of all soil units. The flood plain was expected to have high acidity because of its poor drainage but it also showed low acidity. There is no clear relationship between topography/soil units and exchangeable acidity and there were no significant difference ($p > 0.05$) in both surface and subsurface horizons of undulating and flood plains.

At the subsurface horizons it was low in all upland plains but low to high at the flood plain. The low acidity nature of the upland plains shows a literal movement of the exchangeable acidity from the upland plain into the flood plain. The high exchangeable acidity recorded in the subsurface horizons of the flood plain wasas a result of it being brought in from the upland.It may also be due to the poorly drained nature of the flood plain.

Generally the level of exchangeable acidity across all soil unitssuggests that the soils had little or no acidity problem, therefore, it can support a wide range of crops. The low levels of exchangeable acidity also ensure availability of Ca and Mg in the area, as high acidity can cause Ca and Mg deficiency.

(e) **Impact of topography on organic carbon (O.C) across landforms**

The data for organic carbon is shown in Table 4..8Organic carbon across landforms was low (< 10gkg^{-1}) at both surface and subsurface horizons.

Generally organic carbon was higher at the surface than subsurface horizons across all soil units. It decreased with increase in depth across all the profiles. This was similar with the report of Sai *et. al.*,(2013). They also found out that O.C decreased with increase in soil depth on their study on soils of Khammam District, Andhra Pradesh. However the least surface value was recorded in undulating plains specifically in soil unit KB4. This may be attributed to high effect of gully erosion within the KB4 which removes the top soils rich in organic matter, leaving a thin layer of the Ap.

Although the O.C is generally low across all soil units (Table 4.8), higher values were recorded in the surface of the flood plain associated with soil unit KB6. This higher value of O.C in the surface of flood plain associated with soil unit KB6 may be due to it being deposited from upper slope positions since this landform serve as a collecting point of material being eroded from the upper slope. It may also be due to the less decomposition of organic material in poorly drained soils compared to well drain undulating plains.

Whenthe undulating irregular plains were compared with that of the flood plain associated with soil unit KB6 which had a slope of less than 2%, it was clear that organic carbon has moved from undulatingplains and deposited in the flood plains, due to their variation in slope degrees.There were significantly differences ($p < 0.05$) in the surface horizons of both undulating and flood plains but not significantly differences ($p > 0.05$) in the subsurface horizons of both landforms.

The generallylow organic carbon across landforms may be attributed to factors like intensive cultivation with little effort to improve organic matter content, removal of plant residue for livestock feeding and the use of these plant residues for fencing of buildings by the farmers.

High rate of organic matter mineralization due to high temperature as indicated by low C:N ratio (5.23 to 12.79) at the surface(Table 4.8) also reduces organic matter content. This is in agreement with report of Ibrahim *et. al.*,(2013) on their report on extractable micronutrients status in relation to other soil properties in Jangargari, Yamaltu.

The carbon to nitrogen ratio (C:N) is an indication of the extent of organic matter decomposition and the release of nutrients such as nitrogen to the soil (Maniyunda, 1999). Carbon-nitrogen ratios across the soil units were narrow as the values were less than 25 (Paul and Clark, 1989) being the separating index for mineralization and immobilization of nitrogen in the soils. This narrow C:N ratio reflects high microbial activity and humification process for the release of nutrient elements for crop plants (Maniyunda, 1999).

The C:N ratio values were higher in the surface horizons across all soil units than in the subsurface, indicating that there is high mineralization at the surface.The low values in subsurface horizons may be attributed to leaching or deep percolation of nitrogen insubsoil. Similar reports were observed by (Ogunwale, 1973, Russell, 1973 and Maniyunda, 1999).

(f) **Impact of topography on total nitrogen (TN) across landform/soilunits**

Total nitrogen was rated low (< 1.5 gkg^{-1}) for surface horizons of undulating plains and low to medium (< 2 gkg^{-1}) in the flood plain. At the subsurface it was low across all soil units (Table 4.8). There were not significantly differences ($p > 0.05$) in both surface and subsurface horizons of undulating and flood plains.

Generally higher TN values were recorded in the surface horizons than in the subsurface. This trend of TN distribution across the soil units was similar to that of the organic carbon. The least values wererecorded in soil unit KB4. This low value may be due sharp drop in slope resultingfrom the intensity ofgully erosion in KB4, which might have removed most of the TN into the flood plains since, nitrogen is highly mobile.

The highest TN value was recorded onthe surface soil horizons ofKB6 (flood plain). This may be due to relatively higher organic carbon on the surface than the sub-surface horizons of this soil unit (KB6) and deposition within this landform from upper slope positions.

Another possible reason of high TN in the flood plain may be due to the surface wash of TN from the upslope to the flood plain. It may also be due to the use of N-containing fertilizers by farmers, since this landform was intensively cultivated with varieties of crops.

The total nitrogen decreased with increase in depth and had a highly significant correlation with organic carbon ($r = 0.71188$, $p = 0.001$), (Table 4.5).Such similar correlations werealso reported by Kparmwang, (1993); Maniyunda, (1999). This shows that total nitrogen may be in its organic form. Another reason for low total nitrogen contents of the soils could be from NH^{+}_{3} volatilization and denitrification which arecommon in wetland soils (Kyuma, 1986) which is similar to the flood plains.

(g) Impact of topography on available phosphorous (AP) across landforms/soil units

Available phosphorous across landforms was rated low to medium (< 10 $mgkg^{-1}$ low, 10-20$mgkg^{-1}$ medium and > 20$mgkg^{-1}$ high, according USDA 1993).

Generally it was higher in surface than in the subsurfacehorizons, with its least values recorded in the undulating plains specifically in soil unit KB4. Available phosphorous in soil unit KB4was lower than those recorded in other oil units within the study area. This may be as a result of effect of erosion within this soil unit.The general decrease of P in subsoil horizons may be due to increase in clay content which lowers availability of phosphorous, probably due to fixation of P by sesquioxides this is in line with the report by (Sai *et. al.,* 2013). They also find out that high clay content in soil resulted to AP fixation on their research on soils of Khammam District, Andhra Pradesh.

The available phosphorous values were higher in the surface than in subsurface horizons across all soil units. There were not significantly differences ($p > 0.05$) in both surface and subsurface horizons of both undulating and flood plains

The highest surface value of P was recorded atundulating plains specifically in soil unit KB3 (Table 4.8). This may be due to high application P fertilizer by farmers from the upper slope, particularly from soil unit KB2 which has a slope gradient of 4-7% which is higher than that of soil unit KB3. This variation in slope might have led to erosion in soil unit KB2 and deposition in soil unit KB3.

The lowest surface value of AP was recorded in soil unit KB4. This low surface value of AP in KB4 was due to the high intensities of gully erosion across this soil unit which must have deposited most of the P into the flood plain (KB6).

(h) **Impact of topography on cation exchange capacity (CEC) across the landforms**

The data for cation exchange capacity (CEC) is shown in Table 4.7.Cation exchange capacity (CEC-NH_4OAc) values across all soil units were rated low to medium(> 6 cmol(+)kg^{-1} but < 12cmol(+)kg^{-1}) in the surface horizons and low to high at subsurface horizons of soil units KB2, KB3 and KB5 but low in soil unit KB4 whilein soil unit KB6 it was low to medium.

Generally the CEC values were higher in the subsurface than in the surface horizons. At surface horizons the highest value(10.70 cmolkg^{-1}) was recorded in the flood plain associated with soil unit KB6. The high CEC in the surface of the flood plain may be link with the high organic carbon.The CEC value for this landform (flood plain) was higher than those of the undulating plains,probably because of the relatively higher O.C in the flood plain. When correlated with clay, the CEC correlate positively with clay (r = 0.16616, p = 0.01) (Table 4.5). It is being suspected that 2:1 may be in this unit.

The least value of the CEC was recorded at the undulating plains specifically in soil unit KB4. The general low CEC within this soil unit may be linked with it low organic matter content and the high intensities of erosion within this soil unit. There were not significantly differences ($p > 0.05$) in both surface and subsurface horizons of both undulating and flood plains.

(i) **Impact of topography on soil base saturation across landforms**

The data for base saturation across the landforms is shown in (Table 4.7). The base saturation (NH_4AOc)was low to high at surface of undulating plains and low to medium in flood plain associated with soil unit KB6. There was no significant difference ($p > 0.05$) in the surface horizons of both undulating and flood plains but in the subsurface horizons there were significantly differences ($p < 0.05$).

Thebase saturation (ECEC) values on the surface horizon was moderate to high in soil unitKB2 andKB4 then high in soil unit KB3 andKB6.

Most of the profiles displayed inconsistent decrease with increasing soil depth (Table 4.7).In all soils, the BS by ECEC gave higher values than that of the corresponding values obtained by NH4OAc methodthis is because the percentage sites are occupied by ions other than hydrogen.

The highest value of BS acrosssoil units were recorded in flood plain. This is because the landform was the lowest of all landforms in the study area, so it is possible that the bases have been deposited by chemical denudation into this landform from the upland plains.

The least value of BS was recorded in soil unit KB4. This low value was due to the high intensities of gully erosion across this soil unit. BS (ECEC) shows no significant difference ($p > 0.05$) in both surface and subsurface horizons of undulating and flood plains Table 4.7.

Sanchez (1976) reported that base saturation by ECEC gives more realistic picture of the acidity level of variable charged soils than the base saturation from NH4OAc which tends to overestimate it. This is because the percentage sites is occupied by ions other than hydrogen, however, acid soils may have high cation exchange capacity, but a low percent base saturation, because of exchangeable hydrogen ions.

Soils with high CEC and high BS are fertile unless they are saline or contain toxic heavy metals Isirimah *et. al.*,(2003). The general moderate to high values of base saturation across the soil units may be due to the relatively high clay content.The occurrence of high BS in the subsurface may be linked to accumulation of bases in the lower horizons through lateral movement of water (Malgwi, 2001).

FAO (1999) reported that soils with base saturation greater than 50% are regarded as fertile soils while soils with less than 50% are regarded as not fertile soils. Based on this the soils are generally fertile.

(j) **Impact of topography on soil micro-nutrients across the landforms/soil units**

The data for micro-nutrients (Fe, Zn, Mn and Cu) across the soil units are shown in Table 4.9.

(i) **Extractable iron (Fe)**

Iron (Fe) was low to high (> 4.5 $mgkg^{-1}$) across undulating plains and high in flood plain at both surface and sub-surface.

Iron (Fe) distribution across the soil units recorded its highest value insoil unit KB6 (flood plain), However the surface values were higher than the critical values for crop requirement (2.5$mgkg^{-1}$) as reported by Esu, (1991). Iron (Fe) was higher in soil unit KB6(flood plain) than all the other soil units in both surface and sub-surface probably because of its high mobility. There were no significant difference ($p > 0.05$) in the surface horizons of both undulating and flood plains but it was significantly different ($p < 0.05$) in the subsurface horizons of both landforms.

Iron (Fe) may not be deficient in this soil unit (flood plain) but it continuous accumulation may result to its toxicity.The extremely high value of Fe recorded in soil unit KB6 may be as a result of it deposition in this soil unit (flood plains) which serve as a collecting point to lateral movement of iron from higher landforms. It may also be linked to the high pH recorded in this soil unit.

Within the profile, extractable Fe decreased or increased irregularly with increase in depth across all soil units. The irregular distribution pattern may be due partly to the mobile nature of Fe oxide and their tendency to form concretions in localized spots in soil horizons (Kparmwang *et al.,* 2000).

The undulating plains had Fe values far below that of the flood plains (Table 4.9), though with a noticeable presence of the formation of soft unindurated plinthite (laterite). This could be due to the well drained nature of the landform because of it sloppy nature.

Iron (Fe) deficiency is veryunlikely as iron is known to be soluble under relativelyreducing conditions Chestworth (1991).The presence of high concentrations of Fe in soilscould lead to its precipitation and accumulation to toxic level which may result to salinity, restrict rooting depth and drainage, amongst others which is common in wetland(Chestworth, 1991).

The least value of the 0.1M HCl extracted iron (Fe) across the soil units were recorded in the undulating plains; specifically in soil unit KB4 (Table 4.9). The values of iron (Fe)in this soil unit was lower than the critical values for crop requirement (2.5mgkg^{-1}) as reported by Esu, (1991) and also lower than all other soil units. Iron(Fe) may therefore be deficient in these soils. The general low value of Fe in this soil unit may be due to the high effect of erosion intensities within this soil unit.

(ii) **Extractable manganese**

The extractable Mn in the surface horizons of all the soil units wererated medium acrosssoil units within the undulating plains andmedium to high(greater than 5mgkg^{-1}) in the flood plain (KB6).

The values for Mn were higher (greater than 5 mgkg^{-1}) in the flood plain/KB6 than undulating plains. Manganese are said to be dependent on pH as it increase with increase in soil acidity Brady and weil, (1999) and since the flood plain/KB6 has low pH than all other soil units it may be the reason for its high Mn. The levels of Mn in the study area are below what was reported by Kparmwang, (1996) for some Ustults inBauchi, (7.89 – 12.00 $mgkg^{-1}$), Nigeria.

Esu (1991) reported that the criticalrange of Mn is 1 – 5mg/kg. Therefore, Mn within the flood plain/KB6 is above the critical value, suggesting that Mn cannot be a limiting factor for crop production within this landform but its continuous accumulation may result to it toxicity. But for the landforms of theundulating plains, Mn is needed to improved crop production across these landforms.

(iii) **Extractable zinc (Zn)**

Extractable zinc (Zn) was rated low (less than $1mgkg^{-1}$) across all soil units both in the surface and subsurface horizons.The values ofZn for the study area fall below the critical values ($0.90mgkg^{-1}$) for cropproduction as reported by Lombin (1983a). Therefore for successful crop production, Zn value has to be improved.This is similar to report of Mustapha *et. al.,(*2010). They also found out that Zn concentration within their study area was below the critical value proposed by Lombin, (1983a).

(iv) **Extractable copper (Cu)**

Extractable copper Cu was low to medium across all the soil units. The general distribution of Cu with soil depth shows an irregular trend across all the soil units. Critical levels for 0.1N HCl extractable Cu in soils is 1.00 to 2.00 $mgkg^{-1}$ soil Sims and Johnson, (1991) and 1.0 - 3.0 mg kg^{-1}Tisdale *et al.*, (2003). This implies that Cu is highly deficient across all the soil units, and there is need for its improvement for crop intake.

5.4.0 Soil Classification

Soils of the study area were classified based on the criteria and nomenclature of the USDA Soil Taxonomy (Soil Survey Staff, 2010) and were correlated with the World Reference Base for Soil Resources (FAO-ISRIC-IUSS, 2014). The differentiating characteristics that were employed for the classification included morphological, physical and chemical properties of the soils units that wereconsidered important in both systems of classification.

5.4.1 Criteria for soil classification according to USDA Taxonomy system.

The criteria for soil classification are discussed below;

(i) **Soil moisture regime.**

The annual rainfall in the study area is more concentrated within the months of June to September. The soils are moist in the moisture control section for more than 180 cumulative days when conditions are suitable for plant growth (Soil Survey Staff, 2010). They are dry for more than 90 cumulative days. Therefore,soil units of KB1, KB2, KB3, KB4 and KB5 were inferred to have an ustic moisture regime. This is because they have limited moisture, but the moisture is present at a time when the conditions are suitable for plant growth. Soilsunit KB6 experience water logging during the wet season and prolonged high water table. Therefore they were inferred to have Aquic moisture regime.

(ii) **Soil temperature regime**

The mean annual soil temperature was more than 22^{o}C. The difference between the mean summer and winter soil temperature was less than 6^{o}C at the depth of 50cm. Therefore, the soil temperature that prevails is iso-hyperthermic (Soil Survey Staff, 2010).

(iii) **Diagnostic surface horizon (epipedons).**

The epipedon is a horizon that forms at or near the surface and in which most of the rock structure has been destroyed. It is darkened by organic matter or shows evidence of eluviation, or both.

Thesoil units KB2 p1, p2, p3, KB3 p2, KB4 p1, KB5 and KB6 p1allpossessed the characteristic of Ochric epipedon because they are too thin, too light, have high colour value or chroma, they contain too little organic carbon content, too low phosphorous, to be either mollic, anthropic, histic, melanic, plaggen or umbric epipedon.

Soils of units KB2 p4, KB3 p1, KB4 p4 and KB6 p2 were inferred to have Mollic epipedon because they havestructural units withdiameters of 30 cm or less and a moderately hard or softer rupture-resistance class, a base saturation (by NH_4OAc) of 50 percent or morethroughout and the organic carbon content of the underlying materials decreases irregularly with increase in depth.

(iv) **Diagnostic subsurface horizons (endopedons).**

Profiles of soil units KB2 p2, p3, KB4 p2, and KB6 met the condition of argillation because they showed evidence of clayeluviations to form argillic horizons, had higher percentage of clay than the overlaying horizons, had particle sizes of coarse loam, loam, sandy clay loam and clay, and some thin clay skins in the Bt horizons.

Profiles of soil units KB2 p1, p4, KB3 p2, KB4 p1 and KB5were inferred to as Cambic horizons because they had textural class of sandy clay, clay loam and loamy, showed evidence of absence of rock structures, do not have combination of aquic condition within 50 cm of the soil surface or artificial drainage,has properties that do not meet the requirements for an anthropic, histic, folistic, melanic, mollic, plaggen, or umbricepipedon, a duripan or fragipan, or an argillic, calcic, gypsic,natric, oxic, petrocalcic, petrogypsic, placic, or spodic horizon.

Soils of unit KB3 p1 had gleyic colour pattern all through its depth with evidence of E horizon to meet the condition of Glossic horizon (Soil Survey Staff, 2010). They developed as a result of degradation of argillic horizon from which the clay and free iron oxide are removed to the Btg horizon. It was more than 5cm in thickness and had an eluvial part which constituted about 15-85% volume of the Glossic horizon (Soil Survey Staff, 2010).

5.4.2 **Classes of soils of the landforms of study area**

(a) **The USDA Soil Taxonomy System.**

At the order level, soils of units KB1,KB2 p1, p4, KB3 p2, KB4 p1 and KB5 are classified as Entisols. This is because they do not meet any of the requirements to be grouped into any of the group.

Soils of unit KB2 p2, p3, and KB4 p2were classified as Alfisols. This is because they had an argillic horizon,organic carboncontent were generally less than 6 gkg^{-1} (Table 4.8), to meet the requirements of any other epipedon and high base saturation (Table 4.7) greater than 50 % (by NH_4OAc).Soils unit KB6was classified as Inceptisols because they have aquic condition for some time during the normal year and a massive structure.

At the sub-order, soil unit KB1 was classified as Orthents because they do not meet any of the condition to be grouped under any other sub-group.Those of soil unitsKB2 p1, p4, KB3 p2, KB4 p1 and KB5 were classified as Psamments because they have less than 35 % (by volume) rock fragments and a texture class of loamy fine sand (sandy loam) in all layers within theparticle-size control section.Soils of units KB2 p2, p3, and KB4 p2 were further classified as Ustalfs because of they have ustic moisture regime.

While those of soil unit KB3 p1 are Aqualfs because they have an aquic condition for some time in the normal year.Thesoils of unit KB6 was classified as Aquepts, because they had aquic condition for some time in normal years.

At the Great group level, most dominant properties of the whole soil body were taken into consideration as well as properties of the B horizon. Soils of unitKB1 were classified as Ustorthents because they have an Ustic moisture regime. Those of unitsKB2 p1, p4, KB3 p2, KB4 p1 and KB5 were further classified as Ustipsamments because they had Ustic moisture regime.Soils of unit KB2 p2 and p3 were further classified as Plinthustalfs because they have plinthite within their depth of 150cm of the mineral soil surface in which plinthite formed a continuous phase. While that of unit KB4 p2 was classified as Haplustalfs because it did not possessed any of the special features in the profile that distinguished it from the other great groups.Soil unit KB3 p2 and soil unit KB6 were classified as Epiaqualfs and Epiaquepts respectively because they have episaturation.

At the subgroup level, emphasis was placed on the processes that dominate the soil development. Soils of unitKB1 were considered to be Typic Ustorthents, because they did not meet conditions under the sub-group to be grouped into. Those of units KB2 p1, p4, KB3 p2, KB4 p1 and KB5 were classified as TypicUstipsamments. Soil of unitKB2 p2 and p3 were classified as Typic Plinthustalfs (Soil Survey Staff, 2010). That unit KB4 p2 was further classified as Typic Haplustalfs (Soil Survey Staff, 2010). Whereas that ofsoil unit KB3 p1 was classified as Typic Epiaqualfs, those of unit KB6 were further classified as Typic Epiaquepts (Soil Survey Staff, 2010).

5.4.3 **The World reference base (WRB) System**

According to the World Reference Base for Soil Resources (FAO-ISRIC-IUSS, 2014), soils of unit KB1 were classified as Akroskeletic Regosols, because they are soils within the rocky and hilly areas with no profile development. Those of units KB2 p1, p4, KB3 p2, KB4 p1 and KB5 were classified as Eutric Arenosols because they are soils with an average of loamy sand and had less than 40 % coarse fragments within their depth of 100 cmand a base saturation which is greater than 50 % in the depth of 20 to 100 cm from the soil surface.The soils of unit KB2 p2 and p3 were classified as Eutric Plinthosols because they are soils with plinthite occurring within 150cm of the soil surface. They are Fe-rich in some cases Mn-rich humus and they had a base saturation which is greater than 50 % in the depth of 20 to 100 cm from the soil surface.

That of soil unit KB4 p2 was classified as classified as Vetic Lixisols because they have high clay content in the subsoil than in the topsoil as a result of pedogenetic process (especially clay migration) leading to an argric subsoil horizon. They have high base saturation and low activity clays. They have ECEC of less than 6cmol/kg^{-1} clay in some surface layer within 100cm of soil surface.

Soil unit KB3 was classified as Gleyic Gleysols because they are wetland soils that, unless drained is saturated with ground water for long period enough to develop characteristic greyey color pattern. This pattern is essentially made up of reddish, brownish, or yellowish colour at peds surface and/or in the upper soil layer or layers, in combination with grayish/bluish color inside the peds and or deeper in soils.Thesoils of unit KB6 were placed in the unit Stagnosols because they are periodically wet and mottled in the topsoil and subsoil, with or without concretion. For this reason they are classified as Stagnic Stagnosols.The summery of classification by the USDA Soil Taxonomy and WRB are presented in Table 5.0.

Table 5.0 : Summary of Soil Classification according to USDA 2010 and WRB 2014

			USDA System		WRB System
Soil units	Order	Sub-order	Great group	Sub-group	
KB1	Entisols	Orthents	Ustorthents	Typic Ustorthents	Akroseletic Regosols

KB2 p1, P4	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Eutric Arenosols
KB2 p2, p3	Alfisols	Ustalfs	Plinthustalfs	Typic Plinthustalfs	Eutric Plinthosols
KB3 p1	Entisols	Aqualfs	Epiaqualfs	Typic Epiaqualfs	Gleyic Gleysols
KB3 p2	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Eutric Arenosols
KB4 p1	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Eutric Arenosols
KB4 p2	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Vetic Lixisols
KB5	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Eutric Arenosols
KB6	Inceptisols	Aquepts	Epiaquepts	Typic Epiaquepts	Stagnic Stagnosols

5.5.0 **Land Capability classification**

The land capability classification ofthe study area was based on a detailed soil survey. The United State Department for Agriculture (USDA) system was used.

5.5.1 **Structure of the Land Capability Classification**.

The capability classification provides three major categories of soil groupings:

(1)Capability class (2) Capability subclass, and (3) Capability unit.

5.5.2 **Land capability classes:**

Capability classes are groups of capability subclasses or capability units that have the same relative degree of hazard or limitation. The risks of soil damage or limitation in use become progressively greater from class I to class VIII (Table 4.10).

The capability classes are useful as a means of introducing the map user to cover more detailed information on the soil map.The classes show the location, amount, and general capability of the soils for agricultural use. Only information concerning general agricultural limitations in soil use is obtained at the capability class level.

Description of the USDA capability classes are shown in Table 4.10.

5.5.3 **Land capability sub-classes**

The sub-classes show type of limitation encountered in the classes. Four kinds of limitations are used in the sub-class and are indicated by a subscript letter such as “e” for erosion hazard, “s” for soil properties such as root zone, water table, stoniness, salinity, soil structure and hard pan. While letter “c” denote soils with climatic problems and “w” representing excess wetness. In the study area the major capability sub-classes were e, s and w.

5.5.4 **Land capability unit**

The capability unit condenses and simplifies soils information for planning individual tracts of land, field by field. Capability units with the class and subclass furnish information about the degree of limitation, kind of conservation problems and the management practices needed. Within the study area specific limitations across the soil units were; e= 1-sheet erosion, s=2- moderate to strong sloping, s= sl-3-slope steepness, ro=rocky outcrop, for soils of KB1. e=2, e=3, Sheet erosion and gully erosion respectively, s=d-2, imperfectly drained, e=3-gully erosion, st-2-weak structural development was the major limitations among soils of KB2, KB3, KB4 and KB5. S=d-3-very poorly drained and ms=3-massive structure was the major limitation for soils of KB6.

5.5.5 Land capability classes of landforms

A total of four land capability classes and three sub-classes were indentified in the study area. The land capability map is presented in Figure 4.5.

Note that; II, III, VII and VIII = capability classes, e, s, w and c = subclasses representing erosion, soil structure, wetness and climate in that order, hc, h, ro, sl, d and msare sub soil structures and are representing high clay content, hills, rocky outcrops, slope, drainage and massive structure in that order, 2 and 3 are representing the degree of limitations in the unit.

(i) **Class IIe, s**

Soil unit KB2 falls into the capability class II e-$_2$, II s-sl-2 and II s-c-2as described above earlier. This wouldenhance poor structure; it could also result to hardness during the dry season. This high clay content at the subsurface could also affect water infiltration which may require proper drainage for proper productivity. The rill erosion and moderate to strong sloping within the area would result to loss of nutrients. However they are the best soil within the study area.

(ii) **Class III w s**

Soils of unit KB6 and those of KB3 falls into capability class IIIw-d-1, III w-d-3, III s-ms-3 and III s-sk-2.High clay contents at both surface and subsurface would enhance structural deterioration and massive structure. This may reduce the choice of crops to be grown.

The fine texture makes its workability difficult. Tillage can be hindered by stickiness when the soil is wet during the raining season and hardness when the soil is dry.

(iii) **Class VII e s**

Soils of unit KB4 falls into the capability class VII e-3 and VII s-c-2.High clay contents at both surface and sub-surface horizons which would enhance structural deterioration. The high intensities of gulley erosion within this area will make it difficult for crop production and control. This area can be used for cattle grazing.

(iv) **ClassVIII e, s**

Soils of unit KB1 falls into the capability class VIII e-2, VIII s-sl-3, VIII s-ro-3, VIII s-h-3. The pockets of shallow soils around the rocky area could support plant growth but erosion around the area would threaten the crop growth, the scattered ironstones would affect root penetrations therefore this area is not suitable for arable cropping, it can be used as a tourist site or educational trip site for students.The extent of land capability classes and the summary of the land capability classification of Kubanni area are shown in Table 4.11.

6.0 **CHAPTER SIX**

6.1 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1.1 Summary

A pedological study of the soils of KB1, KB2, KB3, KB4, KB5 and KB6 was carried out to investigate the influence of topography on their characteristics and toclassified and determine their capability potentials.

The study site was located within the central High plains (Basement Complex Rocks) of the Northern Nigeria Savanna region within latitude 11^{o}06.625"N to 11^{o}05.375"N and longitude 007^{o}41.608"E to 007^{o}39.680"E with an elevation above sea level ranging from 631m to 689m.

Six landforms were identified through the processing of satellite images namely; Tableland with very high relief, irregular plains with some moderate relief, smooth plains with some moderate relief, irregular plains with low relief, flat or nearly flat plains and the flood plains. The associated soils on these plains were units KB1, KB2, KB3, KB4, KB5 and KB6 in that order.

Using the landform map, an area of 4.7km long by 200m wide giving a total of 94 ha was selected out of the Kubanni basin. Three transverses were created with grids at 100m intervals. Soil observation points were made at fixed intervals and georeferenced. A detailed soil survey was carried out andtwelve (12) profile pits were dug, described and sampled across the six soil units except for that of KB1 because they were soils around rocky outcrops. A total of 46 samples were collected for laboratory analysis.

The soils were further grouped into three categories namely; Tablelands, undulating plains and the flood plains. Tableland soils were very shallow soils with scattered rocky outcrops which couldnot permit the digging of a profile pit, the undulating plains were very deep soils (greater than 150 cm) while the flood plains were deep soils (less than 150 cm).

The Tableland soils were excessively drained. This is because of it steep slope (18-30%) which resulted into rapid runoff.The undulating plains had drainage ranging from imperfectly drained to well drained with a surface colour ranging from very dark grey (10YR 3/1) to dark yellowish brown (10YR 3/4).Drainage for soils of the flood plain which has a slope degree of (less than 2%) was very poorly drained.It has a surface colour of dark yellowish brown (10YR 4/4) to dark grey brown (10YR 4/2). This landform represents the lowest position in the study area.

The textural classes ranged from sandy clay to loam across undulating plains and sandy loam to loam in flood plain. The undulating plains had a moderate sub-angular blocky structure to weak moderate sub-angular blocky structure. A massive structure was common in the flood plain.This was another feature that makes it unique from all the landforms within the study area probably due to poor drainage.

Within the undulating plains were gullies and borrow pits specifically in soil unit KB4, this may be because of the sharp drop in slope towards the landform which do not allow water to settle.The dominant particle size across all the landforms was clay, giving rise to the argillic horizons in the subsurface horizons of most of the soil units. Clay was higher in surface horizon ofundulating plains than flood plain but in subsurface horizons it was higher in flood plain than the undulating plains. However, there was no clear relationship between clay and topography.

Bulk density was low across all surface horizons of the landforms. At the subsurface horizons it was low in the undulating plains, and low to high in the flood plain. There were no significant difference ($p > 0.05$)in both surface and subsurface horizons of the undulating and flood plains. However bulk density was not a problem across all the landforms. Total porosity values were rated low to moderate, having 30% (poor soils) in the flood plains and 40%in the upland

The AWHC across the surface horizons of all the landforms in the study are were low (less than 20 %). Subsurface horizons had higher WHC than surface horizons. The values of AWHC in subsurface shows that the undulating plains had lower values than the flood plains. It was not significantly different ($p > 0.05$) in both surface and subsurface horizons in soils of both undulating and flood plains.

The pH was rated slightly acidic (6.1 to 6.6) to moderately acidic (5.6 to 6.0) in water and strongly acidic (5.1 to 5.5) in $CaCl_2$ across undulating plains and moderately acidic in water and strongly acidic in $CaCl_2$ in flood plain. Electrical conductivity across all landforms was (< 4dSm^{-1}) indicating that salinity was not a problem within the study area. The SAR was also low (< 15dSm^{-1}) across landforms indicating that sodicity was not also a problem for the soils of the study area. The exchangeable acidity at both surface and sub-surface across landforms was low. Exchangeable bases show that Ca was medium (2 to 5 cmol(+)kg^{-1}) to high (greater than 5cmol(+)kg^{-1}), Na was high (greater than 0.3cmol(+)kg^{-1}) and Mg and K were low(less than 0.3 and 0.15cmol(+)kg^{-1})respectively for soils of unitKB2, KB3 and

KB6. For soil unit KB4 Na was low. Organic carbon was low (less than 10 mg kg^{-1}) across all soil units. This may be attributed to factors like intensive cultivation with little effort to improve the organic matter content, removal of plant residue and erosion effects, however soils of KB6 had higher values than the others soil units. This was because flood plains are receiving landform and the rate of mineralization in flood plains was lower than undulating plains.Total nitrogen was low (less than 0.15 %) for all landforms, but with a relatively higher value in flood plains than undulating plains, it was not significantly different in both surface and subsurface horizons of both the undulating and flood plains. The available phosphorous was low to medium across all landforms but also higher at surface horizons of flood plains than undulating plains.It was not significantly different in both surface and subsurface horizons of both the undulating and flood plains. The base saturation was generally high > 50% (NH_4AOc) and >70 % (ECEC).

The soils were classified according toUSDA soil Taxonomy (Soil Survey Staff 2010) and correlated with the World Reference Base for Soil Resource 2014.Soils of unit KB1 were classified as Typic Ustorthents/Akroseletic Regosols, those of KB2 p1, p4, KB3 p2, KB4 p1 and KB5 were classified as Typic Ustipsammers/Eutric Arenosols, soils of unit KB2 p2, p3 were classified as Typic Plinthsualfs/Petric Plinthosols, unit KB3 p1 as Typic Epiaqualfs/Gleyic Gleysols, unit KB4 p2 as Typic Haplustalfs/Vetic Lixisols while those of KB6 were classified as Typic Epiaquepts/ Stagnic Stagnosols.

The land capability classification was based on the detailed soil survey investigation. It is based on properties that were of permanent limitation or risk to soil damage. The capability classification system has eight classes of four sub-classes and units. The six soil units in the study area were classified into four capability classes and three sub-class because the share similar limitation for them to be grouped into such groups; soil unit KB2 and KB5 were grouped into land capability class II e, s because they have rill erosion and a moderate to strong slope, soils of units KB3 and KB6 were grouped in capability class III w, s because they have excessive wetness and massive structure, hardness and stickiness, soils of unit KB4 were grouped in class VII e, sbecause they have intensive gullies and massive structures and ironstones while soils of unit KB1 were grouped in to class VIII e, s because they have excessive sheet erosion dissected hills, rocky outcrops and shallow depth.

6.1.2 **Conclusion**

The study has revealed the effect of topography on soil properties within the study area to be the removal and deposition of soil materials and nutrient across the landform/soil units as a result of variation in the slope gradients. The study on morphological properties revealed that soil depth, drainage, colour, slope and soil structure were related to topography. Other properties such as consistency and inclusions were not.

Soils of unit KB4 were the only soil unit that was seriously affected by gully erosion. This soil unit/landform constitutes about 17.56% of the total area under study. This may be considered bad land.

Soils of the undulating plains (KB2, KB3, KB4 and KB5) were more promising than the other landforms for agricultural production, at the other hand the Tableland with very high relief are less promising for agricultural production. The undulating plains are well developed soils, which are very deep; they have good soil structure, low AWHC and a gentle slope class that could support wide range of crops. Tablelands with very high relief are soils with very shallow depth which is associated with hills and rock outcrops and a very steep slope. Therefore the Tableland with very high relief will need special land use management practice in other to improved agricultural production around it.All these factors must be considered in planning for a better management practice within the study area.

6.1.3 **Recommendation**

Tablelands with very high relief associated with soil unit KB1 are the least promising landform for agricultural development. This is because of a very steep slope, excessive sheet erosion, hills, and scattered rock outcrop, shallow depth. This landform can be used for range and wildlife production.

The organic matter which was low has to be substantially increased through effective crop residue management, increased use of leguminous plants as well as judicious use of organic fertilizers. Also the level of nitrogen needs to be sustained which is vital in the nutrition of crop plants, nitrogen supplementation must be made to crops grown using organic and inorganic sources. Farmers can also practice strip cropping, mulching and making of ridges across the slope to minimize the effect of erosion and loss of nutrients and improve moisture retention across the undulating plains.

Further study can also be carried out on clay mineralogy in order to ascertain the distributions and type of clay across the landforms this will help in discussing the results with more confidence. Also the suitability classification of the undulating plains and flood plain can further be studied.

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APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB2 p1)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.405', E007^{o}40.172
Elevation:	651m above sea level.
Date of examination:	04/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Ustipsammers (USDA)
	Eutric Arenosols (WRB)
Local relief:	Upper slope
Slope:	Gently sloping (2-4%)
Soil erosion/ deposition:	None
Rock outcrops:	No bedrock exposed
Drainage:	well drained-imperfectly drained.
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	190 cm
Land use/vegetation:	Scattered trees, previously cultivated tomillet
Human influence:	tillage/cultivation

Described by: Mr Agaku T.D

Horizon Descriptions

Horizon	Depth (cm)	Descriptions
Ap	0-14	pale brown (10YR6/3 dry), dark yellowish brown (10YR3/4 moist), sandy clay loam, moderate medium sub angular blocky structure, slightly plastic, slightly sticky wet very friable moist soft dry, few to many fine few roots, , fine to many micro tubular pores, few ant holes,abrupt smooth boundary
Bt1	14-69	Brownish yellow (10YR6/6 dry), yellowish brown (10YR5/4 moist), loam, strong medium sub angular blocky structure, very sticky wet, very plastic moist, firm hard dry, common fine roots, few fine tubular and vesicular micro pores.few fine Fe concretion, few fine ant holes, cracks both vertically and horizontally, few cutans,clear smooth boundary.
Bt2	69-124	Grey (5Y6/1 dry), olive grayish,(10YR5/2 moist), loam, moderate medium sub angular structure, slightly sticky, slightly plastic wet, very friable moist, soft dry, few fine micro and macro tubular and vesicular pores, many Fe concretion, few fine ant and termites holes, cracks both vertically and horizontallydiffuse, smooth boundary.
Cg	124-190	Light olive Grey (5Y6/2 dry), dark olive grey (5Y3/2 moist), sandy loam, structureless, slightly sticky slightly plastic wet firm moist loose dry.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB2 p2)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.253', E007^{o}40.942
Elevation:	658m above sea level.
Date of examination:	03/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic plinthustalfs (USDA)
	Eutric Plinthosols (WRB)
Local relief:	Upper slope
Slope:	Gently sloping or undulating (2-4%)
Soil erosion/deposition:	None
Rocky outcrops:	No bedrock exposed
Drainage:	well drained-imperfectly drained.
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	190 cm
Land use/vegetation:	Scattered trees, ridge and grasses, previously cultivated with millets

Human influence: tillage/cultivation

Described by: Mr. Agaku T.D

Horizon Descriptions

Horizon	Depth (cm)	Descriptions
Ap	0-20	Light yellowish brown (10YR6/4 dry), dark yellowish brown (10YR4/4 moist), clay loam, moderate medium sub angular blocky structure, very plastic, very sticky wet, very friable moist, soft dry, many fewfine roots, many fine micro tubular and vesicular pores cracks vertically,abrupt smooth boundary.
Bt	20-67	Brown (7.5YR4/4 dry), strong brown (10YR4/6 moist), clay loam, moderate medium sub angular blocky structure, very sticky, very plastic wet, firm moist, hard dry, common fine-medium roots, many micro and few macro tubular and vesicular pores, few coarse ant holes, cracks both vertically and horizontally, few cutans, clear smooth boundary.
Btg	67-140	Light olive Grey (5Y6/2 dry), olive grayish,(10YR5/2 moist), loam, weak medium sub angular structure, very sticky, very plastic wet, very friable moist, soft dry, many micro and macro tubular and vesicular pores, many Fe concretion, many medium ant and termites holes, cracks both vertically and horizontallyabrupt, smooth boundary.
Btgv	140-190	Light olive Grey (5Y6/2 dry), olive grey (5Y5/2 moist), sandy loam, structureless (massive), slightly sticky slightly plastic wet, firm

moist loose dry, many Fe/Mn concentration. cracks both vertically and horizontally.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB2 p3)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.167’, E007^{o}40.814
Elevation:	665m above sea level.
Date of examination:	06/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic plinthustalfs (USDA)
	Eutric Plinthosols (WRB)
Local relief:	Crest slope
Slope:	Gently sloping or undulating (2-4%)
Soil erosion/deposition:	None
Rocky outcrops:	No bedrock exposed
Drainage:	excessively drained.
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	170 cm

Land use/vegetation:	Scattered trees, ridge and grasses, previously cultivated with millet
Human influence:	tillage/cultivation
Described by:	Mr.Agaku T.D

Horizon	**Depth (cm)**	**Descriptions**
Ap	0-15	Strong brown (7.5YR5/6 dry), brown (7.5YR4/4 moist), loam, moderate medium sub angular blocky structure, slightly plastic, slightly sticky wet, very friable moist, soft dry, many fine few roots, few fine micro and macro tubular and vesicular pores, few cutans,abrupt smooth boundary.
Bt	1 5-28	Red (2.5YR4/6 dry), red (2.5YR5/8 moist), sandy loam, weak fine sub angular structure, very sticky, very plastic, firm hard, few medium tubular and vesicular micro pores, few cutans, few medium ant holes, few Fe/Mn concretions, clear smooth boundary.
Btc	28-80	Red (2.5YR5/8 dry), red,(2.5YR4/6 moist), sandy clay loam, weak medium sub angular blocky structure, slightly sticky, slightly plastic wet, friable moist, soft dry, many common micro and macro tubular and vesicular pores, many Fe concretions, common fine ant and termites holes, many Fe/Mn concretion, diffuse, smooth boundary.
Cv	80-170	Red (2.5YR4/6 dry), dark red (2.5YR3/6 moist), sandy loam, structure, slightly sticky slightly plastic wet, friable moist, loose dry, many micro tubular and vesicular pores, unconsolidated ironstone overlaying by plinthite.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB2 p4)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}05.902’, E007^{o}40.322
Elevation:	673m above sea level.
Date of examination:	06/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Ustipsammers (USDA)
	Eutric Arenosols (WRB)
Local relief:	Crest slope
Slope:	Gently sloping or undulating (2-4%)
Soil erosion/deposition:	None
Rocky outcrops:	No bedrock exposed
Drainage:	well drained.
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	190 cm

Land use/vegetation:	Scattered trees, ridge and grasses, previously cultivated with millet
Human influence:	tillage/cultivation
Described by:	Mr. Agaku T.D

Horizon	**Depth (cm)**	**Descriptions**
Ap	0-34	Very pale brown (10YR7/4 dry), brownish yellow (10YR6/6 moist), sandy clay loam, weak fine sub angular blocky structure, non-plastic, non-sticky wet, very friable moist, soft dry, many fine common roots, few fine micro and macro tubular and vesicular pores, clear smooth boundary.
Bt	34-104	Yellowish Red (5YR5/8 dry), yellowish red (5YR4/6 moist), sandy clay loam, strong coarse sub angular structure, very sticky, very plastic, firm hard, few medium roots, few medium tubular and vesicular micro pores, few cutans, few medium ant holes, many fine saprolite, present of creaks, diffuse smooth boundary.
B/C	104-190	Yellowish brown (10YR5/6 dry), dark yellowish brown,(10YR4/6 moist), sandy clay loam, structureless (massive), very sticky, very plastic wet, firm moist, hard dry, many common micro and macro tubular and vesicular pores, diffuse, few fine medium ant holes, few fine cutans, fine – medium saprolite. Many Fe concretion, common fine ant

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB3 p1)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}07.413, E007^{o}39.717
Elevation:	685m above sea level.
Date of examination:	06/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Epiaqualfts (USDA)
	Gleyic Gleysols (WRB)
Local relief:	Middle slope
Slope:	Gently or undulating (2-4%)
Soil erosion/deposition:	None
Rock outcrops:	No bedrock exposed
Drainage:	well drained –imperfectly drained.
Estimated depth water table:	196 cm
Depth to impenetrable layer:	Not encountered

Land use/vegetation:	park land, previously cultivate with rice and vegetable
Human influence:	tillage/cultivation
Described by:	Mr. Agaku, T.D

Horizon Descriptions

Horizon	**Depth (cm)**	**Descriptions**
Ap	0-45	Dark grey (10YR4/1 dry), very dark grey (10YR3/1 moist), few mottles, sandy clay loam, moderate medium sub angular blocky structure, non-plastic, non-sticky wet, very friable moist, soft dry, many fine few roots, many fine saprolite, many fine micro and macro tubular and vesicular pores, few fine ant holes many mica flask, Abrupt smooth boundary.
E	45-62	White (10YR8/1 dry), light brown grey (10YR6/2 moist), sandy loam, weak fine sub angular blocky structure, non-sticky, non-plastic, very friable soft, fine few roots, many macro tubular and vesicular micro pores. Many fine saprolite, many Fe and Mn concretions, many mica flasks, Abrupt smooth boundary.
Btg	62-130	Grey (10YR5/1 dry), dark grey,(10YR4/1 moist) few mottles, sandy clay, moderately medium sub angular blocky structure, slightly sticky, slightly plastic, firm hard, many fine roots, many micro and macro tubular and vesicular poresmany medium Fe concretions. Few coarse ant and termites holes, high presents of cutans, cracks, Abrupt, smooth boundary.
Cg	130-190	Grey (5YR7/2 dry),(5YR5/1 moist) few mottles, loam, structureless (massive), very sticky very plastic, firm hard, cracks, few micro tubular and vesicular pores, many coarse Mn concretion. High presents of mica flask.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB3 p2)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.462, E007^{o}41.256
Elevation:	647m above sea level.
Date of examination:	04/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Ustipsammers(USDA)
	Eutric Arenosols (WRB)
Local relief:	Middle slope
Slope:	Moderately to strong sloping (4-7%)
Soil erosion/deposition:	None
Rock outcrops:	No bedrock exposed
Drainage:	well drained-imperfectly drained.
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	Not encountered

Land use/vegetation:	Scattered trees, previously cultivated with millet
Human influence:	tillage/cultivation
Described by:	Mr, Agaku T.D

Horizon Descriptions

Horizon	Depth (cm)	Descriptions
Ap	0-15	pale brown (10YR6/3 dry), dark yellowish brown (10YR4/4 moist), sandy loam, moderate medium sub angular blocky structure, slightly plastic, slightly sticky wet, very friable moist, soft dry, many fine few roots, many fine micro tubular pores, few ant holes, abrupt smooth boundary.
B	15-35	light yellowish brown (10YR6/4 dry), dark yellowish brown (10YR4/4 moist), loam, strong coarse sub angular blocky structure, slightly sticky, slightly plastic wet, firm moist, hard dry, common fine roots, few fine tubular and vesicular micro pores, few fine Fe/Mn concretion, few fine ant holes, clear smooth boundary.
Bc	35-75	Light Brownish Grey (10YR6/2 dry), grayish brown,(10YR5/2 moist), sandy clay loam, structureless (massive), slightly sticky, slightly plastic wet, firm moist, hard dry, many fine micro and macro tubular and vesicular pores many Fe/Mn concretion, few medium ant and termites holes, diffuse, smooth boundary.
Cg	75-200	Grey (5Y6/1 dry),(5Y moist), sandy loam, structureless (massive), slightly sticky slightly plastic wet, firm moist, loose dry, weather granite (saprolite).

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB4 p1)

General Site Information

Location:	Kubanni Wusasa
	N11°06.529', E007°41.398
Elevation:	635m above sea level.
Date of examination:	10/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Ustipsammers (USDA)
	Eutric Arenosols(WRB)
Local relief:	Lower slope (Gully)
Slope:	Very strong sloping (7-12%)
Soil erosion/deposition:	Gully
Rock outcrops:	No bedrock exposed
Drainage:	well drained
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	190 cm

Land use/vegetation:	Bad land
Human influence:	Grazing
Described by:	Mr.Agaku T.D

Horizon	Depth (cm)	Descriptions
Ap	0-10	Reddish brown (7.5YR6/6 dry), strong brown (7.5YR5/6 moist), loam, weak fine sub angular blocky structure, slightly plastic, slightly sticky wet, very friable moist, soft dry, many fine few roots, few fine micro and macro tubular and vesicular pores, few fine saprolite,clear smooth boundary.
Bt	10-65	Strong brown (7.5YR5/8 dry), yellowish red (5YR4/6 moist), loam, moderately medium sub angular structure, very sticky, very plastic, firm hard, few medium tubular and vesicular micro pores, few medium ant holes, many fine saprolite, clear smooth boundary.
B/C	65-90	Light grey (2.5YR7/2 dry), light brownish grey,(2.5YR6/2 moist), sandy clay loam, structureless (massive), slightly sticky, slightly plastic wet, firm moist, hard dry, few fine cutans, many fine micro and macro pores medium saprolite. Many Fe/Mn concretion,

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB4 p2)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.482', E007^{o}41.333
Elevation:	634m above sea level.
Date of examination:	10/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Haplustalfs (USDA)
	Vetic Lixisols (WRB)
Local relief:	Lower slope (Gully)
Slope:	Very strong sloping (7-12%)
Soil erosion/deposition:	Gully
Rock outcrops:	No bedrock exposed
Drainage:	well drained
Estimated depth water table:	Not encountered
Depth to impenetrable layer:	190 cm

Land use/vegetation:	Bad land
Human influence:	Grazing
Described by:	Mr. Agaku T.D

Horizon	**Depth (cm)**	**Descriptions**
A	0-35	Reddish brown (7.5YR6/6 dry), strong brown (7.5YR5/6 moist), sandy clay loam, weak fine sub angular blocky structure, slightly plastic, slightly sticky wet, very friable moist, soft dry, many fine few roots, few fine micro and macro tubular and vesicular pores, few medium saprolite, abrupt smooth boundary.
C	35-180	Grey (5Y6/1 dry), olive grey (5Y5/2 moist), sandy clay loam, structureless (massive), slightly sticky, slightly plastic wet, firm moist, hard dry, many coarse saprolite.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB5 p1)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.581, E007^{o}41.505,
Elevation:	636m above sea level.
Date of examination:	04/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Ustipsammers (USDA)
	Eutric Arenosols (WRB)
Local relief:	Lower slope
Slope:	Level or nearly level (0-2%)
Soil erosion/deposition:	None
Rock outcrops:	No bedrock exposed
Drainage:	well drained
Estimated depth water table:	Not encountered

Depth to impenetrable layer:	Not encountered
Land use/vegetation:	Scattered trees, previously cultivated with millet and vegetables.
Human influence:	tillage/cultivation
Described by:	Mr Agaku T.D

Horizon Descriptions

Horizon	Depth (cm)	Descriptions
Ap	0-14	Very pale brown (10YR7/4 dry), brown (10YR4/3 moist), sandy loam, moderate medium sub angular blocky structure, non-plastic, non-sticky wet, very friable moist, soft dry, many fine-medium roots, few fine micro tubular pores, few ant holes, clear smooth boundary.
B1	14-36	light yellowish brown (10YR6/4 dry), dark yellowish brown (10YR4/6 moist), loam, strong medium sub angular blocky structure, non-sticky, non-plastic wet, very friable moist, soft dry, common fine roots, few Fe/Mn concretion, mica flask, many tubular micro pores, clear,smooth boundary.
B2	36-107	Brownish yellow (10YR7/5 dry), (10YR7/5 moist), silt loam, moderate medium sub angular blocky structure, non-sticky, non-plastic wet, friable moist, soft dry, very fine micro pores, many medium Fe concretions, many micro and macro tubular pores, clear smooth boundary.
B3	107-200	Light Grey (10YR7/2 moist), silt loam, weak moderate sub angular structure, slightly sticky, slightly plastic wet, very friable moist, soft dry, few micro tubular pores, few ant holes, many coarse Fe/Mn concretion, few cutans, clear smooth boundary.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB5 p2)

General Site Information

Location:	Kubanni Wusasa
	N11°06.588, E007°41.457
Elevation:	636m above sea level.
Date of examination:	04/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Ustipsammers (USDA)
	Eutric Arenosols (WRB)
Local relief:	Lower slope
Slope:	Level or nearly level (0-2%)
Soil erosion/deposition:	None
Rock outcrops:	No bedrock exposed
Drainage:	well drained
Estimated depth water table:	Not encountered

Depth to impenetrable layer:	Not encountered
Land use/vegetation:	Scattered trees, previously cultivated with millet and vegetables
Human influence:	tillage/cultivation
Described by:	Mr Agaku T.D

Horizon Descriptions

Horizon	**Depth (cm)**	**Descriptions**
Ap	0-5	Very pale brown (10YR7/4 dry), brown (10YR4/3 moist), sandy loam, moderate medium sub angular blocky structure, non-plastic, non-sticky wet, very friable moist, soft dry, many fine few roots, few fine micro tubular pores, few ant holes,clear smooth boundary.
B1	5-33	light yellowish brown (10YR6/4 dry), dark yellowish brown (10YR4/6 moist), loam, strong medium sub angular blocky structure, non-sticky, non-plastic wet, very friable moist, soft dry, common fine roots, few fine tubular and vesicular micro pores, clearsmooth boundary.
B2	33-132	Brownish yellow (10YR5/7 dry), yellowish brown,(10YR5/4 moist), loam, weak medium sub angular blocky structure, slightly sticky, slightly plastic wet, friable moist, soft dry, many fine micro and macro tubular and vesicular pores, many Fe concretions. Few coarse ant and termites holes,clear, smooth boundary.
B3	132-200	Light Grey (10YR7/2 moist), silt loam, weak moderate sub angular structure, slightly sticky slightly plastic wet, very friable moist, soft dry, few micro tubular and vesicular pores, few ant holes, many coarse Mn concretion, clear smooth boundary.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB6 p1)

General Site Information

Location:	Kubanni Wusasa
	N11^{o}06.626, E007^{o}41.531,
Elevation:	630m above sea level.
Date of examination:	04/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Epiaquelfs (USDA)
	Stagnic Stagnosols (WRB)
Local relief:	Fadama
Slope:	Level or nearly level (0-2%)
Soil erosion/deposition:	Flooded
Rock outcrops:	No bedrock exposed
Drainage:	Very poorly drained
Estimated depth water table:	120cm
Depth to impenetrable layer:	Not encountered

Land use/vegetation:	Fadama planted with sugar cane
Human influence:	tillage/cultivation
Described by:	Mr. Agaku T.D

Horizon Descriptions

Horizon	Depth (cm)	Descriptions
Ap	0-36	Light grey (10YR7/2 dry), dark grayish brown (10YR4/2 moist), loam, structureless (massive) structure, slightly plastic, slightly sticky wet, firm moist, hard dry, many fine-medium roots, crack both vertical and horizontal, many micro tubular pores, few cutans, few ant holes, clear smooth boundary.
Bt	36-82	Very pale brown (10YR7/4 dry), brownish yellow (10YR6/6 moist), few fine faint mottles, silty loam, structureless (Massive), slightly sticky, slighty plastic wet, firm moist, very hard dry, many fine-medium roots, many micro-macro tubular pores, few mica/feldspars flasks, few Mn concretion, few ant holes, clear and smooth boundary.
Btg	82-95	Light grey (10YR7/2 dry), strong brown (7.5YR5/6 moist), few fine faint mottles, sandy loam, structureless (Massive), non-sticky, non-plastic wet, very friable moist, soft dry, many fine roots,many, mica flask, many tubular micro pores, clear irregular boundary.
C	95-110	strong brown (7.5YR5/6 moist), sandy loam, single grain, non-sticky non plastic wet, loose moist, loose dry, common fine roots, common mica flasks, clear smooth boundary,.
2A	110-120	Grey (10YR6/1 moist), loam, structureless (Single grain), slightly sticky, slightly plastic wet, firm moist, hard dry.

APPENDIX A: PROFILE DESCRIPTIONS

(PROFILE KB6 p2)

General Site Information

Location:	Kubanni Wusasa
	N11°06.593, E007°41.441,
Elevation:	632m above sea level.
Date of examination:	04/06/2013
Weather Condition prior to description:	Sunny
Taxonomy classification:	Typic Epiaquelfs (USDA)
	Stagnic Stagnosols (WRB)
Local relief:	Fadama
Slope:	Level or nearly level (0-2%)
Soil erosion/deposition:	Flooded
Rock outcrops:	No bedrock exposed
Drainage:	Very poorly drained
Estimated depth water table:	120cm
Depth to impenetrable layer:	Not encountered

Land use/vegetation:	Fadama planted with sugar cane
Human influence:	tillage/cultivation
Described by:	Mr.Agaku. T.D

Horizon Descriptions

Horizon	Depth (cm)	Descriptions
Ap	0-10	Very pale brown (10YR7/4 dry), dark yellowish brown (10YR4/4 moist), loam, moderate medium sub angular blocky structure, slightly plastic, slightly sticky wet, firm moist, hard dry, many fine-medium roots, few micro tubular pores, few ant holes, clear wavy boundary.
B	10-73	Very pale brown (10YR7/4 dry), yellowish brown (10YR5/4 moist), loam, structureless (massive), slightly sticky, slightly plastic wet, firm moist, hard dry, few fine medium-coarse roots, few Fe/Mn concretion, mica flask, many tubular micro pores, diffuse smooth boundary.
Bt	73-93	Dark grayish brown (10YR5/1 moist), common medium prominent mottles, loam, structureless (massive), slightly sticky, slighty plastic wet, firm moist, hard dry, very fine micro pores, few Fe concretions, clear, smooth boundary.
Btg	93-104	Grey (10YR5/1 moist), common medium prominent mottles, silty loam, structureless (massive), slightly sticky slightly plastic wet, firm moist, hard dry, few fine roots, common mica flask., few ant holes, few concretion, few cutans, Abrupt clear boundary.
C	104-120	Strong brown (5YR5/6 moist), sand, single grains, non-sticky, non-plastic wet, loose moist, loose dry.

APPENDIX B:

Summary of result of t-test between the undulating plains and the flood plains
Surface values of undulating/flood plains

	← Undulating/flood plains		→	
variables	Df	t-value	pr> (t)	Level of Significance
sand	4.79	1.73	0.145	NS
silt	2.71	-3.93	0.035	S
clay	7.09	3.14	0.016	S
Bulk density	1.27	2.58	0.189	NS
Total porosity	1.07	-2.04	0.277	NS
AWHC	1.09	-0.70	0.604	NS
pH (H_2O)	6.20	5.78	0.001	S
pH ($CaCl_2$)	9.17	-0.78	0.455	NS
Ca	2.51	-0.64	0.573	NS
Mg	5.06	-3.94	0.018	S
K	1.83	5.89	0.033	S
Na	1.34	-2.07	0.233	NS
Bs (NH_4OAc)	9.83	0.94	0.370	NS
Bs (ECEC)	3.71	-0.70	0.524	NS
CEC	1.96	-1.47	0.287	NS
ECEC	2.42	-1.00	0.405	NS
OC	9.35	-4.21	0.002	S
TN	1.05	-0.87	0.535	NS
AP	7.79	0.74	0.478	NS
Fe	1.28	-5.54	0.075	NS
Zn	9.51	0.73	0.484	NS
Mn	9.02	13.40	0.001	S
Cu	1.26	1.52	0.331	NS

$p < 0.05$= significant (S), $p > 0.05$ = not significant (NS)

APPENDIX B:

Summary of result of t-test between the undulating plains and the flood plains cont.
Sub-Surface values of undulating/flood plains

	Undulating/flood plains			
variables	Df	t-value	pr> (t)	Level of Significance
sand	26.90	3.38	0.002	S
silt	8.91	-0.35	0.732	NS
clay	8.31	-0.83	0.431	NS
Bulk density	9.28	-1.14	0.283	NS
Total porosity	8.25	-3.31	0.01	S
AWHC	8.69	-1.37	0.204	NS
pH (H_2O)	10.3	-0.34	0.741	NS
pH ($CaCl_2$)	13.1	0.87	0.402	NS
Ca	21.3	3.31	0.003	S
Mg	16.0	2.56	0.021	S
K	32.2	4.33	0.0002	S
Na	8.45	3.60	0.006	S
Bs (NH_4OAc)	31.1	4.30	0.0002	S
Bs (ECEC)	7.42	1.38	0.207	NS
CEC	24.0	1.65	0.112	NS
ECEC	21.2	3.73	0.001	S
OC	14.0	1.69	0.114	NS
TN	11.3	0.71	0.449	NS
AP	14.6	-0.59	0.566	NS
Fe	7.06	-3.17	0.015	S
Zn	9.43	-0.89	0.394	NS
Mn	10.2	-2.61	0.025	S
Cu	8.03	-3.29	0.011	S

$p < 0.05$= significant (S), $p > 0.05$ = not significant (NS)

APPENDIX C: RATING FOR SOIL DATA INTERPRETATION

1. Soil Depth (cm)

Very shallow	< 25
Shallow	25 – 50
Moderately shallow	50 – 100
Deep	100 – 150
Very deep	> 150

2. Soil Reaction

Extremely acid	< 4.5
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Moderately acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Slightly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	> 9.0

3. Organic Carbon (gkg^{-1})

Low	< 10
Medium	10 – 15
High	> 15

APPENDIX C: RATING FOR SOIL DATA INTERPRETATION

Cont.

4. Total Nitrogen (gkg^{-1})	
Low	< 1.5
Medium	1.5 – 2.0
High	> 2.0

5. Available Phosphorus (Bray 1) (mgkg^{-1})	
Low	0 - 10
Medium	10 - 20
High	> 20

6. Exchangeable Cation [cmol(+)kg^{-1}]	**Ca**	**Mg**	**K**	**Na**
Low	0 – 2	0 – 0.3	0 – 0.15	0 – 0.1
Medium	2 – 5	0.3 – 1.0	0.15 – 0.30	0.1 – 0.3
High	> 5	> 1.0	> 0.30	> 0.3

7. Cation Exchange Capacity [cmol(+)kg^{-1}]	**NH_4OAc**	**ECEC**
Low	< 6	< 4
Medium	6 – 12	4 – 10

High	> 12	> 10

Source: Soil Survey Manual, U.S Dept. of Agriculture. 1993.

APPENDIX C: RATING FOR SOIL DATA INTERPRETATION

Contd.

8. Base Saturation (%)			**NH_4OAc**	**ECEC**
Low			< 50	<70
Medium			50 – 80	70-90
High			> 80	>90
9. Micronutrients ($mgkg^{-1}$)	**Zn**	**Cu**	**Mn**	**Fe**
Low	< 1	< 0.2	< 1	< 4.5
Medium	1 – 2	0.2 – 1.0	1 – 5	-
High	> 2	>1.0	2 – 5	> 4.5
10. Bulk Density (Mgm^{-3})				
Low	< 1.85			
High	> 1.85			

Source: Soil Survey Manual, U.S Dept. of Agriculture. 1993

11. Total porosity (%)

Poor soils	< 30

Unsatisfactory soil	< 40
Satisfactory soil	40-45
Good soil	45-50
Best soil	> 50

Source: Kachinkii (1965).