GEO-ELECTRICAL INVESTIGATION FOR GROUNDWATER IN BOI AND ENVIRONS, NEAR BAUCHI NIGERIA

BY

YOHANNA, ANDARAWUS

(MSC/GL/11/0187)

SEPTEMBER, 2014.

GEO-ELECTRICAL INVESTIGATION FOR GROUNDWATER IN BOI AND ENVIRONS, NEAR BAUCHI NIGERIA

BY

YOHANNA, ANDARAWUS

(MSC/GL/11/0187)

A Thesis submitted to the Department of Geology , Modibbo Adama University of Technology, Yola, Nigeria, in Partial fulfilment of the requirements for the award of Master of Science (M.Sc) Applied Geophysics, Department of Geology, School of Pure and Applied Sciences .

SEPTEMBER, 2014.

DECLARATION

I hereby declare that this project report/thesis was written by me and is a record my own research work. It has not been presented before in any previous application for a higher degree. All references cited have been duly acknowledged. And the work was carried out under the supervision of Prof. A. Nur.

________________________ _________________

Yohanna Andarawus Date

DEDICATION

This project is dedicated to my late sister Mrs Salamatu Yohanna and to my parents late Yohanna Bororo and Mrs Rhoda Yohanna for their love, support and understanding.

APPROVAL PAGE

This thesis entitled 'Geo-electrical' Investigation for Groundwater in Boi and Environs, Near Bauchi Nigeria 'by Yohanna Andarawus (MSc/11/GL/0187) meets the regulations governing the award of degree of Masters in Applied Geophysics of Modibbo Adama University of Science and Technology Yola and is approved for its contribution to knowledge and literary presentation.

______________________ ______________

Prof. F. A. Nur Date

Supervisor

______________________ ______________

Dr. N.E. Bassey Date

Internal Examiner

______________________ ______________

Prof. A.I. Olayinka Date

External Examiner

______________________ ______________

Dr. Y.D. Mamman Date

Head of Department

______________________ ______________

Prof. D.T. Gungula Date

Dean, School of Postgraduate Studies

ACKNOWLEDGEMENTS

I am very grateful to my supervisor Prof. Ahmed Nur for his positive corrections and guidance throughout my study and also my profound gratitude goes to all my lecturers, Prof. E. E. Ntekim, Dr. N. Bassey, Dr. Y. D. Mamman, Dr. I. Jackson, Dr. H. Vela, C. J. Dio and Ahmed Hifzubilla for equipping me for the challenges ahead.My heartfelt gratitude goes to Mr Bulus Joseph Azi and Mr Simon Muru for encouraging and allowing me to used their Terrameter. My unreserved appreciation also goes to Taraba State rural water supply and environmental sanitation agency (UNICEF ASSISTED) for allowing me to use their Lab for the geochemical analysis.I am also grateful to Mr and Mrs Salman Haruna, Asc. Bulus Madaki,Eng. Jamaji Yusuf, Eng. Micah Andrew, Andok Godwill Katwal for assisting me both financially and morally. Big thanks to all my friends, Enoch Lezak, Sakunga Galumje, Agbo Peter , Mohammed Modibbo, UsmanYaro , Alh . Idris Ali Zoaka, and all friends that contributed to the success of this work. Thank you all.

ABSTRACT

This project aimed at providing quality data/ information from the subsurface for groundwater development and also to determine the portability of water in Boi and environs, Southern Bauchi Nigeria. The research work is justified due to the fact that there are numerous abortive wells and boreholes in the area. Geophysical prospecting method adopted for this study was electrical resistivity method using vertical electrical sounding with Schlumberger configuration. The ABEM SAS-200C Terrameter was used along with four metals electrodes. Data sheet was used for recording field data during geophysical data acquisition. The ground resistance measured was recorded and multiplied by their corresponding geometric factors (K) for each electrode spacing to obtain apparent resistivity (P= KR) . Software IX1D version 1.0, was used for computer iteration and modeling. The general feature of the sounding curves obtained were three layers earth models, the H, Q, A and K type curves were observed. Surfer 9 software was used to produce the isoresistivity maps, geo-electric sections and hydraulic head maps of the area. The geo-electric section shows the presence of three geo-electric layers. The top soil with resistivity ranging from 81Ωm to 264.21Ωm and thickness of 0.56m to 3.77m, laterite with resistivity of 526.43Ωm to 999.71Ωm and thickness 1.93m to 3.47m , weathered/fracture have resistivity of 10.62Ωm to 238Ωm and thickness of 2m to infinite depth and fresh basement have resistivity of 1000.33Ωm to1821Ωm and have depth of 6m to infinite depth. Water samples were collected and analysed. Milwaeke meter was used to measure physical parameters such as total dissolved solids (TDS), electrical conductivity (EC) and temeperature . The geochemical result of groundwater quality analysis revealeds average values as pH 6.39 , EC 618.20 mS/cm, TB 2.74mg/l, T^{0c} 28.03^{0}C, TDS 312.50mg/l, Ca^{2+} 7.80 mg/l, Mg^{2+} 0.10 mg/l, Na^{+} 46.78mg/l, K^{+} 0.16mg/l,Cu^{2+} 0.015, Fe^{2+} 0.69mg/l, Mn^{2+} 0.11mg/l, SO_4^{2-} 12.3mg/l, Cl^{-} 2.04mg/l, HCO_3^{-} 11.6mg/l, F^{-} 0.52 mg/l, PO_4^{-} 0.06mg/l, and total hardness 57.20 mg/l. The result of the water quality analysis shows that iron, fluoride, electrical conductivity , turbidity and total hardness to have concentration above the permissible limits.Therefore , water of the study area can not be use for domestic, agricultural and industrial purposes without treatment based on the analysis and boreholes should be drill down the fresh bedrock as indicated by geophysical investigation, because high permeability occur at greater depth and also toward areas of thicker overburdens.The area have dorminantly N-S, NW-SE, NE-SW and W-E groundwater flow directions, which could be associated to fractures-controlled flows.The groundwater flow direction can be use to isolate possible areas for aquifer exploitation for water resource development in the study area.

Keywords: Geoelectric, Isoresistivity, Hydraulic head, Electrical, Resistivity, Terrameter, Boi

TABLE OF CONTENTS

LITERATURE REVIEW

CHAPTER THREE

METHODOLOGY

LIST OF FIGURES

LIST OF TABLE

LIST OF PLATES

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Safe water is a basic necessity of life and when it is not available and/or contaminated, it could have serious public health implications, ranging from diseases to outbreak of epidemics. In the past, rain water, streams, and lakes were the major sources of water to humans. However, they are unsuitable sources of drinking water due to pollution and contamination as result of human activities. The aforesaid, among others, have necessitated the need for groundwater exploration in Boi and Environs. Available reports have shown that there are abandoned boreholes in the study area. The development of groundwater in the study area is beset with the problem of failed (abortive) handdug wells and boreholes arising from poor knowledge of hydro –geophysical characteristics of the basement aquifers. The reasons for this may include: selection of wrong point, poor data quality/incomplete information from the subsurface, lack of technical‘ know-how’ and poor development of drilled holes among others, which are rampant in Basement Complex terrain (Abiola *et al.*, 2013).

The useful exploitation of groundwater in basement complex terrain requires a good understanding of its hydrological characteristics. The groundwater in the basement complex terrain is mainly contained in the porous and permeable weathered zones. The groundwater yield from the weathered horizon is often supplemented by the accumulated ground water in the fractured and jointed column of the basement complex rocks (Satpathy and Kanungo, 1976; Olorunniwo and Olorunfemi, 1987).

The electrical resistivity method is one of the geophysical methods applied in ground water investigation in the basement complex terrain(Limaye , Owoade and Moffat , 1989). The relevance of the method is based on the usual significant resistivity contrast between the weathered and or fractured column and the very resistive fresh bedrock. The occurence of groundwater in basement rocks is mainly in the weathered/fractured zones of the basement. Reseachers (i.e Acworth,1987; Olorunfemi and Okakune, 1992; Olurunfemi and Fasuyi 1993; Edet and Okereke, 1997; Nur and Ayuni, 2004;Nur and Kujir, 2006; Zohdy *et al.*, 1974 and Olasehinde, 2010) have utilized resisitivity method as a tool for groundwater exploration in basement areas.

Experience all over the world have shown that the rate of failure of boreholes is usually highest in the basement terrain. This is mainly due to inadequade knowledge of the basement aquifers , which results in-situ weathering and /or denudation of basement rocks. Many communities ,private individuals and the Nigerian government have carried out various borehole projects to find reliable and safe drinking water. As a result , there is an increase in application of surface geological and geophysical techniques for the locating potential water bearing formations in many parts of Nigeria (Nur , 2012). Resistivity method is the most widely used in groundwater exploration; the method is cheap when compared to the other geophysical methods(Nur and Afa, 2002,Nur and Ayuni, 2011).

Surface geophysical survey as a veritable tool in groundwater exploration, has the basic advantage of saving cost in borehole construction by locating target aquifer before drilling is embarked upon (Obiora and Ownuka, 2005).There are approximately one hundred independent geoelectric arrays (Szalai and Szarka, 2008) But, Schlumberger array is found to be more suitable and common in groundwater exploration. It is well known that resistivity methods can be successfully employed for groundwater investigations, where a good electrical resistivity contrast exists between the water-bearing formation and the underlying rocks (Zohdy *et al.*, 1974).

In general, VES method with Schlumberger array assumes considerable importance in the field of groundwater exploration because of its ease of operation, low cost and its capability to distinguish between saturated and unsaturated layers. Thus this technique has been used in this study. This method is regularly used to solve a wide variety of groundwater problems. Such as determination of depth, thickness and boundary of a aquifer (Bello and Makinde, 2007; Asfahani, 2006; Ismailmohamaden, 2005), determination of zones with high yield potential in an aquifer (Akaolisa, 2006; Oseji *et al.*, 2005), determination of the boundary between saline and fresh water zones (El-Waheidi *et al.,* 1992; Khalil, 2006), delineation seawater intrusion in coastal Aquifer (Sung-Ho *et al.*, 2007; Benkabbour *et al.,* 2004), delineation groundwater contamination (Park *et al.,* 2007), determination of groundwater quality (Arshad *et al.,* 2007), exploration of geothermal reservoirs (Cid-Fernández and Araujo, 2007; El-Qady, 2006), estimation of hydraulic conductivity of aquifer (Khalil and Monterio, 2009; Asfahani, 2007; Yadav, 1995),estimation of aquifer transmissivity (Yang and Lee, 2002) and estimation of aquifer specific yield (Onu, 2003).

The electrical resistivity technique enables the determination of subsurface resistivity by sending an electric current into the ground and measuring the potential field generated by the current. The depth of penetration is proportional to the Schlumberger array which uses closely spaced potential electrodes and widely spaced current electrodes. The Schlumberger method have a greater penetration than the Wenner. In the resistivity method, the Wenner configuration discriminates between resistivities of different geoelectric lateral layers while the Schlumberger configuration is used for the depth sounding (Olowofela *et al.,* 2005).

Separation between the electrodes in homogeneous ground and varying the electrodes separation provides information about the stratification of the ground (Dahlin, 2001). However, in general, the depth of infiltration is small in this method and only shallow subsurface layers have been surveyed (Danielsen *et al.,* 2007).

1.2 Location, Extent and Accessibility

The study area is located between latitudes $9^0$31'N to $9^0$37'N,and longitudes $9^0$30'E to $9^0$36'E,on scale of 1:50,000 Tafawa Balewa sheet 170SW Federal Survey of Nigeria 1976 (Figure.1) and is accessible through the Bauchi - Kabwir major road and through tarred, untarred roads that link the various villages, settlements and towns together. The study area covers an area extent of 121km^{2}..

1.3 Statement of the Problems

Groundwater development on basement complete terrains in Nigeria, is besets with problems of failed (abortive) handdug wells and boreholes arising from, poor knowledge of hydrogeophysical characteristics of the basement aquifers. The reasons for this may include: Poor data quality, incomplete information from the subsurface, wrong point selection and lack of technical known how. About 1.1 billion people all over the world lack access to safe or portable drinking water, more than 3.4 million die each year from water related diseases from developing countries.

Hence this study aimed at providing quality/complete information from the subsurface and good point selection for groundwater development and also to provide complete information about the portability of water in Boi and environs .

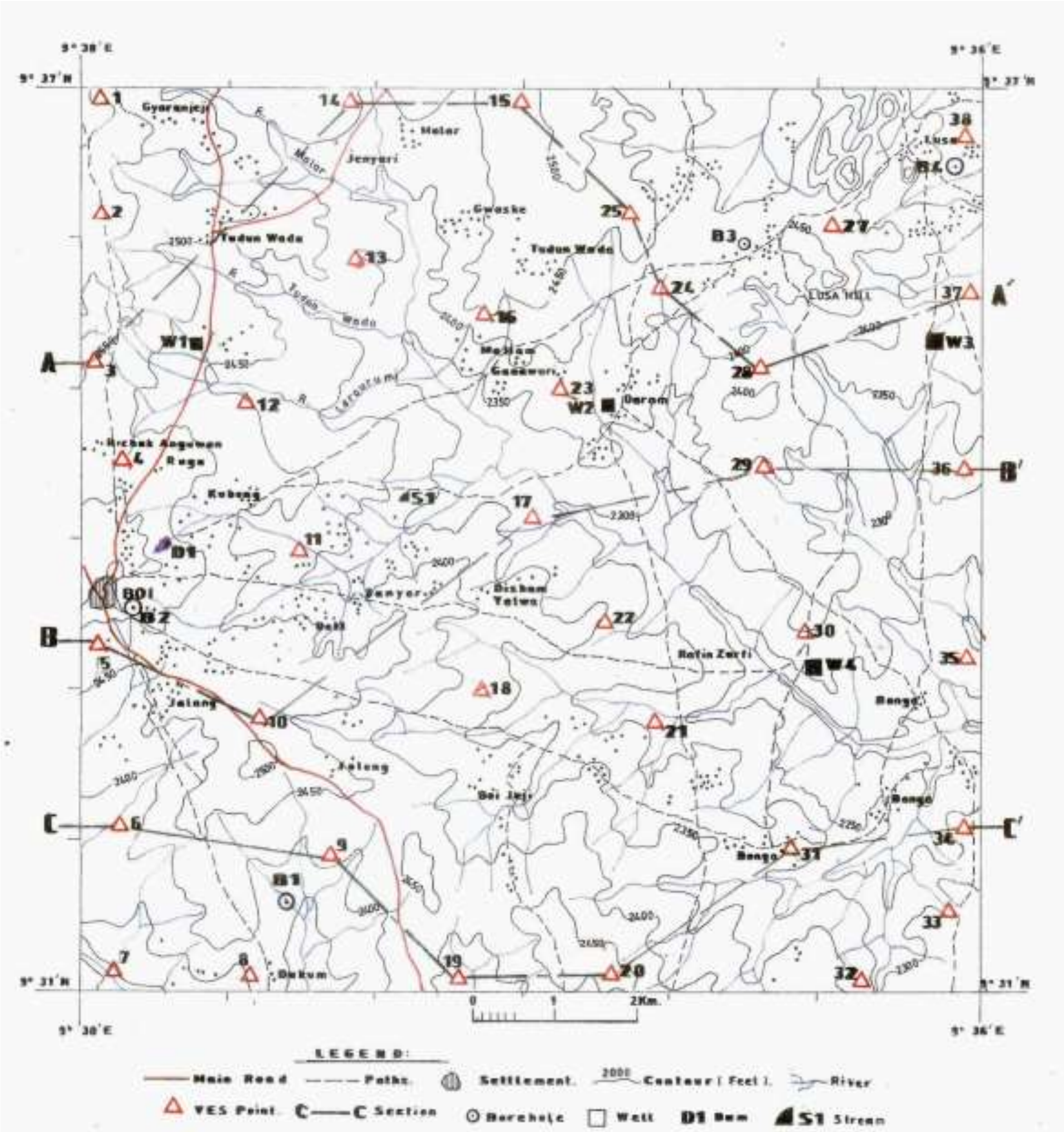


Figure 1: Topographical Map of the Study Area showing VES Locations

(After: Federal Survey of Nigeria Topo Sht. 170sw of 1976)

1.4 Aims and Objectives

The aim of this research is to conduct vertical electrical sounding in Boi and environs with the view to fulfill the following objectives:

1. To determine the pattern of resistivities and depth variation of geologic materials in the study area.
2. To relate the resistivity and thickness to water bearing layers in the study area, in order to determine unit that are favorable for groundwater development in the study area.
3. To determine the groundwater quality as well as the natural geochemical environment of the study area and groundwater flow direction of the area.

1.5 Climate and Vegetation

The climate of the study area is the Sudan Savannah type with the climatic season of wet and dry seasons. The wet season is characterized by high storm and it varies from year to year. The dry season is long lasting for about six months of rainy season, from October to April, followed by six months of rainy season, from May to September with highest recorded rainfall in August and is characterized by an average minimum temperature of 15^{0}C and an average maximum temperature of 40^{o}C with mean annual rainfall of 918.9 mm. The major occupation of the people is agriculture, and the major crops grown include maize, guinea corn, and groundnut. Generally , the area is devoid of thick forest but consists of grasses, shrubs, and scattered trees. Shrubs however form the dominant vegetation(Iloeje,1989).

1.6 Relief and Drainage Pattern of the Area

Boi is situated on a gently undulating terrain. The topographic elevation varies from 2250 (fts) to 2550 (fts) , the high relief of the North East region off the study area is occupied by hilly tract of Lusa (Figure 1). The drainage pattern of the study area is mainly dendritic (tree like branching). This indicates a South and South East flow direction within the study area (Figure 1) . It is drained largely by the River Tudunwada and some minor tributeries . The sources of water supply to the people are through surface water such as streams, ponds, and lakes , and groundwater is obtained from hand-dug wells and boreholes.

CHAPTER TWO
LITERATURE REVIEW

2.1 Previous Work

Most of the previous work on the study area were in regional extent.This include hydrological investigation carried out by Conred Nigeria Limited for the exploration of ground water through handdug wells and boreholes.Carter *et al.* (1963) did some work on the geology, hydrology and water quality of most part of former Northern Nigeria including the study area. Harzel *et al.* (1963) describeds the hydrogeology of crystalline aquifers of Northern Nigeria including the study area.Schroeter (1974) describeds the hydrological condition of Bauchi and its surrounding area. He concluded that water is found on the superficial weathered mantle form the crystalline rocks of the basement complex. Ajakaiye (1983) conducted an electrical and seismic surveys in Northern Nigeria including the study area,with the aim of determining the groundwater potentials. Harzel and John (1985) describeds the development of groundwater resources for farming communities in Bauchi and environs.

Edok–Eter Mandilas (Nig) limited (1976 -1979),a consulting firms specialized in the water resource has carried the assessment of the water. The effort of this company forms the basis of groundwater studies in the area.Tarhile and Wooming (1997) describeds the characteristics and use of shallow wells in Northern Nigeria including the study area.

Nuru *et al.* (2005) carried out a hydrogeophysical investigation of Bauchi and environs. Seven (7) Schlumberger vertical electrical sounding and fifteen (15) seismic refraction profiles were used to investigate the subsurface. The resistivity curve was interpreted using partial curve matching and computer programming. The result obtained revealed the presence of three layer and four layer earth models with the aquifer being the weathered and or fracture basement. The result obtained from the seismic refraction profile also indicated a three layer model with second layer representing the weathered and/or fractured basement having the average velocity of 1809m/s and a mean thickness of 13.6m. from hydro geological studies of borehole data, a mean depth to water table 4.12m, mean hydraulic conductivity of 0.9m/day and average transitivity of 19.88m^2/day were recorded.

2.2 Regional Geology of the Area

The Nigeria Basement Complex lies between the West African Craton and the Congo Craton.Recent geological,geochemical and geochronological investigation suggests that the Nigerian basement is a rejuvenated basement, indicating a tectonic evolution.This is in line with postulated ensimatic model rather than an ensialic model for the Basement.Are shown therefore that geologic significant events occurred at approximately 2800my,2000my, 1000my,and 600my ago (Ogezi, 1985).

The Basement Complex include metasediment of high metamorphic grade such as paragneisses,basic and calcareous schist, marble and quartzite as well as orthogneisses and possibly early (Ebunean) granite.The metasediment recognized within the Basement Complex are believed to be relics of an old supercrustal cover of probably Birimian age, and are termed older metasediments in other to distinguish them from late Protarozoic supercrustal sediments which are known as the younger metasediments. The Basement has also been extensively intruded by the granitic and chanokitic rocks of the Pan – African age (Macleod *et al.*, 1971).

The batholic masses of the plutonic granites and granodiorites which forms the larger portion of the basement complex are usually referred to as the Pan African granite (older granites to differentiate them), from the high level intrusive granites. The batholitic masses are dominated by the pophyritic biotite granite and granodiorites which form the main rock.The origin and rejuvenation of these rocks are described to the large scale horizontal and vertical movements controlled by deep seated forces.At least,two tectonic metamorphism cycle affected the Nigerian Basement Complex.An earlier Eburnean orogeny 2000 ± 200my and the Pan African orogeny 600my ± 150my . The Eburnean orogeny formed the Eburnean granite and the metamorphose into which are folded Upper Proterozoic supercrustal low grade metasedimentary and metavolcanic rocks. The Pan African orogeny was the last major event which marked the emplacement of the original rock.The basement complex is predominantly controlled by N–S planer structural trends and it is characterized by several set of Fracture with NE –SW and NW – SE trends. Basement Complex in spite of the minor regional variations in rock types, age and structure between different sectors. The similarity of age, regularity, and uniformly of N–S trends of lineaments and fractures , and the lack of any obvious structural and metamorphic breaks between the different sector gives the Nigerian basement an apparent unit.

The basement complex has been affected by up to four thermo-tectonics and orogenies (Macleod *et al*.,1971) :

Liberian Orogeny	(2800 + 200 million years)
Eburnean Orogeny	(2000 +_ 200 million years)

Kibaran Orogeny (1100 +_200 million years)

Pan-African Orogeny (600+_150 million years)

The major deformation and metamorphism experienced within these belts were as a result of Pan African orogeny (600+_150 million years) with little effected on the adjacent cratons. Apart from these events,a number of other minor non-orogenic events involving ring fracture(faulting),cauldron subsidence and hot spot magmatism occurred during the Mesozoic times resulting into the emplacement of granite intrusions such as the Younger Granites .The main sub-groups, in order of decreasing age in the central Nigerian region, are :

Firstly: The migmatite gneiss or crystalline basement complex,this is the most extensive and it usually occupies low plains. The main minerals resources are marble and banded iron formation.

Secondly : The schist or meta sedimentary or supra crustal belt;these are structurally controlled, elongate, approximately N-S To NNE-SSW trending synformal Precambrian belts composed of meta-sediments and metavolcanic with rare mafic-ultramafic rocks close to major deep-seated lineaments. Important associate mineral resources includes ironstone,gold,manganese and marble.

Thirdly : The Pan-African or Older Granites(500+_60my)consists of granite, diorite, rare syenite, gabbroic, doleritic and charnockitic rocks and pegmatite contain gemstone, columbite, tantalite etc.

Therefore the basement complex contains the oldest type of rocks and range in age from Precambrian to Cambrian . It is underlain by gneisses with small bodies of dioritic and charnockitic rocks, migmatites and metasedimentary series of Precambrian age. They have been intruded by granites of Pan-African age(Older Granite), (Ogezi, 1985). Macleod et al ,1971 stated that in region of intense deformation and metamorphism, these contacts between granite and the surrounding rocks are characterized by streaky or banded rocks which results from the intermingling of granite materials with country rocks. These banded rocks are generally the gneisses,and various degree of intermingling are indicated roughly by the use of such terms as ‘’granite gneiss’’ for those in which granite materials predominates and migmatites or composite gneiss for those consisting to a large extent of materials of sedimentary derivation. The Pan-African granite range texturally from coarse-grained (porphyritic) type to fine grain muscovite granite.Geochronological data has shown that the complex has been subjected to multiple thermotectonic events (Ajibade, 1988) . During these events ,initial sedimentary rocks were metamorphosed and reactivated by subsequent episodes ,these thermo tectonic episodes took place during the Kibarian (1100 +_ 150my) (Macleod *et al*.,1971) .

2.3 Structural Geology

Geological structures are of great importance to the geologist, especially in the determination of geological history of an area. The structures encountered in the study area includes joints, foliation, veins, fractures and faults. These structures are all associated with tectonic activities, movement, information about structures in the study area are useful in search of minerals and underground water. The rocks in the crust of the earth are subjected to various forces during and after their formation impacting features characteristics of such forces. Structures developed in a rock during its formation are called primary structures, examples includes rocks contacts,flow banding or layering etc. Whereas, structures resulting from forces subsequent to rocks formation are called secondary structures, examples are jonts, fault, fold etc (Ekwueme, 1993).

2.3.1 Fracture

Is any separation in a geologic formation, such as joints or a fault that divides rocks into two or more pieces. A fracture will sometimes form deep fissures or crevice in rocks. Fractures are commonly caused by stress exceeding the rock strength, causing the rock to lose cohesion along its weakest plane. Fractures can provides permeability for fluid movement, such as water. Highly fractures rocks can make good aquifer, since they may possess both significant permeability and fracture porosity etc (Ekwueme, 1993).

2.3.2 Dykes

These are tabular, vertical or steeply inclined discordant plutonic bodies that cuts across the structures of the country rocks the intrude i.e is a sheet of rock that formed in a crack in a pre-existing rock body. However when the crack is between the layers and layered rock, it is called a sill, not a dyke. Dyke therefore be either intrusive or sedimentary in origin (Ekwueme, 1993).

2.3.3 Joints

Joints are fracture on a rock in which there have been no observable movements of one side relative to the other. Virtually, most of all the different lithological units have one form of joint or the other. They are break (Fracture) of natural origin in the continuity of either a layer or body of rock that lack any visible or measurable movement parallel to the surface (plane) of the fracture. Although they can occur as joints, the most frequently occur as joint sets and systems. Faults differs from joints in that they exhibit visible or measurable lateral movement between the opposite surfaces of the fracture. Joints are among the most universal geologic structures as they are found in most every exposure of rock. They vary greatly in appearance, dimension and arrangement and occur in quite different tectonic environments (Ekwueme, 1993).

2.3.4 Veins

Veins are sheet-like or tabular discordant bodies which may or may not be mineralized. They are formed by the complete or partial infilling of fractures within rock. Majority of the infilling materials of the veins in the study area are quartz i.e is a distinct sheet like body of crystallized minerals within a rock. Are form when minerals constituents carried by an aqueous solution within rock mass are deposited through precipitation. The hydraulic flow involved is usually due to hydrothermal circulation. Tectonic implication of veins is that they need either hydraulic pressure in excess of hydrostatic pressure (to form hydraulic fracture or hydrofracture breccias) or they need open space or fractures, which requires a plane extension within the rock mass (Ekwueme, 1993) .

2.3.5 Foliation

Foliation can be defined as the parallel orientation of platy minerals or mineral banding in rocks. The most pronounced fabric within the area. These form alternation of light and dark minerals of quartz and or feldspars with biotite. These were found on outcrops of migmatites. Foliation refers to repetitive layering in metamorphic rocks. Each layer may be as thin as sheet of paper, or over a meter thickness. The word comes from Latin folium, meaning “leaf” and refers to the sheet-like planar structure. It is caused by shearing forces (pressure pushing different sections of the rock in different directions). Foliations where seen on bands in gneiss (gneissic banding) (Ekwueme, 1993).

2.3.6 Fault

Fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement. Large faults within the earths crust results from the action of plate tectonics forces, with the largest forming the boundaries between the plates. Energy released associated with rapid movement on active faults is the cause of most earthquakes (Ekwueme, 1993).

2.4 Hydrogeology

Groundwater is water that filled all pores and voids found within a geological formation. The occurrence and distribution of ground water in an area is controlled by geological factors such as lithology, texture of the rocks and also the structures in the rocks, as well as climatic factors such as rainfall. The capacity of the crystalline rock to store, transmit and yield water chiefly depends on the extent of openness and continuity of the fractures and on the degree to which the fractures are hydraulically connected. To understand groundwater potential of the study area, surface water of the study area must be considered(Carter *et al.,* 1963).

2.4.1 Surface Water Hydrology

Drainage of the study area is mainly by surface streams which have dentritic pattern of flow. River Lere and Boi are the major rivers that border the study area, these streams retain surface flow only for short period after the rain. The immaturity of the drainage and general topography preclude surface conservation schemes of any appreciable magnitude (Carter *et al.,* 1963).

2.4.2 Groundwater Hydrology

The study area is a crystalline basement complex environment. The crystalline Basement Complex aquifers can be divided into:

i. The weathered basement (overburden) and

ii. The fractured basement aquifers(Carter *et al.*, 1963).

The hydrogeology of the study area was first established based on Hydrogeological field reconnaissance carried out on May,1977 to February, 1978 by Conred Nigeria limited. They arrived at a stratigraphic sequence of the study area. The sequence includes the weathered and fractured Basement Complex rocks. The weathered Basement Complex rock consists mainly of in-situ decomposed rocks. At shallow depths, the decomposed rocks are characteristically clayey, concretionary brown to reddish brown, ferruginous and lateritic. The weathered basement complex, which overlie the fresh crystalline rocks are largely covered by thin blanket of alluvium consist mainly of lenses of silts, clay, sands, gravels, and local intermixes of materials and boulders. The materials are mainly derived from weathering of adjacent hills and reworked alluvium. They were transported by running water and deposited in lower areas and stream valleys. The groundwater occurs under water table condition. Borehole yield depends mainly on amount of recharge, depth and areal extent of the aquifer(Carter *et al.,* 1963). Some of the tributeries uses Boi Dam as their discharge points(Figure 1).

Fractured crystalline rocks underlie all parts of the area, the greater part are buried beneath overburden materials and are sometimes encountered in boreholes or hand-dug well at variable depths. Outcrops and crystalline rocks may occur as flattish masses on the surface, in some stream channels or as hills. Fracturing in crystalline rocks are due to jointing, faulting and shearing associated with early tectonic cycles that affected the Basement Complex and the tectonic related to later intrusions. These processes can result in the formation of superficial, shallow and deep fracture. Most of the fractured zones are buried beneath the overburden materials through which it receives its recharge and it requires more details of geological investigation to delineate them. The extend of weathering ,fracturing and erosion is generally limited in crystalline rocks. Consequently, groundwater occurs only in small pockets or basins. Usually, rocks dominated by unstable ferromagnesian minerals tend to weather into clayey, sometimes micaceous impermeable non-water bearing formation while rocks consisting of quartz and other stable minerals disintegrate into porous and permeable water bearing gravelly or sandy medium (Carter *et al.*, 1963).

2.5 Resistivity of Some Rocks, Soils and Ores

Resistivity of rocks and minerals vary considerably for a number of factors. The electrical nature of rocks is mainly electronic and since most mineral grains are conductors and conduction takes place through interstitial water; which is usually present and contains some dissolved salts. Hence, resistivity of rocks depends on the resistivity of contained electrolyte and is inversely related to the porosity and degree of saturation of the formation

(Lowrie, 2007). In crystalline rocks, with low porosity the conduction is mainly along the fractures and the degree to which these present usually govern the resistivity of the formations. Hence, looking for this fracture is indirectly looking for aquifer in the basement environment. Hence, it can be said that resistivity vary considerably, not only on formation but also within one particular layer. Thus there is no specific correlation of lithology with resistivity. The effective resistivity can also be expressed in terms of the resistivity and volume of the pore water present according to an empirical formula given by Archie, $\rho = a\ \varphi^{-b}\ f^{-c}\ \rho^{w}$ where φ is the porosity, f the fraction of pores containing water of resistivity ρw and a,b and c are empirical constants, ρw can vary considerably according to the quantities and conductivities of dissolved materials (Table 1)

Resistivity is one of the most variable of physical properties. Certain minerals as native metal and graphite conduct electricity via the passage electrons, and electrical current is carried through a rock mainly by the passage of ions in pore water. Thus, most rocks conduct electricity by electrolytic rather than electronic processes. It follows that porosity is the major control of the resistivity of rocks, and that resistivity generally increases as porosity decreases. However, even crystalline rocks with negligible itergranular porosity are conducting along cracks and fissures(Lowrie, 2007).

Table I. Ranges Resistivity of some common rocks. Soil, and Ores

Rocks	Resistivity (Ωm)
Quartizite	10^3 - 10^5
Basalt	10^1 - 10^5
Diorite	10^4-10^5
Fractured basalt	$10^0 – 10^2$
Fresh granite	$10^3 – 10^6$
Weathered granite	$10^0 – 10^2$
Limestone	$10^1 – 10^4$
Porous limestone	10^2-10^3
Jointed,frractured and flow top basalts	10^2-10^5
Argillite	$10^1 – 10^2$
Graphic shist	$10^{-2} – 10^0$
Gravel	$10^1– 10^3$
SOIL	
Alluvium	$10^0 – 10^3$
Clay	$10^0 – 10^2$
ORES	
Chalcopyrite	$10^{-4} – 10^{-1}$
Graphite	$10^{-4} – 10^{-1}$
Pyrrhotite	$10^{-5} – 10^{-4}$
Hematite	$10^{-1} – 10^3$

Source: Lowrie, 2007

CHAPTER THREE

METHODOLOGY

3.1 Reconnaissance Survey

The topographical , geologic maps and other materials relevant to the area of study , was obtained and studied . The reconnaissance survey of the area was conducted with the aim of determining the lithology and the trends of the major rock types and their structures in the study area , which led to the choice of the best area that geophysical survey using resistivity method was conducted .

3.2 Geologic Mapping

The area is underlain by Nigerian Basement Complex rocks, which is made – up of crystalline rocks.The Basement Complex consist essentially of rock with granitic composition and in different stages of metamorphism occurs as gneisses , migmatite , quartzite , phyllite , Schist and pegmatite . The rock of the study area include the Biotite Granite, Granite Gneiss and Migmatitic Gneiss believed to be Birimian in age (MCcurry, 1976) . Geologic mapping of the area was carried out in order to know the general geology of the study area. Fresh rock samples were collected for identification and description. Photographs of outcrops and structures were taken . The study area is underlain by the following rocks of the older Granites of Precambrian to lower Paleozoic Viz : Biotite Granite , Migmatitc Gneiss and Granite Gneiss (Figure. 2) . Some these rocks occur in boulders, outcrops and there is also laterite exposure in the study area.

3.2.1 Biotite Granites

Biotite granites covers most of the Northwestern part of the study area, and ranges from medium to coarse grained with minor variation in texture . The color of the biotite granite ranges from white to grey, that is leucocratic . These granites are extensive and found mostly at Northwestern part of the study area. Some of the biotite granites occurred as boulders (Plate I) . At Northeastern part of Lusa there was also biotite granite exposure of which are leucocratic and the grain sizes ranges from medium to coarse grain sizes . The biotite granite lithology terminate at Jolong and Daram in southern part of the study area and extend Northward and Westward of the study area respectively .

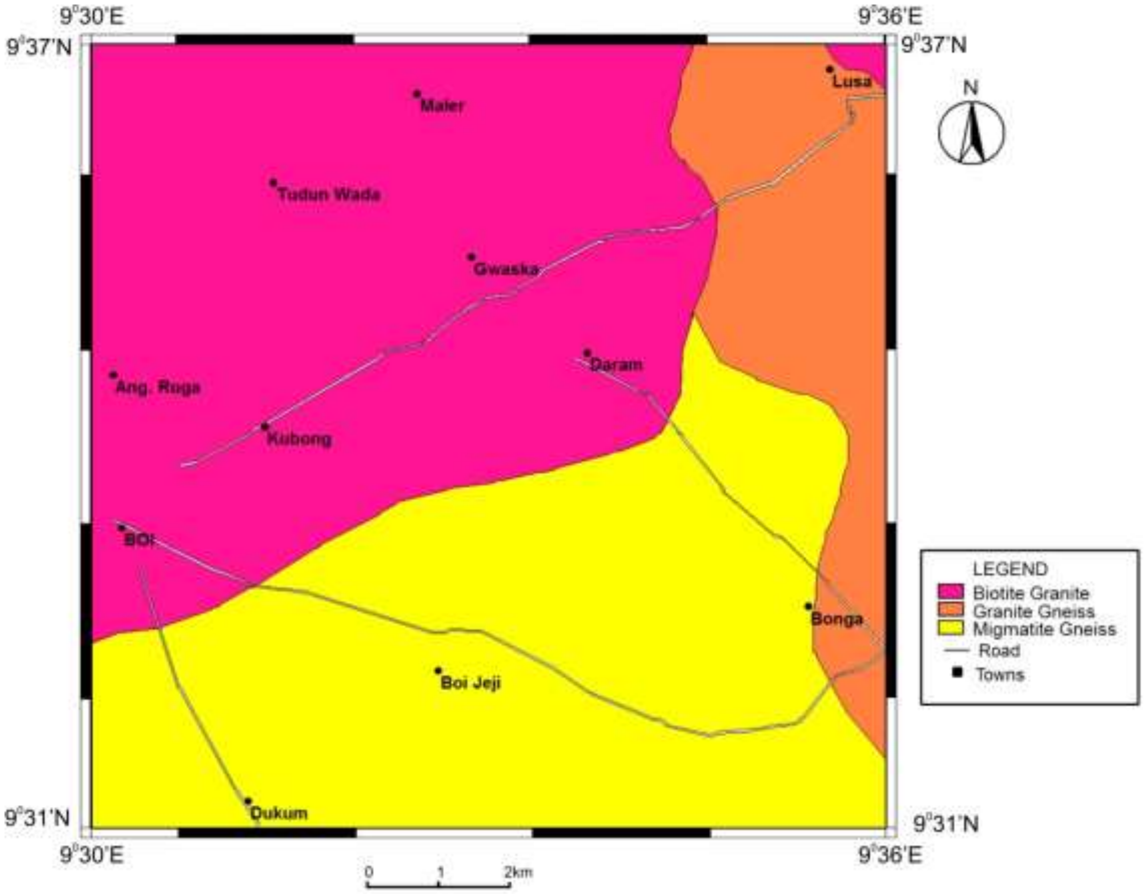


Figure 2: Geologic Map of the Study Area (After Geological Survey of Nigeria 2006)

Plate I : Boulders of Biotite Granite at Angwan Ruga

3.2.2 Migmatite Gneiss

Migmatite gneiss occupy a large portion of the study area (plate II), they were seen outcropping at the south and southeastern part of the study area . The outcrops were of low relief when compare to the biotite granites. Migmatites are foliated, there are alignment of the light and dark minerals and the texture is medium to coarse grain. The migmatite gneiss lithology terminate at Jolong and Daram in North,and at Bonga at the Eastern part of the study area. And extern southward of the study area. On these outcrops there are veins and segregations of light-colour granitic composition called leucosome, with dark coloured amphiboles and biotite rich materials called melanosomes . The leucosome is the lightest coloured parts of migmatite while melanosome is the darker part . The migmatite seen have undergone series of fracturing and folding . The rocks are made up intercalation of dark and light layers respectively .

3.2.3 Granite Gneiss

Granite gneiss occupy Northeastern part of the study area . The rocks have contact with migmatite which are transitional and generally have a complete structural comformity with foliation . The term granite gneiss is generally applied to a heterogeneous group of rocks, predominantly of granodioritic in composition,in which variable amounts of remnant streaks schlieren and larger relics bodies of original gneiss are recognizable (MCcurry, 1976) . The granite gneiss lithology dominate the extreme Northeastern and southeastern part of the study area . Was seen at Lusa, Manga and Bonga respectively . The rocks here shows alternating colour of dark and light and yield a structure called gneissose foliation . They are medium to coarse grain sizes .

3.3 Laterite

Laterite was encountered in the study area at Kubong and at Desham Yelwa (plate.III). Laterites are formed from the leaching of parent sedimentary rocks (sandstones , clays , limestones) ; metamorphic rocks (schists gneisses migmatites) ; igneous rocks (granites , basalts gabbros peridotites) ; and mineralized proto-ores ; which leaves the more insoluble ions, predominantly iron and aluminium (Whittingon and Muir, 2000) . The mechanism of leaching involves acid dissolving the host minerallattice followed by hydrolysis and precipitation of insoluble oxides and sulfates of iron, aluminium and silica under the high temperature condition- of a humid sub-tropical monsoon climate.

Plate II : Showing Migmatite Gneiss Exposure at Jolong

Plate III : Laterite Exposure at Kubong

An essential feature for the formation of laterite is the repetition of wet and dry seasons (Whittingon and Muir, 2000) . Rocks are leached by percolating rain water during the wet season; the resulting solution containing the leached ions is brought to the surface by capillary action during the dry season . Soil types rich in iron and aluminium formed in hot and wet tropical areas . Nearly all laterites are rusty-red because of iron oxide . They develop by intensive and long - lasting weathering of the underlying parent rocks . Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness , grade , chemistry and ore mineralogy of the resulting soils (Whittingon and Muir, 2000). Thick laterite layers are porous and slightly permeable, so the layers can function as aquifers in rural areas. Locally available laterites have been used in an acid solution , followed by precipitation to remove phosphorus and heavy metals at sewage-treatment facilities. Laterites are a source of aluminium ore ; the ore exists largely in clay minerals and the hydroxides, gibbsite , boehmite , and diaspore which resembles the composition of bauxite (Whittingon and Muir, 2000) .

3.4 Geophysical survey

The geophysical prospecting method adopted for this study is the Electrical resistivity method and Vertical Electrical Sounding (VES) techniques. The ABEM SAS-200C Terrameter was used along with four metal electrodes(Plate IV), hammer for driving the electrodes in the ground, and four connecting cables (two black coloured for current and two red coloured cables for potential electrodes),measuring tape, cutlass for cutting traverses, and clips. Global Positioning System (GPS) was used to ascertain the coordinate of the VES points. Calibrated rope and data sheet were used for recording the field data during geophysical data acquisition. The resistivity meter contains both the transmitter unit,through which current enters the ground and the receiver unit, through which the resultant potential difference is recorded.

The Schlumberger array was adopted for the study and the electrode spread of AB/2 was varied from 1 to a maximum of 100m .Sounding data were presented as sounding curves , obtained by plotting apparent resistivity against AB/2 or half the spread length on a log - log paper ground resistance (R) measurements were recorded with the ABEM SAS-200C Terrameter . The electrical resistances obtained were multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity ($\rho = kR$) in ohm-meter. This configuration was used as it provided subsurface

Plate IV: ABEM Terrameter SAS 200C Model Used in Geophysical Survey During the Study information considering the depth of penetration which ranges between 1/3 and ¼ of the total current electrode separation (David and Ofrey, 1989; Osemeikhian and Asokhia, 1994; Mallam and Ajayi, 2000).

The models obtained from the calculations above were used for computer iteration to obtain the true resistivity and thickness of the layers. Computer-generated curves were compared with corresponding field curves by using a computer program “IX1D” version 1.0.The software was further used for both computer iteration and modelling. Thirty–eight(38) vertical electrical soundings (VES) were carried out in the study area.

3.5 Hydrogeological Studies

A total of ten water samples were collected from the study area . Four samples were collected from hand-dug wells, four from boreholes, and two from surface water bodies as shown in Fig.1. The water samples were collected in 50ml rubber containers. Before the collection, the sample containers were rinsed three times in the field using the representative groundwater samples according to Rajkumar *et al*.(2010) method. The physical parameters measured were total dissolved solids (TDS),electrical conductivity (EC), temperature and pH was measured in the field using TDS/conductivity meter (Milwaekee meter). The samples were analyzed chemically within 48 hours of collection using DR/2010 Spectrophotometer, and digital titration method. Depth to water levels was measured using electric water level sounder. The surfer 9 Software was used in the construction of the hydraulic head distribution.

3.6 Instrument Used in Vertical Electrical Sounding

The instrument used in vertical electrical sounding is the Terrameter. There are different types of Terrameters this include SAS 300A, 300B, 300C, 1000 etc. Most resistivity meters employ low frequency alternating current rather than direct current. This is because when a direct current is employed there will be a build up of anions around the negative electrodes and cations around the positive electrode resulting into a electrolytic polarization which inhibit the further arrival of ions at the electrodes (Kearey and Brooks, 1984). The periodic reversal of the current prevents electrolytic polarization.

The Terrameter such as SAS 300B can be supplemented with SAS 2000 booster. The signal averaging system (SAS) is a method where consecutive readings are taking automatically and the result is averaged continuously which are presented automatically on the display. The SAS 2000 Booster supplements the SAS 300B Terrameter in situation where the voltage or current must be increased. The Terrameter SAS 300B operates in two modes. In resistivity surveying mode, it comprises a battery powered, deep penetration resistivity meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions(Kearey and Brooks, 1984).

Discriminatory circuitry and programming separates direct current (DC) voltages, self potentials and noise from incoming signal. DV/I calculated automatically and displayed in digital form in kilo ohms to 1999 kilo ohms. The overall range extends from 0.5 milli ohms by means of the SAS 2000 Booster. In voltage measuring mode, the SAS 300 comprises a self potential. The result is displayed in volt (V) or milivolt (MV) the range extent from 0.0lmv to 500v.

The Terrameter SAS 300B contains three main units all housed in a single casing: the transmitter, receiver and the micro- processor. The electrically isolated transmitter sends out well defined and regulated signal currents. The receiver discriminates noise and measures voltage correlated with transmitter signal current and also measure uncorrelated DC potentials with same discrimination and noise rejection (voltage measuring mode) the SAS 300B permits signals to be measured at extremely low levels with excellent penetration and low power consumption. It can also be used in wide variety application where effective signal noise discrimination is needed (Kearey and Brooks, 1984).

There are several types of arrays, these include:

i. Wenner array
ii. Schlumberger
iii. Dipole - Dipole etc(Lowrie, 2007).

3.7 Schlumberger (Array) Configuration

In Schlumberger array four electrodes are placed along a straight line at the earth surface (Figure 3) in the same order AMNB, With AB $\geq$ 5 MN. In Schlumberger Configuration the current and potential pairs of electrodes also have a common mid-point, but the distance between adjacent electrodoes differ. The distance between the potential electrodes must be one-fifth of the distance from centre of the array and one current electrode(Lowrie, 2007).

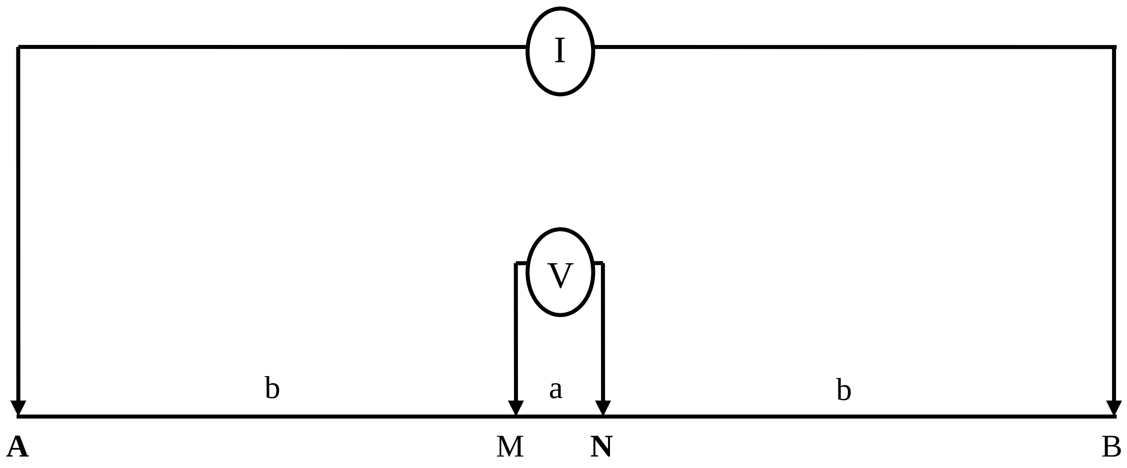


Figure 3: Schlumberger Configuration; (After: Lowrie, 2007)

$$\rho_a = \frac{V}{I} \pi \frac{b(b+a)}{a} \approx \frac{V}{I} \pi \frac{b^2}{a}$$

If a << b

NOTE: that if a is small compare to b, v/a ~E the electric field. The electric field from an electrode is

- $\frac{d\Phi}{dI} = \frac{IP}{2\pi r^2}$ and since

there are two electrode the total electric field becomes $= \frac{IP}{\pi r^2}$ and so

$$\rho_a = \frac{E\pi b^2}{I}$$

Further, it is convenient to consider the spacing to be the distance from the center of the array to the outmost electrodes i.e. AB/2 in this case b in the above expression becomes AB/2 – a/2. If a << AB/2 the above formula for ρ_a are unchanged. Data from a Schlumberger sounding plotted against VES spacing(Lowrie, 2007) .

CHAPTER FOUR

RESULTS

4.1 Qualitative Analysis

The sounding data obtained(Appendix 1) were presented as sounding curves by plotting the apparent resistivity against AB/2 or halve the spread length on log-log paper. Smoothened data were inputed into a computer system using IX1D software to generate sounding curves. The curves were smoothened until a smooth layer curves were obtained (Appendix 2). The general features of the sounding curves observed were three layers types. The H,Q,A and K were observed on the geological formations of the study area. Thirty of these curve types are H type (Appendix 2) with resistivity relationship of $P_1 > P_2 < P_3$(Lowrie, 2007) ,at VES 1, VES 2, VES 3 VES 4, VES 5, VES 6, VES 7, VES 8, VES 9 VES 10, VES 11, VES 14, VES 15, VES 16, VES 17, VES 18, VES 19, VES 20, VES 21, VES 22, VES 23, VES 26, VES 27, VES 28, VES30, VES 32, VES 33,VES 36, VES 37 and VES 38, they constitute 78.95% of the total curve of the study area. Type Q curves has resistivity relationship of $P_1 > P_2 > P_3$ .They constitute 13.16% of the total curves of the study area and were obtained in VES 12, VES 24, VES 29, VES 31 and VES 34(Appendix 2). Type A curves has resistivity of $P_1 < P_2 < P_3$. They constitute 5.26% of the total curves in the study area, and were obtained in VES 25,and VES 35 respectively(Appendix 2). Type K curves has resistivity $P_1 < P_2 > P_3$ .They constitute 2.63% of the total curves in the study area, and was obtained at VES 13(Appendix 2). First order geometric parameters (resistivities and thicknesses) of all sound points are presented in (Appendix 3). This contain details of layers thicknesses, resistivities, longitudinal conductance, transverse resistivities and their fitting errors for all the points sounded in the study area, while field and synthetic data are shown in Appendix 1.The general features of the sounding curves observed have fitting ranging from 0.215% to 0.98% respectively. These curves were interpreted in terms of their hydrogeological significance to serve as basis for the definition of aquifer architecture within the study area, since each of the type curves represents certain geometry of the geoelectric layers in the subsurface. The main aquiferous zone,therefore,is at the base where selective mineral weathering has provided a gravel like materials constituting a lot of medium to coarse grained quartz particles, which make for better permeability and better yield. Immediately underlying the aquiferous zone is the fresh bedrock(Abiola *et al.,* 2013).

4.2 Isoresistivity Maps

Iso-resistivity map, is a map that link points of equal electrical apparent resistivity. This was prepared for AB/2 = 60m and AB/2 = 100m respectively. Iso-resistivity contour maps were produced by plotting the resistivity values obtained from sounding curves at a given electrode spacing common to all the sounding points for $\frac{AB}{2}$ = 60m, and $\frac{AB}{2}$ = 100m and the points of equal resistivity values were contoured. This is a qualitative interpretation that presents the variation in resistivity at a given electrode spacings but simply indicates the general lateral change in electrical properties around the area.

4.2.1 Iso-resistivity for AB/2 = 60m

This shows resistivity values ranging from 150Ωm to 850Ωm (Figure 4). The map reveals the heterogeneity in the composition of the subsurface. The high resistivity values were found along the Northwestern and Northeastern parts of the study area, while the low resistivity values were found along the Southeastern, Southwestern and central parts of the study area.The anomalous zones are found at northern part of Boi with length of 4.1km and a width of 2.1km, at Doli, the anomaly extend to Ndukum with a length of 7.4km and a width of 6km . At Bonga which has a width of 1.6km and alength of 4km and finally at Mallar which extend to Lusa with a length of 9.6km and a width of 4.5km.

4.2.2 Iso-resistivity for AB/2 = 100m

This shows resistivity values ranging from 150Ωm to 1050Ωm (Figure 5). The map revealed heterogeneity of the ground,w hose composition varies. The Southeastern and Northeastern part of the study area has the high resisitivity values, while the North, Northwestern and Southwestern parts of the study area has low resistivity values. The anomalous zones were seen at Doli with a length of 8km and width of 8km which extend to Ndukum and western part of Bonga,at Mallar have length of 3.1km and width of 1.1km. At northern part of Boi with a length of3.5km and width of 2km and at Mallar with length of 3.2km and width of 1.1km, at western part of Mallar has length of 4km and width of 1.1km respectively.The areas with major anomalies include, Ndukum, Boi town, Doli, Mallar and Tudunwada. Areas with low isosresistivity includes Bonga, Gyara, Lusa ,Vingam and Mallar Ganawuri.

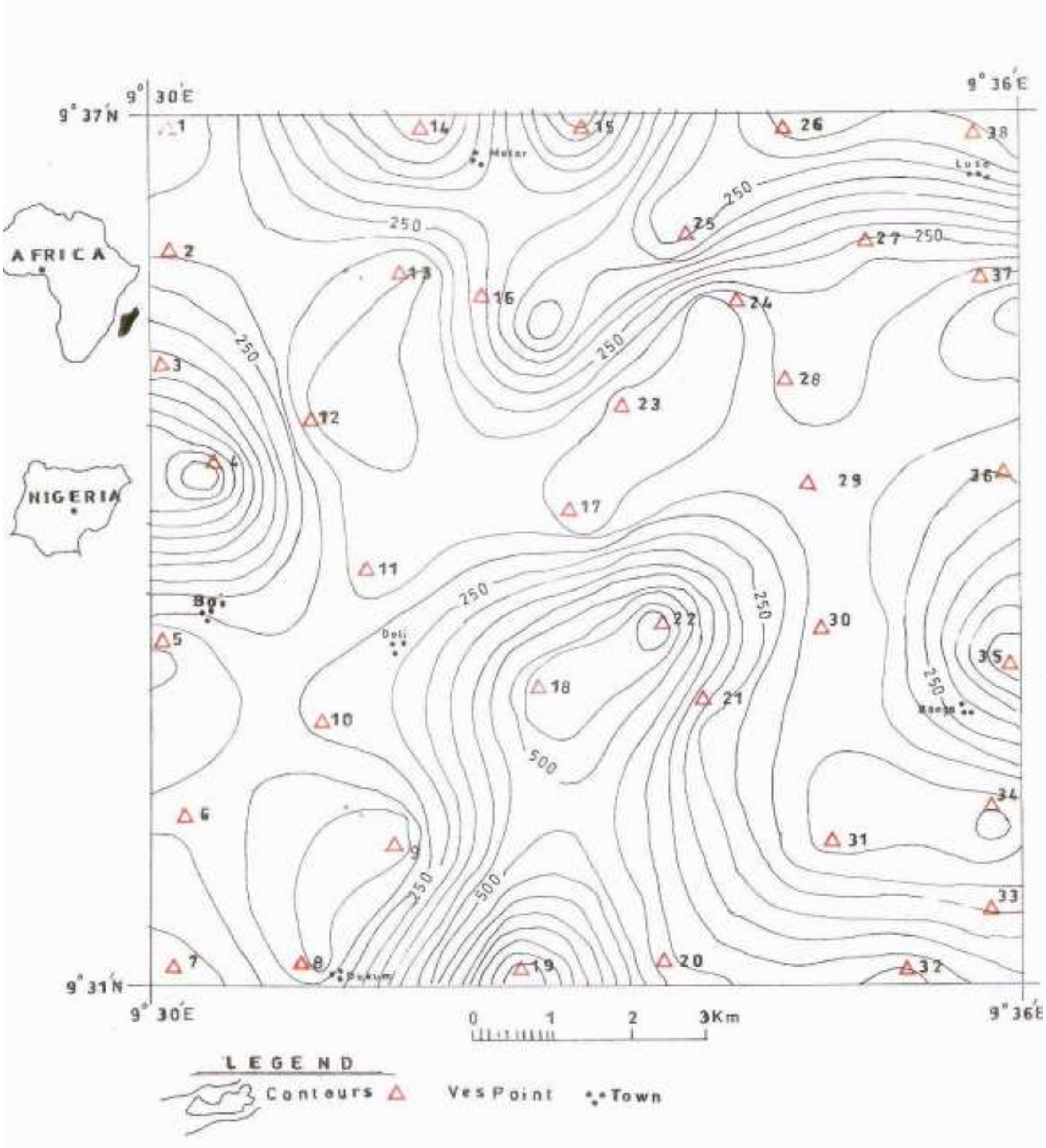


Figure 4: Iso Resistivity Map for AB/2=60m of Boi and Environs (Contour Interval 50Ωm)

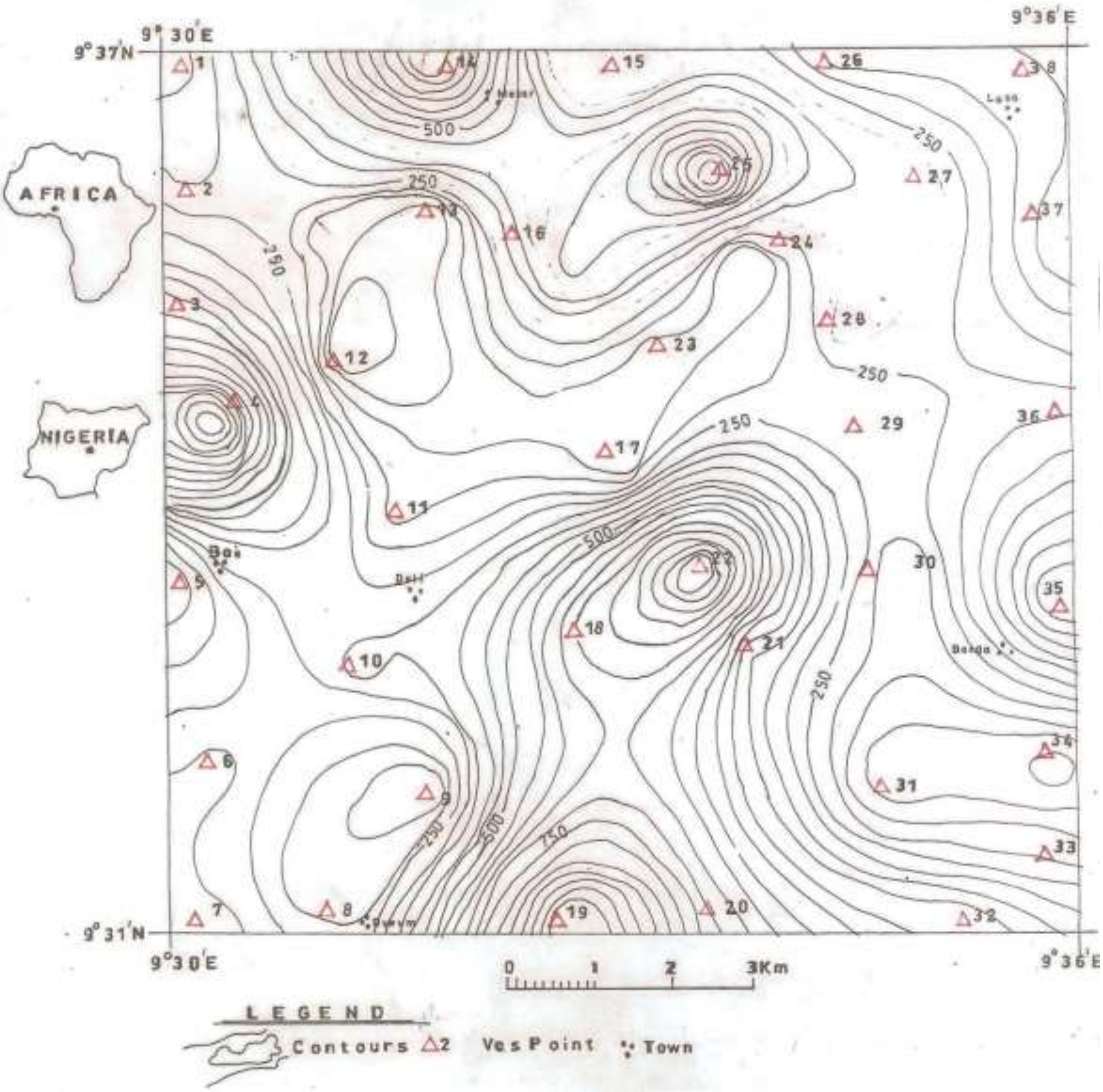


Figure 5: Iso Resistivity Map for AB/2 = 100m of Boi and Environs (Contour Interval 50Ωm)

4.3 Geo-electrostratigraphic Sections

The VES interpretation results were used to prepare geoelectric sections. These sections were obtained using interpreted results at various VES stations along the corresponding sections. To obtain each section first the maximum length of each profile was taken and drawn to scale both of vertical and horizontal scale as shown in each section, the position of each VES point was then marked out using station intervals, then resistivity boundaries beneath each VES station were located along with their thickness drawn. There are three sections in all. The geo-electric sections delineated a maximum of four geoelectric subsurface layers comprising the top soil, laterite ,weathered layer/fractured basement and fresh bedrock.

4.3.1 Geo-electric Section Along A-A^1

This section revealeds the presents of three geo-electric layers, the topsoil or laterite, weathered/fractured basement and fresh basement (Figure 6). The topsoil has resistivity ranging from 113.35Ωm to 264.21Ωm and thickness ranging from 0.56-3.77m, laterite have resisistivity value ranging from 576.20Ωm to 758.72Ωm and thickness ranging from 1.93-3.47m.The weathered/fractured basement has resistivity value ranging from 10.62Ωm to 200Ωm and thickness ranging from 2m to infinite depth. The fresh basement have resistivity value ranging from 1000.33Ωm to 1250Ωm and thickness ranging from 6.35m to infinite depth respectively. All the VES points on this section have three layers respectively. Which includes VES 3, VES 14, VES 15, VES 25, VES 24, VES 28 and VES 37.

4.3.2 Geo-electric Section Along B-B^1

This geo-electric section revealeds the presence of three geo-electric layers, the top soil or laterite, weathered/fractured basement and fresh basement(Figure 7). The topsoil has resistivity value ranging from 81Ωm to 211.12Ωm and thickness of 1.56 to 2.84m. Laterite has resistivity value ranging from 564.88Ωm to 999.71Ωm and thickness of range of 2.54-3.86m. Weathered/fractured basement has resistivity value ranging from 26.60Ωm to 238.85Ωm and thickness of 2.22m to infinite depth while the fresh basement has resistivity value ranging from 1094.70Ωm to 1821Ωm and thickness of 4.64m to infinite depth. The shortest depth to the fresh basement was found at VES 36 respectively.

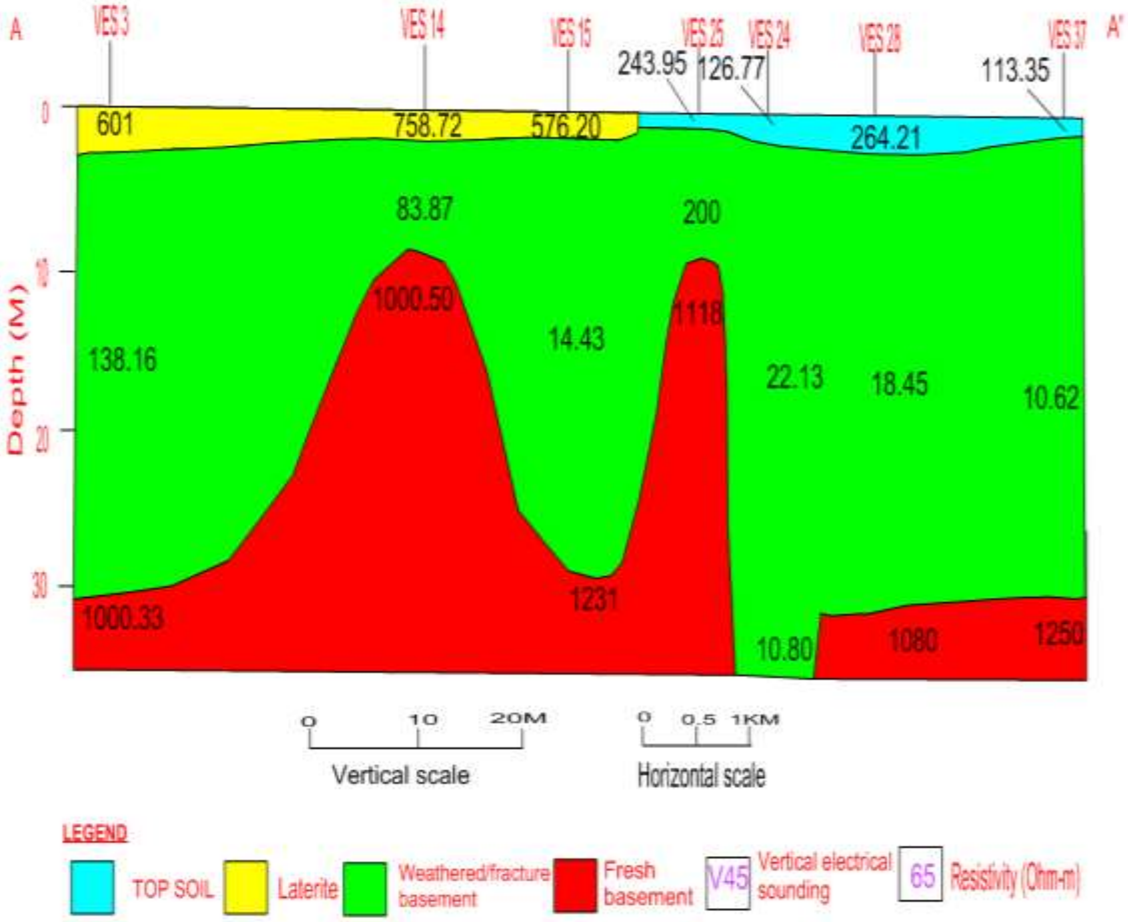


Figure 6 : Geo-electrostratigraphic Section Along A-A[1] of the Study Area

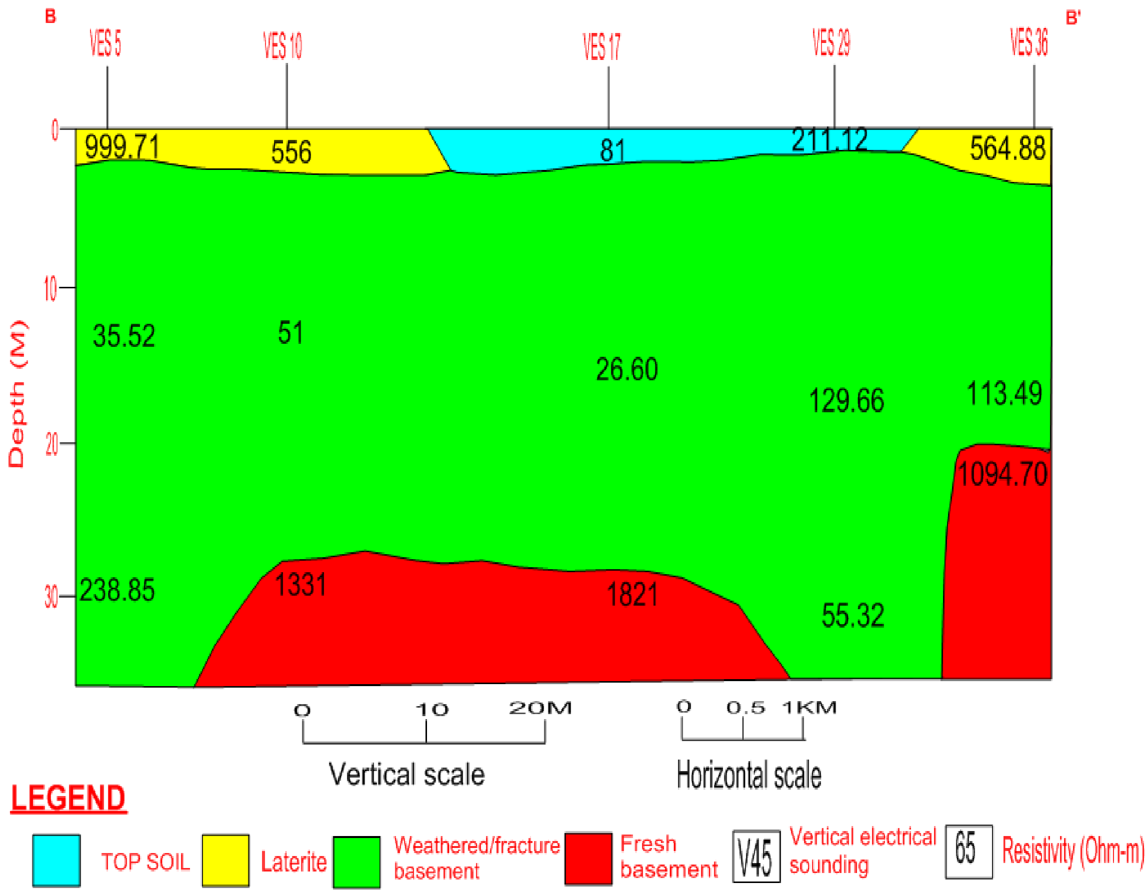


Figure 7: Geo-electrostratigraphic Section Along B-B[1] of the Study Area

4.3.3 Geo-electric Section Along C-C¹

This section revealeds the presence of three geo-electric layers, the top soil or laterite, weathered/fractured basement and the fresh basement (Figure 8). The topsoil has resistivity range of 111.58Ωm and thickness of 2m - 2.34m , laterite has resistivity values ranging from 526.86Ωm to 1679Ωm and thickness of 1.57 to 2.55m , weathered/fractured basement have resistivity value ranging from 12.38Ωm to 217.68Ωm and thickness of 2.30 t0 infinite depth while the fresh basement has resistivity value ranging from 1039.01Ωm to 1546Ωm and thickness of 4m to infinite depth respectively. All the VES points on this section have three layers respectively .

4.4 Water Quality Analysis

The suitability of water for domestic, industrial, and agricultural practice is controlled by the concentration of the dissolved constituents in water. The concentrations of the dissolved constituents are correlated with the standards of the World Health Organization[WHO](2011),European Union[EU](2011] or other agencies charged with the responsibility of providing safe drinking water to the ever increasing population of the world such as Federal Environment Protection Agency [FEPA] (1991) .Water quality for industrial practice depends on the type of industrial activities. The hydrogeochemical results from the different water sources and the summary of the hydrogeochemical parameters are presented in (Appendix 4).The result revealed that the pH values range from 5.08 to 6.74, electrical conductivity (Ec) range from 328 mS/cm to 987 mS/cm, total dissolved solids (TDS) ranges from 162 mg/l to 471 mg/l, total hardness (TH) ranges from 22mg/l to 80mg/l ,turbidity range from 1.03mg/l to 7.41 Nephelometric Turbidity Unit(NTU). The physical parameters such as TDS,T^{0C} and PH are generally within the acceptable limit of WHO and European(EU) (2011) standard while Ec ,TB and TH are above the permissible limit (Appendix 4).Calcium (Ca^{2+}) mean overall concentration of 7.80mg/l is below the acceptable limit of WHO, however, the overall mean value is however below the maximum permissible limit. Manganese Mg^{2+} mean value of 0.10mg/l,and range of 0.01-0.13mg/l is below the acceptable limit for drinking water by WHO and EU(2011). Sodium (Na^{+}) mean overall value of 46.78 mg/l and range of 23 - 50.8mg/l below the permissible limit. The mean values of K^{+} (0.16mg/l) , and has concentration range of 0.10 - 0.20mg/l, However, all samples revealed concentration values below the maximum permissible limit. Copper (Cu^{2+}) has mean value of 0.015mg/l

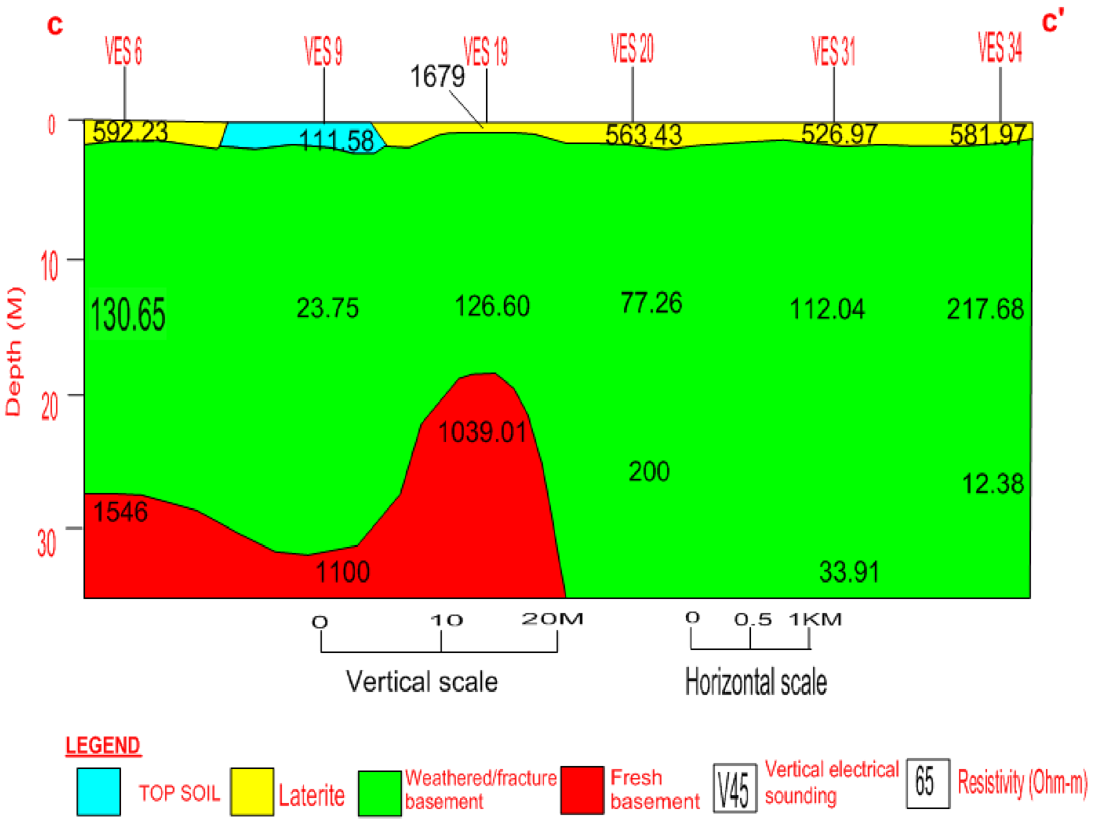


Figure 8: Geo-electrostratigraphic Section Along C-C[1] of the Study Area

and range concentration value of 0.01-0.03mg/l which are all below the permissible value for drinking. Manganese (Mn^{2+}) manganese has mean value of 0.11 mg/l and concentration range of 0.01 - 0.19mg/l which is within the permissible limit for drinking by WHO and EU(2011). The concentration of iron(Fe^{2+}) vary from 0.42 - 0.83mg/l, and has mean value of 0.69 mg/l. The concentration of iron in all the samples are above the permissible limit for drinking water by WHO and EU (2011). The concentration of $SO4^{2-}$ range from 2 - 23 mg/l, and mean values of 12.3 mg/l and is within the permissible limit for drinking, domestic and industrial uses by WHO and EU. Chloride concentration range from 1.33-2.69mg/l and has mean value of 2.04mg/l is also within the permissible limit for drinking water by WHO and EU respectively. Fluoride overall mean value of 0.52 mg/l and concentration range of 0.09 - 0.91 mg/l is above the acceptable
limit. Bicarbonate concentration vary from 11.5-11.8 mg/l and has mean value of 11.6 mg/l is below the acceptable limit.

4.5 Groundwater Flow Directions

Hydraulic head map of the area was produced by joining points of equal hydraulic heads and Piezometric lines were drawn at a right angle to indicates groundwater flow direction of the area(Figure 9). The hydraulic head map of distribution of the study area indicates regional groundwater from the recharge area around Mallar, Angwan Ruga,in the Northwest and flows towards Daram and Bonga areas in the east, and also flows towards Ndukum and Boi areas in the South and southwest. Another recharge zone occurs around Gwaska area in the North and flows towards Lusa in the Northeast . Groundwater also flows towards Rafin Zurfi area, and discharges into the River Mallar and River Tudun wada Southestern. part of the study area. Ndukum areas in the south constitute the second discharge area. Area with the highest hydraulic head was found at the Northern, Northwestern parts of the study area, with some areas at the central, southern, parts of the study area. While areas with the lowest hydraulic heads was found at the Southwestern part of the study area with some discharge zones also at the Northestern, central and southern parts of the study areas respectively.

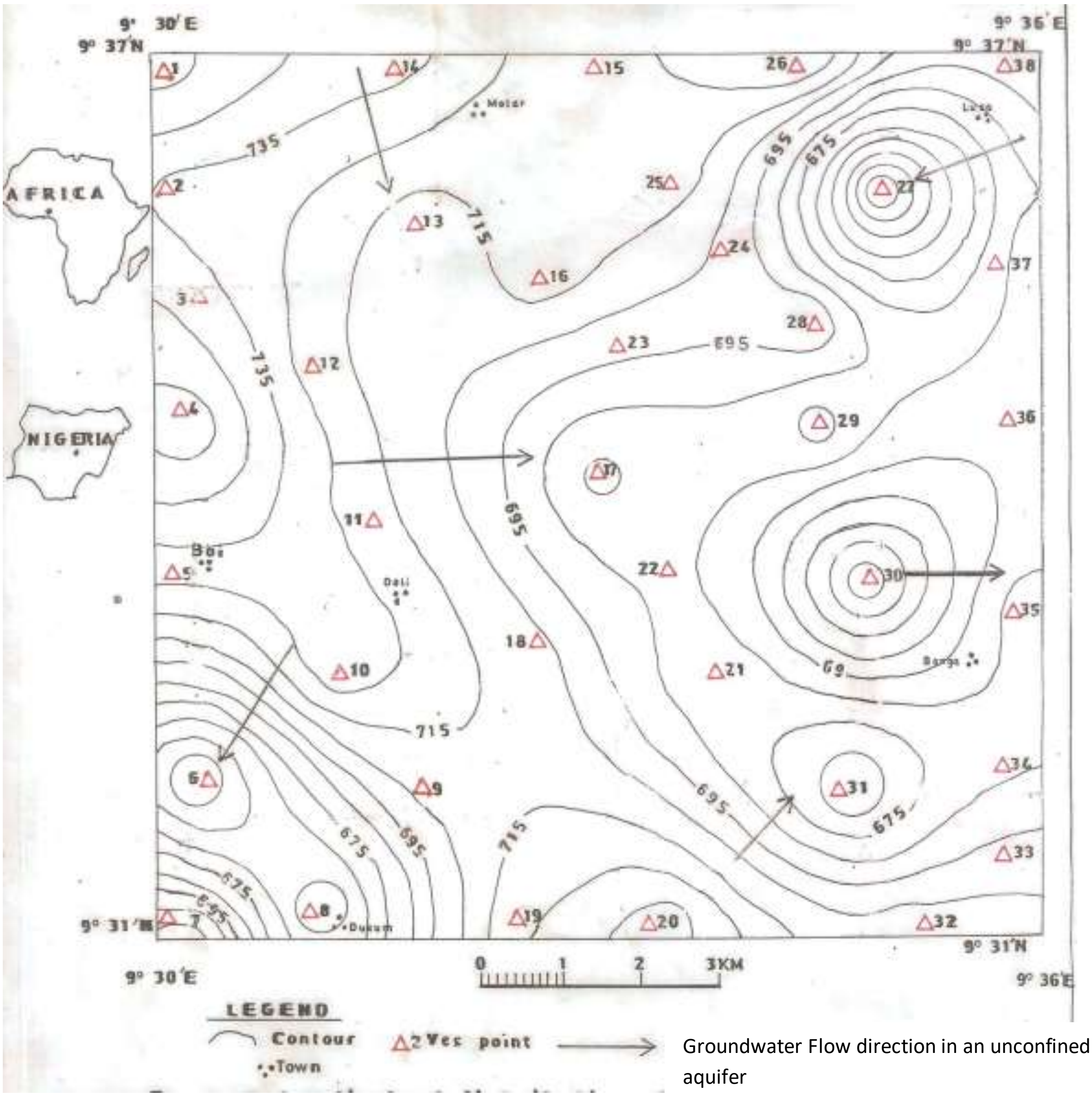


Figure 9 : Hydraulic Head Distribution of Boi and Environs

(Contour Interval 10m).

CHAPTER FIVE

DISCUSIONS

The curves obtained from the vertical electrical soundings data in Boi area are predominantly H , Q , A and K type curves : these curves are typical of the Basement Complex terrains. Table 2 , shows the area , to have three layers . The average value of each layers thickness and their nominal resistivity of each layer is calculated and their values is given as follows :H_1 = 1.37m , H_2 = 20.85m. The average resistivity values of the layers are ρ_1 = 363.35Ωm, ρ_2 = 96.07Ωm , ρ_3 = 12488.58Ωm.Other geo-electric parameters such as the longitudinal conductance(S) and transverse resistance(T) are determined from the values of the thickness and resistivities of each layers . Longitudinal conductance(S) is calculated using the following formula, Longitudinal conductance Si = $\sum H_i/\rho_i$ and Traverse resistance Ti = $\sum H_i \times p_i$. where H represent thickness in meters ρ represent resistivity in ohmsmeter while subscript(i) indicating position of the layers respectively . The average value of the longitudinal conductance of each layer is given as $S_1 = 6.1x10^{-3}$ Siemen,$S_2 = 4.6x10^{-1}$Siemen and their transverse resistance values to be T_1 = 1171.73Ωm , T_2 = 1819.22Ωm . The quantitative interpretation of the vertical electrical sounding data has helped in the delineating the aquiferous zones and thickness of the rock layers in Boi area . From the analysis of the interpreted result obtained from the study area (Boi),there are fractures which could not cause serious problems if the area is to be used for construction purposes and the area is also good for groundwater development.

The geochemical results of groundwater quality in Boi and environs indicated that the order of cation concentration are : $Na^+ > Ca^{2+} > Fe^{2+} > K^+ > Mn^{2+} > Mg^{2+} > Cu^{2+}$ while the anions are in the order of $SO_4^{2-} > HCO_3^- > Cl^- > F^- > PO_4^{2-}$ and for physical parameters measured are EC > TDS > TH > T^0 > pH > TB respectively . The cations, anions and physical parameters present in the study area which values are excess for drinking water includes, iron, fluorides , turbidity , total hardness and electrical conductivity . Though iron is an essential element in human nutrition its defenciency may result in unpaired mental development in children reduced work performance in adult and in severe cases anaemia or unpaired oxygen delivery. High concentration of iron could be attributed to the weathering of acidic rocks , acidic mines, water drainage , landfills leachates (Sawyer and MCCarthy, 1967). High concentration of fluoride could be due to leaching from rocks rich in fluoride . Though fluoride occurs in many common rocks forming minerals such as fluorites (CaF_2) which occurs in both igneous rocks , apatite ($Ca_5[PO_4]_3(Cl,F,OH)$, topaz ($Al_2F_2[SiO_4]$) , muscovite [$KAl_2(OH,F)_2(AlSiO_3O_{10})$] and range of amphibole and mica minerals (Sawyer and MCCarthy, 1967).

Felsic igneous rocks which have high concentration of SiO_2 , tend to have higher concentration of fluoride than mafic rocks. The average Fluoride content in rocks is $1000kg^{-1}$ in alkali rocks,$400kg^{-1}$ in intermediate rocks dropping to $100kg^{-1}$ in ultramafic rocks if all these rock are weathered can cause high concentration of fluoride in groundwater. Fluoride is released as fluoride during weathering. Fluoride is an essential micro-nutrients for mammals serving to strengthen the apatite matrix of skeletal tissue and teeth . High concentration of fluoride in water above the permissible limit may induce skeletal and dental disorder , and cause harm to kidneys , nerves and muscles and low concentration of fluoride in plants can cause damage in leafs and growth retardation in plants (Sawyer and MCCarthy, 1967) . Turbidity which is the measure of relative clarity or cloudness of water . High concentration in the study area could be cause by suspended and colloidal matter , such as clay , silt , finely divided organic and inorganic matter and other microscopic organism (Sawyer and McCarthy, 1967) . Total dissolved solids test measures the total amount of dissolved minerals in water. The solids can be iron, chlorides , sulphates , calcium or other minerals found on the earth's surface . The dissolved minerals can produce an unpleasant taste or appearance and can contribute to scale deposits on pipe walls . Primary sources for TDS in receiving water in the study area are agricultural and residential run-off ,leaching of soil , contaminations and point source water pollution . Total hardness having mean concentration value of 57.20mg/l and is within the acceptable limit by WHO and EU (2011) and has range concentration value of 20mg/l to 80mg/l , with the exception of sample at Kubong which is above the acceptable limit , and may be caused by dissolved polyvalent metallic ions . And also may be caused by abundance of calcium and magnesium dissolved in water. Are found in groundwater that has come in contact with certain rocks especially the alkali feldspars which can release calcium and magnesium. The values of the total hardness indicate that the water in the area is soft water with the exception of sample at Kubong based on Sawyer and McCarthy (1967) values . According to Sawyer and McCarthy (1967) that hardness value of 0 - 75 mg/l is classified as soft, 75 - 150 mg/l as moderately hard , 150 - 300 mg/l as hard and > 300 mg/l as very hard . According to Okafor (1994) , water used in boilers should be soft and non corrosive while laundry water should be colourless and soft. Water for industrial activities should be ordourless, colourless, free from suspended matter and microorganisms and of low iron and manganese content. According to Todd(1980) water containing more than 0.2 mg/l of iron and manganese are objectionable for most industries. Salinity hazards expressed as electrical conductivity (Ec) and total dissolved solids (TDS) is also considered in the evaluation of water quality for irrigational practices (Ishaku and Matazu, 2001). Total hardness of water limits its use for domestic, industrial and agricultural activities, Water hardness can cause scaling of pots, boilers and irrigation pipes,it may also cause health problems to human such as kidney failure(Ishaku *et al.*,2012). Electrical conductivity (EC) is a good measure of salinity hazard to crops.Excess salinity reduces the osmatic activity of plants and thus interferes with the absorption of water and nutrient from soil (Ishaku *et al.*, 2012).

Hydraulic head map of the area was produced by joining poits of equal hydraulic heads and Piezometric lines were drawn at a right angle to indicates groundwater flow direction of the area. Result of groundwater head contouring also showed that groundwater flow is dominantly in N-S,NW-SE,NE-SW and W-E directions which possibly could be associated to fracture-controlled flow.Groundwater flow direction of the area has helped in isolating possible areas for aquifer exploitation for water resource development.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Thirty eight vertical electrical soundings were carried out in Boi and environs, using Schlumberger configuration with AB/2 ranging from 1 to 100m. The results obtained from computer iteration shows that thirty curves were H - type, five were Q – type, two were A – type and one was K – type. The iso-resistivity maps were produced for AB/2 = 60m and AB/2 = 100m,and the results shows that the anomalous zones were observed along the northern, western, southern ,eastern and central parts of the study area. The resistivity values ranges from 150Ώm to 950Ώm.Geo – electric sections produced reveals the presents of three geoelectric layers, the top soil/laterite, weathered/fractured basement and the fresh basement. The hydraulic head map of the area produced showed groundwater flow to be dorminantly N – S, NW – SE, NE – SW and W – E direction. Groundwater quality analysis shows that the concentration of fluoride, iron, total hardness and some physical parameters such as electrical conductivity and turbidity to be aboved the permissible limits by the WHO and EU standard of drinking water (2011).Which can cause serious problem when use for agricultural, domestic and industrial purposes without treatment. The mean concentration of cations are $Na^{+} > Ca^{2+} > Fe^{2+} > K^{+} > Mn^{2+} > Mg^{2+} > Cu^{2+}$ while the anions are in the order of $SO_4^{2-} > HCO_3^{-} > Cl^{-} > F^{-} > PO_4^{2-}$ and for physical parameters measured are EC > TDS > TH > T^0 > pH > TB respectively

6.2 Conclusions

The following conclusions can be drawn from this study. The thirty-eight vertical electrical sounding(VES) were carried out in Boi area, Bogoro L.G.A of Bauchi State Northeast Nigeria. The curves in the study area revealed three layers earth models, they are: H, Q, A and K type curves. The quantitative and qualitative interpretation of the thirty-eight VES conducted at different locations in the study area revealed the area to be underlain with three geo-electric layers: topsoil/ laterite, weathered/fratured basement and fresh basement. The first layer is topsoil/ laterite with an average thickness and resistivity range values of 0.56-3.86m and 81Ώm to 1679Ώm respectively. The second layer is weathered/fractured basement and is the water bearing zone in the study area having thickness and resistivity range 2m to infinite depth and 10.62Ώm to 338.85Ώm respectively. The third layer is identified as the fresh basement with thickness and resistivity values of 4m to infinite depth and 1000.33Ωm to 1821Ωm respectively. The top soil is easy to excavate except where basement rock outcrops. The lowest weathering depth is in the Northern, Northwestern and central part of the study area while the lowest fresh basement depth along the southern and southeastern part of the study area.

Geo-electrostratigraphic sections along the profiles revealed that most of the fractures are within a depth of 10-30m.The fractures are generally isolated fracture and may not pose any serious problems as regard civil construction. The fracturesd zones should be used mainly for groundwater resources development as they usually serve as zones of groundwater storage.

The mean concentrations of the dissolved constituents are below the maximum permissible limits of WHO (2011) for drinking water with the exception of iron , fluoride, total hardness and some physical parameters such as electrical conductivity and turbidity, which are above the permissible limits . The water quality is however unfit for human consumption without treatment due the high concentration of iron and fluorine which are above the WHO and EU permissible limits. Total hardness having mean concentration value of 57.20mg/l and is within the acceptable limit by WHO and EU and has range concentration value of 20mg/l to 80mg/l. The values of the total hardness indicate that the water in the area is soft water with the exception of sample at Kubong which was classed as hardwater. Result of groundwater head contouring also showed that groundwater flow is dominantly in N-S,NW-SE,NE-SW and W-E directions which possibly could be associated to fracture-controlled flow

6.3 Recommendations

Due to the general nature of the site, close vertical electrical sounding investigation is recommended when groundwater resources is to be developed as the sounding intervals is very wide and hence close-up sounding are necessary to give a very clear hydrogeophysical disposition.

Boreholes should be drill down the fresh bedrock at a depth indicated by the geophysical investigation, since higher permeability are received at greater depth because clay content from weathering of feldspars is low and fractures occurs at great depth.

Boreholes should be located towards areas of thickest overburden, because greater groundwater is form in these areas.

All the water samples analysed in the study area require treatment because of higher concentration of iron, fluoride and also higher electrical conductivity and turbidity before consumption.

6.4 Contribution to Knowledge

The Geo-electrical investigation for groundwater in Boi and environs, Bauchi Nigeria., Has contributed to knowledge in the following areas:

1. From the literature review, reconnaissance survey to the geologic mapping conducted in the study area, has updated knowledge of the general literature and the geology of Boi and environs. Since the topographic, geologic map and the general literature of the area was reviewed and updated

2. The pattern of resistivity and depth variation of geologic materials in the study area have been known

3. From the geoelectric section of the area prepared, has provided knowledge of the probable depth to weathered/fractured basements, fresh basements ,their thickneses and nominal resistivities. Since weathered/fractured basements are points for groundwater development on basement complex terrains.

4. The portability of water in the study area, in regards to drinking, domestic and industrial use have been known.Since the concentration of iron, fluoride and othe physical parameters such as electrical conductivity,turbidity and total hardness were above the permissible limit for drinking by World Health Organisation and European Union standard.

5. Result of groundwater head contouring showed that groundwater flow of the study area is dominantly in N-S,NW-SE,NE-SW and W-E directions which possibly could be associated to fracture-controlled flow.The groundwater flow direction of the study area has helped in isolating possible areas for aquifer exploitation.

REFERENCES

Abiola, O. Ogunribido.T.H.T, and Omoniyi. B. A. (2013): Geo-electric assessment of groundwater prospects in Supare Estate, Supare Akoko, Southwestern Nigeria. *Journal of Geosciences vol.3.No.1*,pp23-33.

Acworth, R. I. (1987):The development of crystalline basement aquifers in a tropical environment. *Quarterly Jour. of Engineering Geology 20*.pp265-272.

Ajakaiye, D.E. (1983):Electrical and Seismic refraction Survey in search of Groundwater in Northern Nigeria. *Int. Journal of Africa Earth Science Vol.1 pp355*

Akaolisa, C., (2006). Aquifer transmissivity and basement structure determination using resistivity sounding at Jos Plateau state Nigeria. Environ. Monitor. Assess., 114: pp27-30

Arshad, M., J.M. Cheema and S. Ahmed,(2007). Determination of lithology and groundwater quality using electrical resistivity survey. *Int. Jour. Agric. Biol., 9:* pp143-146.

Asfahani, J. (2006). Geoelectrical investigation for characterizing the hydrogeological conditions in semi-ari region in Khanasser valley, Syria. *Jour. Arid Environ*., 68: pp31-5

Asfahani, J. (2007). Neogene aquifer properties specified through the interpretation of electrical sounding data, Salamiyeh region, central Syria. Hydrol. Processes, 21: pp2934-2943.

Ajibaje, A.C, Rahaman M.A.O, and Ogezi A.E. (1988): The Precambrian Geology of Nigeria.Geology of Nigeria publication pp313-324.

Bello, A.A. and V. Makinde,(2007). Delineation of the aquifer in the South-Western part of the Nupe Basin, Kwara State, Nigeria. *Journals. Am. Sci., 3*: pp36

Benkabbour, B., E.A. Toto and Y. Fakir, (2004). Using DC resistivity method to characterize the geometry and the salinity of the Plioquaternary consolidated coastal aquifer of the Mamora plain, Morocco. Environ. Geol., 45:pp 518-526.

Cid-Fernandez, J.A. and P.A. Araujo, (2007). VES characterization of a geothermal area in the NW of Spain.EIEAF Che.,6:pp2173-2177.

Cater, J.D. Barber, W. and Tait E.A. (1963). The Geology of part of Adamawa, Bauchi and Borno Provinces in North Eastern Nigeria. Bull. NO. 30 Geological Survey of Nigeria pp. 245.

Dahlin, T. (2001). The development of DC resistivity imaging techniques. Comput.Geosci.,27:pp1019-1029.

Danielsen, J., T. Dahlin, R. Owen, P. Mangeya and E. Auken,(2007). Geophysical and hydrogeologic investigation of groundwater in the Karoo stratigraphic sequence at Sawmills in Northern Matabelel and,Zimbabwe :A case history. *Hydrogeol.Journals*. 15:pp945-960.

El-Qady, G, (2006). Exploration of a geothermal reservoir using geoelectrical resistivity inversion: Case study at Hammam Mousa, Sinai, Egypt. *Jour. Geophys. Eng., 3*: pp114-121.

El-Waheidi, M.M., F. Merlanti and M. Pavan, (1992). Geoelectrical resistivity survey of the central part of Azra plain (Jordan) for identifying saltwater/freshwater interface.*Jour.Applied Geophys*.,29:pp125-133.

Edet, A.E. and Okereke, C. S. (1987):Assessment of hydrogeological conditions in basement aquifers of the Precambrian Oban Massif,South-Eastern Nigeria .*Journal of Applied Geophysics 36*:pp195-204.

Edok Eter Mandilas Ltd (1976). Hydrology and Geophysical Investigation for Groundwater in Bauchi State. Unpublished Report.

European Union(2011). Standard for drinking water,3rd European Union water conference.

Federal Environmental Protection Agency (FEPA). (1991). Guidelines and Standards for environmental pollution in Nigeria.pp16

Federal Survey of Nigeria (1976).Topographic map of Tafawa balewa Southwest of 1976,scale of 1:100000.

Ekwueme, B. N. (1993):An easy approach to igneous petrology University of Calabar Press pp 19-153.

Geological Survey Agency of Nigeria(2006). The Geological survey agency of Nigeria, Federal Ministry of Mines and power.

Hockey, R. A. (1964):The Geology of part of Southwestern Nigeria ,Geological Survey of Nigeria bulletin pp31-87.

Iloeje, N.P. (1981): A New Geography of Nigeria. Longman Nig. Ltd., Lagos.PP 231

Ishaku, J.M. and Matazu, H.I. (2001). Evaluation of Water Resources of Numan area, northeastern Nigeria. *Journal of Mining and Geology vol. 37(2),* pp195-202.

Ishaku, J.M.Ahmed, A.S and Abubakar, M.A. (2012). Assessment of groundwater quality using chemical indices and GIS mapping in Jadda area, Northeastern Nigeria: *Journal of science and geotechnical engineering vol;1*,pp35-60.

Ismailmohamaden, M.I. (2005). Electric resistivity investigation at Nuweiba Harbour Gulf of Aqaba, South Sinal, Egypt. Egypt. *Jour.of Aquatic Res., 31*: pp57-68.

Khalil, M.A. and F.A.S. Monterio, (2009). Influence of degree of saturation in the electric resistivity-hydraulic conductivity relationship. Surv. Geophys., 10.pp300

Khalil, M.H. (2006). Geoelectric resistivity sounding for delineating salt water intrusion in the Abu Zenima Area, West Sinai, Egypt. *Jour. Geophys. Of Eng., 3*: pp243-251.

Hazel, J.R. Cratchley, C.R and Jones, C.R. (1963). The Hydrogeology of crystalline aquifers in Northern Nigeria. *Jour. of geolscie.vol.2* pp223

Hazel, J.R. and John, B.W. (1985). The development of Groundwater Resources for farming communities in Bauchi state, Nigeria. *Jour. of Hydrogeologists vol.2* Cambridge, United Kingdom pp154.

Kearey, T.and Brooks,C. (1984). An Introduction to Geophysical Exploration. Blackwell Science Ltd. Oxford U.S.A pp. 256.

Limaye, S. O. (1989). Groundwater for irrigation and Domestic uses in crystalline Basement in India. In Groundwater Exploration and Development in Crystalline Basement Aquifers (Preceeding, Zimbabwe 15-34 June 1989, 1, Session 1 -5) common wealth Science Council Pall. London. pp 127 – 132

Lowrie, W. (2007):Fundamentals of geophysics second second edition,Cambridge university press pp56-78

Macleod, W.N, Turner, D.C. and Wright (1971). The Geology of the Jos Plateau Vol. (1) General Geology Bull. Geological Survey of Nigeria No. 32 pp. 91-95.

McCurry, P. (1976). The Geology of Precambrian to lower Paleozoic rocks of Northern Nigeria – A review in: Kogbe C.A (Ed) Geology of Nigeria Elizabeth Publishing Co. Ibadan, Nigeria pp. 15-38.

Meinzer, O.E.(1923).The Occurrence of Groundwater on the United State of America.U.S, Goelogical Survey. Water supply paper pp489.

Nur, A. (2013). Geophysics, a tool for imaging the Earth interior,14th inaugural lecture of Modibbo Adama University of Technology Yola.pp28-29.

Nur, A. and Ayuni, K.N. (2011):Hydro-geophysical study of Michika and Environs, Northeast Nigeria. *International Journal of the Physical Sciences,vol.6(34)* pp7816-7827.

Nur, A. and Kujir,A.S.(2006).Hydro-geophysical study in the Northeastern part of Adamawa State, Nigeria. *Journal of Environmental Hydrology(JEH),vol.14* paper 19,San Antonio, USA.

Nur, A. Obiefuna, G.I and Uche, M.U. (2005). Hydrogeophcial Investigation of Bauchi and environs, North Eastern Nigeria. *Global Journal of Geological Sciences, Vol. 3* (2), pp 143 – 151

Nur, A. and Ayuni, N.K. (2004). Hydrogeophysical study in Jalingo Metropolist and Environs of Taraba State,NE, Nigeria, *Global Journal of Geological Sciences ,vol.2(1*),PP101-109.

Nur, A. and Afa, D.E. (2002). Geoelectrical and hydrogeological investigation in parts of Adamawa State, Northeast Nigeria, Nigerian association of Hydrogeologists (NAH),vol.13,pp55-61.

Olurunfemi, M.O. and Fasuyi, S.A. (1993) Aquifer types and geoelectrical /hydrogeological characteristics of the central basement terrain of Nigeria. *Journal of African Earth Sciences 16*:pp309-317.

Olurunfemi, M.O and Okakune, E.T. (1992). Hydrogeological and Geological significance of of Geoelectrical survey of Ile-Ife ,Nigeria. *Journal of Mining and Geology 28*,pp221-222.

Olasehinde, P.I. (2010) The groundwater of Nigeria: A solution to sustainable National water needs,17th inaugural lecture of Federal University of Technology Minna,pp56

Olowofela, J.A., V.O. Jolaosho and B.S. Badmus, (2005). Measuring the electrical resistivity of the earth using a fabricated resistivity meter. *Eur. Jour. Phys., 26*: pp501-515.

Onu, N.N., (2003). Estimates of the relative specific yield of aquifers from geo-electrical sounding data of the coastal plains of Southeastern Nigeria. *Jour. Technol. Educ. Nig.*, 8:pp69-83.

Oseji, J.O., E.A. Atakpo and E.C. Okolie, (2005). Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta state, Nigeria. *Jour. AppliedSci.Environ.Mgt.9*.pp157-160.

Obiora, D.N. and O.S. Onwuka, (2005). Groundwater exploration in Ikorodu, Lagos-Nigeria: A surface geophysical survey contribution. *Pacific Jour. Sci.Technol.*, 6: 86-93.

Okafor, D.W. (1994). The physico-chemical qualities of water of River Bakoji catchment area of Niger State, Nigeria. *Jour.Water Res., vol.4 (182)*, pp 22-27.

Ogezi A.E O. (1985). Origin and Evolution of the Basement Complex of Northwestern Nigeria in the light of New Geochemical and Geochronological Data. In Precambrain Geology of Nigeria pp 301-312.

Ogezi,A.E.O. (2002a). Geology of Nigeria. African Atlases ,atlas of Nigeria. Less edition pp60-61 Paris forwarded by O.Obasanjo English and French.

Olurunniwo, M.A and Olurunfemi, M.O. (1987). Geophysical Investigation for Groundwater in Precambrian Terrains. A Case History of Ikare, Southwestern Nigeria. *Jour. Afri. Earth Sci 6*, pp787 – 796

Owoade, A. and Moffat, W.S. (1989). Groundwater Prospects in SouthWestern Nigeria 15th WEDC Conference; Water Engineering and Development in Africa Kano, Nigeria, pp 12 -116

Park, Y.H., S.J. Doh and S.T. Yun, (2007). Geoelectric resistivity sounding of riverside alluvial aquifer in an agricultural area at Buyeo, Geum River watershed, Korea: An application to groundwater contamination study. *Jour.Environ. Geol., 53*: pp849-859.

Rahaman, M. N. (1988):Recent Advances in the study of the Basement Complex of Nigeria,in Precambrian Geology of Nigeria pp106

Rajkumar,N., Subramani,T. and Elongo, L. (2010). Groundwater Contamination Due to Municipal Solid Waste Disposal- A GIS Based Study in Erode City. *International Journal of Environmental Sciences, Vol.1, No.1*, pp 39-55

Sunghu, S.H., J.Y. Lee and N. Park, (2007). Use of vertical electrical soundings to delineate seawater intrusion in a coastal area of Byunsan, Korea. *Glabal Jour.Environ. Geol., 52*: 1207-1219.

Szalai, S. and L. Szarka, (2008). On the classification of surface geoelectric arrays. Geophys. Prospect., 56: 159-175.

Satpathy, B.N and Kanungo, D.N (1976). Groundwater Exploration in Hard Rock Terrain. A Case History of Geophysical Prospecting.pp 202.

Sawyer, C.N. and McCarthy, P.L. (1967). Chemistry for Sanitary engineers, 2nd ed. McGraw-Hill, Newyork 518 p.

Shroeter, D.N. (1974). Hydrology of Bauchi Town. Geological Survey of Nig. Vol. 7, No. 1 pp 77-90.

Todd, D.K. (1980). Groundwater hydrology, 2nd ed. Newyork. John Wiley & Sons, 503p.

Tarhule,A.R and Wooming K.O. (1997):The characteristics and the used of shallow wells in a stream fadama;a case study of Northern Nigeria,Journal of applied Geography vol.17 .United Kingdom publication.pp29

World Health Organization (2011). Guidelines for drinking water quality. Fourth Edition. Geneva. Swirtzerland.

Whittington, B.I and Muir, D. (2000).Pressure Acid Leaching of Nickel laterite,A review mineral processing and extraction metarlugy review 21(6) pp527.

Yadav, G.S. (1995). Relating hydraulic and geoelectric parameters of the Jayant aquifer, *India. Jour. Hydrol., 167*: 23-38.

Yang C. and V. Lee, (2002). Using direct current resistivity sounding and geostatistics to aid in hydrogeological studies in the Choshuichi Alluvial Fan, Taiwan. Ground Water,40:pp165-17

Zohdy, A.A.R., Eaton,G.P, and Mabey,D.R (1974). Application of Surface Geophysics to Ground-Water Investigations. 1st Edn., Chapter Book 2, USGS Publication, USA., pp:116

Appendix 1: Sounding Data of the Study Area

VES 1

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	100.00	101.20
2	1.5	0.2	83.40	80.01
3	2	0.2	69.40	70.36
4	3	0.2	55.00	56.33
5	4	0.2	47.60	46.12
6	5	0.2	45.40	45.55
7	6	0.2	44.00	43.33
8	8	0.2	43.20	42.32
9	10	0.2	43.00	41.89
10	15	1.5	46.40	47.64
11	20	1.5	50.40	51.32
12	30	1.5	63.00	63.11
13	40	1.5	76.50	77.12
14	60	1.5	100.00	102.34
15	80	1.5	116.00	117.72
16	100	1.5	132.00	134.11

VES 2

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	272.50	272.89
2	1.5	0.2	250.50	249.88
3	2	0.2	221.00	222.12
4	3	0.2	158.21	157.45
5	4	0.2	110.00	112.22
6	5	0.2	82.00	83.21
7	6	0.2	65.90	66.53
8	8	0.2	57.10	55.43
9	10	0.2	59.50	60.25
10	15	1.5	76.40	77.48
11	20	1.5	95.48	96.77
12	30	1.5	125.54	124.34
13	40	1.5	149.01	149.10
14	60	1.5	177.00	177.90
15	80	1.5	188.50	190.44
16	100	1.5	191.00	192.34

VES3

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m
1	1	0.2	594.10	595.20
2	1.5	0.2	580.00	578.98
3	2	0.2	557.50	557.88
4	3	0.2	408.76	406.79
5	4	0.2	410.00	412.11
6	5	0.2	340.81	342.82
7	6	0.2	285.00	286.44
8	8	0.2	220.00	224.67
9	10	0.2	198.50	200.23
10	15	1.5	180.82	178.99
11	20	1.5	190.50	189.22
12	30	1.5	240.52	242.35
13	40	1.5	298.12	299.66
14	60	1.5	400.00	401.46
15	80	1.5	504.00	506.22
16	100	1.5	589.12	592.44

VES 4

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m
1	1	0.2	676.50	673.30
2	1.5	0.2	536.00	537.90
3	2	0.2	402.20	404.00
4	3	0.2	227.50	226.30
5	4	0.2	150.80	151.10
6	5	0.2	124.90	124.80
7	6	0.2	118.10	118.10
8	8	0.2	124.50	124.40
9	10	0.2	140.10	140.20
10	15	1.5	193.20	194.20
11	20	1.5	256.10	254.80
12	30	1.5	376.20	376.70
13	40	1.5	495.00	494.30
14	60	1.5	714.10	713.50
15	80	1.5	910.00	909.40
16	100	1.5	1080.00	1081.00

VES 5

S/NO	AB/2 (M)	MN/ 2 (M)	Resistivity Data (Ohm-m)	Synthetc Values (Ohm-m)
1	1	0.2	960.70	961.80
2	1.5	0.2	890.80	890.70
3	2	0.2	786.00	787.40
4	3	0.2	549.10	548.60
5	4	0.2	350.50	346.90
6	5	0.2	210.30	211.70
7	6	0.2	130.80	131.50
8	8	0.2	64.00	63.62
9	10	0.2	45.00	45.09
10	15	1.5	39.10	39.01
11	20	1.5	40.10	40.24
12	30	1.5	46.50	46.39
13	40	1.5	55.00	55.05
14	60	1.5	74.55	74.46
15	80	1.5	93.05	93.09
16	100	1.5	110.00	110.00

VES 6

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetc Values (Ohm-m)
1	1	0.2	368.20	368.60
2	1.5	0.2	329.40	329.40
3	2	0.2	281.00	280.40
4	3	0.2	190.00	189.70
5	4	0.2	130.60	131.00
6	5	0.2	99.41	99.73
7	6	0.2	85.00	84.39
8	8	0.2	74.28	74.45
9	10	0.2	74.00	74.06
10	15	1.5	82.00	82.11
11	20	1.5	93.11	92.91
12	30	1.5	116.10	115.80
13	40	1.5	140.10	140.60
14	60	1.5	196.50	196.40
15	80	1.5	257.00	257.20
16	100	1.5	320.00	319.40

VES 7

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	400.00	359.80
2	1.5	0.2	330.10	330.40
3	2	0.2	270.10	269.70
4	3	0.2	209.20	208.90
5	4	0.2	180.00	180.90
6	5	0.2	170.10	169.90
7	6	0.2	168.20	166.80
8	8	0.2	170.10	171.00
9	10	0.2	180.20	180.70
10	15	1.5	210.20	209.80
11	20	1.5	234.90	234.10
12	30	1.5	207.20	207.40
13	40	1.5	237.93	237.93
14	60	1.5	297.10	297.10
15	80	1.5	297.10	297.10
16	100	1.5	340.10	340.20

VES 8

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	106.40	106.20
2	1.5	0.2	90.57	90.33
3	2	0.2	75.40	75.91
4	3	0.2	58.20	58.07
5	4	0.2	50.50	50.36
6	5	0.2	47.16	47.05
7	6	0.2	45.52	45.54
8	8	0.2	44.51	44.45
9	10	0.2	44.00	44.33
10	15	1.5	45.60	45.54
11	20	1.5	48.10	47.94
12	30	1.5	55.00	55.11
13	40	1.5	65.00	64.85
14	60	1.5	89.10	89.49
15	80	1.5	117.10	117.30
16	100	1.5	146.90	146.10

VES 9

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	106.00	105.90
2	1.5	0.2	98.00	98.36
3	2	0.2	87.00	87.18
4	3	0.2	65.00	64.47
5	4	0.2	48.00	47.89
6	5	0.2	37.80	37.87
7	6	0.2	32.00	32.23
8	8	0.2	27.40	27.42
9	10	0.2	26.00	25.90
10	15	1.5	25.50	25.40
11	20	1.5	26.30	26.28
12	30	1.5	30.00	30.13
13	40	1.5	36.00	35.97
14	60	1.5	51.00	50.85
15	80	1.5	67.00	67.21
16	100	1.5	84.00	83.85

VES 10

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	251.50	251.80
2	1.5	0.2	249.00	248.60
3	2	0.2	242.50	242.90
4	3	0.2	225.00	225.20
5	4	0.2	203.00	202.40
6	5	0.2	180.00	179.40
7	6	0.2	159.00	159.20
8	8	0.2	131.00	131.10
9	10	0.2	116.00	116.30
10	15	1.5	107.50	106.90
11	20	1.5	110.50	110.20
12	30	1.5	128.00	128.40
13	40	1.5	155.00	155.50
14	60	1.5	222.00	222.40
15	80	1.5	296.00	294.60
16	100	1.5	368.00	367.50

VES 11

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	311.00	311.20
2	1.5	0.2	269.10	268.70
3	2	0.2	225.00	225.00
4	3	0.2	160.50	160.70
5	4	0.2	124.80	125.00
6	5	0.2	105.30	104.50
7	6	0.2	90.65	91.16
8	8	0.2	74.13	74.47
9	10	0.2	65.15	65.02
10	15	1.5	56.02	56.17
11	20	1.5	55.90	55.99
12	30	1.5	64.50	64.40
13	40	1.5	78.55	78.30
14	60	1.5	112.80	112.50
15	80	1.5	148.20	149.00
16	100	1.5	186.00	185.70

VES 12

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	249.00	249.20
2	1.5	0.2	230.00	229.70
3	2	0.2	209.00	209.20
4	3	0.2	179.00	178.20
5	4	0.2	160.00	160.60
6	5	0.2	150.00	150.40
7	6	0.2	144.00	143.60
8	8	0.2	134.00	133.70
9	10	0.2	125.00	125.00
10	15	1.5	105.00	104.70
11	20	1.5	88.00	88.48
12	30	1.5	69.00	68.67
13	40	1.5	58.00	58.00
14	60	1.5	46.00	46.21
15	80	1.5	40.00	39.73
16	100	1.5	36.00	36.10

VES 13

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	143.00	144.30
2	1.5	0.2	144.01	145.10
3	2	0.2	146.92	146.90
4	3	0.2	158.45	159.70
5	4	0.2	173.75	173.02
6	5	0.2	190.51	190.97
7	6	0.2	208.40	208.00
8	8	0.2	236.54	236.57
9	10	0.2	252.50	252.51
10	15	1.5	264.20	264.35
11	20	1.5	242.00	242.84
12	30	1.5	180.93	180.33
13	40	1.5	136.00	136.93
14	60	1.5	88.08	88.19
15	80	1.5	72.00	72.66
16	100	1.5	69.00	69.23

VES 14

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	723.70	726.60
2	1.5	0.2	667.00	668.40
3	2	0.2	590.50	587.80
4	3	0.2	418.00	415.110
5	4	0.2	281.50	282.60
6	5	0.2	200.50	201.80
7	6	0.2	160.00	159.00
8	8	0.2	133.20	133.50
9	10	0.2	140.50	140.20
10	15	1.5	190.20	189.80
11	20	1.5	248.90	247.60
12	30	1.5	359.20	360.40
13	40	1.5	464.00	464.60
14	60	1.5	644.20	644.20
15	80	1.5	786.00	785.20
16	100	1.5	890.00	889.90

VES 15

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	454.40	455.90
2	1.5	0.2	417.00	418.40
3	2	0.2	367.00	365.90
4	3	0.2	248.00	247.00
5	4	0.2	150.30	150.70
6	5	0.2	90.07	88.86
7	6	0.2	52.95	53.36
8	8	0.2	25.00	25.11
9	10	0.2	18.00	17.86
10	15	1.5	15.60	15.56
11	20	1.5	15.80	15.88
12	30	1.5	17.80	17.86
13	40	1.5	21.10	21.00
14	60	1.5	29.50	29.16
15	80	1.5	38.00	38.18
16	100	1.5	47.00	47.30

VES 16

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	1989.00	1980.10
2	1.5	0.2	1617.70	1634.70
3	2	0.2	1316.60	1306.90
4	3	0.2	872.20	873.70
5	4	0.2	658.70	658.90
6	5	0.2	540.20	538.80
7	6	0.2	456.20	456.60
8	8	0.2	340.70	341.90
9	10	0.2	272.00	271.30
10	15	1.5	220.00	219.70
11	20	1.5	245.00	245.90
12	30	1.5	333.00	333.10
13	40	1.5	410.00	408.80
14	60	1.5	510.90	509.80
15	80	1.5	553.70	554.80
16	100	1.5	559.30	559.40

VES 17

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	900.00	899.30
2	1.5	0.2	840.40	840.70
3	2	0.2	750.50	753.50
4	3	0.2	546.50	544.60
5	4	0.2	354.00	355.10
6	5	0.2	224.30	220.50
7	6	0.2	133.90	136.20
8	8	0.2	60.20	60.03
9	10	0.2	37.60	37.53
10	15	1.5	29.40	29.37
11	20	1.5	30.00	29.98
12	30	1.5	34.44	34.46
13	40	1.5	41.14	41.36
14	60	1.5	58.50	58.69
15	80	1.5	77.50	77.45
16	100	1.5	97.00	96.36

VES 18

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	579.00	579.60
2	1.5	0.2	552.40	554.00
3	2	0.2	516.00	515.30
4	3	0.2	420.40	418.70
5	4	0.2	330.00	328.70
6	5	0.2	260.80	262.50
7	6	0.2	220.10	220.50
8	8	0.2	186.80	186.40
9	10	0.2	188.00	187.40
10	15	1.5	234.50	236.30
11	20	1.5	298.60	296.80
12	30	1.5	484.20	405.70
13	40	1.5	495.00	492.70
14	60	1.5	610.00	611.30
15	80	1.5	676.00	676.70
16	100	1.5	708.90	108.20

VES 19

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	100.30	995.60
2	1.5	0.2	548.00	552.10
3	2	0.2	316.60	316.20
4	3	0.2	170.20	169.40
5	4	0.2	148.20	147.50
6	5	0.2	147.50	148.40
7	6	0.2	155.20	155.60
8	8	0.2	178.50	178.70
9	10	0.2	209.00	208.80
10	15	1.5	297.10	296.50
11	20	1.5	390.00	386.50
12	30	1.5	554.00	554.90
13	40	1.5	700.00	703.80
14	60	1.5	938.10	941.00
15	80	1.5	1100.40	1102.70
16	100	1.5	1204.20	1199.60

VES 20

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	352.00	351.70
2	1.5	0.2	326.20	327.20
3	2	0.2	296.20	287.40
4	3	0.2	225.20	224.80
5	4	0.2	170.10	169.10
6	5	0.2	135.10	135.80
7	6	0.2	115.50	114.40
8	8	0.2	98.58	98.82
9	10	0.2	97.66	100.43
10	15	1.5	115.10	115.30
11	20	1.5	141.00	141.30
12	30	1.5	208.00	208.90
13	40	1.5	277.10	279.40
14	60	1.5	414.40	416.60
15	80	1.5	550.10	560.40
16	100	1.5	690.40	686.88

VES 21

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	326.10	326.50
2	1.5	0.2	253.10	252.80
3	2	0.2	196.10	195.50
4	3	0.2	138.90	139.80
5	4	0.2	122.05	121.50
6	5	0.2	115.25	115.00
7	6	0.2	112.25	112.30
8	8	0.2	110.00	110.30
9	10	0.2	112.86	110.10
10	15	1.5	112.86	112.80
11	20	1.5	119.48	118.80
12	30	1.5	139.24	139.60
13	40	1.5	170.14	169.40
14	60	1.5	244.00	242.60
15	80	1.5	320.18	321.60
16	100	1.5	400.21	401.40

VES 22

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	220.00	219.10
2	1.5	0.2	175.70	176.70
3	2	0.2	145.50	145.70
4	3	0.2	116.50	115.70
5	4	0.2	106.00	106.30
6	5	0.2	105.10	104.40
7	6	0.2	105.50	105.60
8	8	0.2	112.50	113.30
9	10	0.2	125.50	125.60
10	15	1.5	168.20	168.60
11	20	1.5	220.90	220.00
12	30	1.5	325.30	328.30
13	40	1.5	438.00	437.50
14	60	1.5	659.00	655.40
15	80	1.5	874.00	872.50
16	100	1.5	1090.20	1088.40

VES 23

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	125.08	125.10
2	1.5	0.2	120.10	120.30
3	2	0.2	110.00	110.50
4	3	0.2	92.56	92.90
5	4	0.2	73.58	73.50
6	5	0.2	62.12	62.60
7	6	0.2	54.35	54.60
8	8	0.2	48.14	48.80
9	10	0.2	44.81	44.15
10	15	1.5	42.92	43.55
11	20	1.5	43.98	43.62
12	30	1.5	50.20	48.70
13	40	1.5	60.21	58.24
14	60	1.5	83.02	82.80
15	80	1.5	109.78	109.60
16	100	1.5	138.32	137.00

VES 24

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	122.00	121.70
2	1.5	0.2	112.30	112.70
3	2	0.2	100.00	100.40
4	3	0.2	74.06	73.94
5	4	0.2	53.62	53.47
6	5	0.2	40.52	40.54
7	6	0.2	33.00	33.06
8	8	0.2	26.52	26.55
9	10	0.2	24.53	24.46
10	15	1.5	22.52	23.48
11	20	1.5	21.69	21.86
12	30	1.5	18.99	18.00
13	40	1.5	16.88	16.15
14	60	1.5	14.48	14.26
15	80	1.5	13.40	13.83
16	100	1.5	12.39	12.42

VES 25

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	106.48	106.40
2	1.5	0.2	108.00	108.10
3	2	0.2	112.38	112.10
4	3	0.2	120.01	120.10
5	4	0.2	128.32	1028.00
6	5	0.2	136.16	136.30
7	6	0.2	146.00	146.70
8	8	0.2	158.12	158.80
9	10	0.2	172.45	172.10
10	15	1.5	200.75	200.50
11	20	1.5	233.93	233.40
12	30	1.5	418.52	418.40
13	40	1.5	596.31	596.40
14	60	1.5	596.31	600.00
15	80	1.5	754.30	751.50
16	100	1.5	876.80	877.70

VES 26

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	456.00	455.60
2	1.5	0.2	378.10	377.60
3	2	0.2	290.10	291.00
4	3	0.2	160.00	159.70
5	4	0.2	98.70	98.71
6	5	0.2	80.49	80.32
7	6	0.2	80.59	81.03
8	8	0.2	100.00	100.10
9	10	0.2	124.50	124.00
10	15	1.5	183.10	184.80
11	20	1.5	248.10	244.60
12	30	1.5	360.00	360.70
13	40	1.5	470.30	471.40
14	60	1.5	674.00	674.20
15	80	1.5	850.20	850.40
16	100	1.5	1000.10	999.70

VES 27

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	210.00	210.50
2	1.5	0.2	137.00	136.20
3	2	0.2	95.00	95.17
4	3	0.2	66.50	66.59
5	4	0.2	60.00	60.29
6	5	0.2	58.50	58.72
7	6	0.2	59.00	58.50
8	8	0.2	60.00	59.74
9	10	0.2	62.20	62.36
10	15	1.5	73.00	73.13
11	20	1.5	88.00	87.69
12	30	1.5	120.00	120.40
13	40	1.5	154.00	153.70
14	60	1.5	220.00	219.90
15	80	1.5	288.00	287.50
16	100	1.5	356.00	356.40

VES 28

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	256.00	255.90
2	1.5	0.2	241.00	240.00
3	2	0.2	215.50	216.50
4	3	0.2	160.00	160.10
5	4	0.2	110.00	110.40
6	5	0.2	77.00	76.03
7	6	0.2	55.00	55.50
8	8	0.2	40.00	39.96
9	10	0.2	39.80	39.73
10	15	1.5	54.00	54.08
11	20	1.5	71.00	71.19
12	30	1.5	105.00	105.30
13	40	1.5	139.00	139.10
14	60	1.5	206.00	206.60
15	80	1.5	274.00	274.30
16	100	1.5	344.00	342.20

VES 29

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	198.30	198.30
2	1.5	0.2	183.10	183.20
3	2	0.2	169.20	169.10
4	3	0.2	150.80	150.50
5	4	0.2	139.80	140.90
6	5	0.2	136.00	135.40
7	6	0.2	132.00	131.80
8	8	0.2	126.40	126.00
9	10	0.2	120.00	120.30
10	15	1.5	104.80	105.20
11	20	1.5	92.08	82.05
12	30	1.5	79.64	79.13
13	40	1.5	80.86	81.36
14	60	1.5	106.00	106.10
15	80	1.5	139.00	138.60
16	100	1.5	172.40	172.50

VES 30

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	140.90	140.70
2	1.5	0.2	114.00	113.90
3	2	0.2	90.84	91.14
4	3	0.2	59.34	59.20
5	4	0.2	45.55	45.48
6	5	0.2	40.02	39.98
7	6	0.2	37.50	37.67
8	8	0.2	36.00	36.09
9	10	0.2	35.79	35.76
10	15	1.5	36.48	36.58
11	20	1.5	39.03	38.79
12	30	1.5	46.70	46.49
13	40	1.5	57.40	57.36
14	60	1.5	82.81	83.25
15	80	1.5	110.00	110.60
16	100	1.5	139.00	138.10

VES 31

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	310.00	309.20
2	1.5	0.2	281.10	281.10
3	2	0.2	245.60	247.10
4	3	0.2	185.60	185.20
5	4	0.2	142.20	141.70
6	5	0.2	112.30	112.50
7	6	0.2	91.65	91.83
8	8	0.2	65.30	65.09
9	10	0.2	50.56	50.76
10	15	1.5	42.80	42.56
11	20	1.5	47.07	47.21
12	30	1.5	57.50	57.68
13	40	1.5	63.45	63.36
14	60	1.5	63.51	63.57
15	80	1.5	56.03	55.7
16	100	1.5	45.02	45.20

VES 32

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	271.00	271.30
2	1.5	0.2	239.50	239.00
3	2	0.2	199.50	199.00
4	3	0.2	127.90	128.70
5	4	0.2	90.10	90.02
6	5	0.2	76.94	76.64
7	6	0.2	76.94	76.96
8	8	0.2	93.04	92.62
9	10	0.2	112.00	122.90
10	15	1.5	162.00	162.70
11	20	1.5	208.70	208.60
12	30	1.5	290.30	287.70
13	40	1.5	450.00	350.40
14	60	1.5	430.90	430.70
15	80	1.5	460.90	462.00
16	100	1.5	459.10	458.50

VES 33

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	299.00	299.50
2	1.5	0.2	255.90	255.60
3	2	0.2	203.50	203.10
4	3	0.2	112.90	113.70
5	4	0.2	64.88	64.61
6	5	0.2	44.91	44.70
7	6	0.2	39.66	39.55
8	8	0.2	44.57	44.39
9	10	0.2	53.46	53.70
10	15	1.5	76.56	77.06
11	20	1.5	98.09	98.06
12	30	1.5	132.20	132.40
13	40	1.5	157.80	157.10
14	60	1.5	182.10	182.20
15	80	1.5	183.50	183.80
16	100	1.5	172.00	171.80

VES 34

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	79.10	79.19
2	1.5	0.2	76.37	76.23
3	2	0.2	74.21	74.18
4	3	0.2	72.78	72.96
5	4	0.2	72.00	72.06
6	5	0.2	70.04	69.74
7	6	0.2	66.31	66.37
8	8	0.2	59.00	59.07
9	10	0.2	53.01	52.98
10	15	1.5	43.90	43.89
11	20	1.5	39.04	39.13
12	30	1.5	32.58	32.52
13	40	1.5	27.09	27.05
14	60	1.5	19.67	19.66
15	80	1.5	16.00	16.06
16	100	1.5	14.46	14.41

VES 35

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	70.10	70.10
2	1.5	0.2	74.39	72.40
3	2	0.2	76.00	75.90
4	3	0.2	80.50	80.30
5	4	0.2	82.43	82.07
6	5	0.2	88.00	89ss.31
7	6	0.2	93.00	90.15
8	8	0.2	105.21	105.70
9	10	0.2	119.48	119.40
10	15	1.5	166.11	166.30
11	20	1.5	216.11	216.80
12	30	1.5	293.76	293.90
13	40	1.5	370.04	370.90
14	60	1.5	490.04	490.90
15	80	1.5	578.00	578.40
16	100	1.5	650.00	650.20

VES 36

S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic Values (Ohm-m)
1	1	0.2	364.00	363.80
2	1.5	0.2	363.00	361.70
3	2	0.2	358.00	357.90
4	3	0.2	343.50	344.50
5	4	0.2	324.30	324.30
6	5	0.2	300.30	229.90
7	6	0.2	272.88	274.20
8	8	0.2	226.91	226.90
9	10	0.2	198.15	198.90
10	15	1.5	178.42	178.10
11	20	1.5	192.50	192.30
12	30	1.5	234.52	234.90
13	40	1.5	280.00	280.10
14	60	1.5	336.22	336.30
15	80	1.5	368..80	368.30
16	100	1.5	390.90	390.70

VES 37

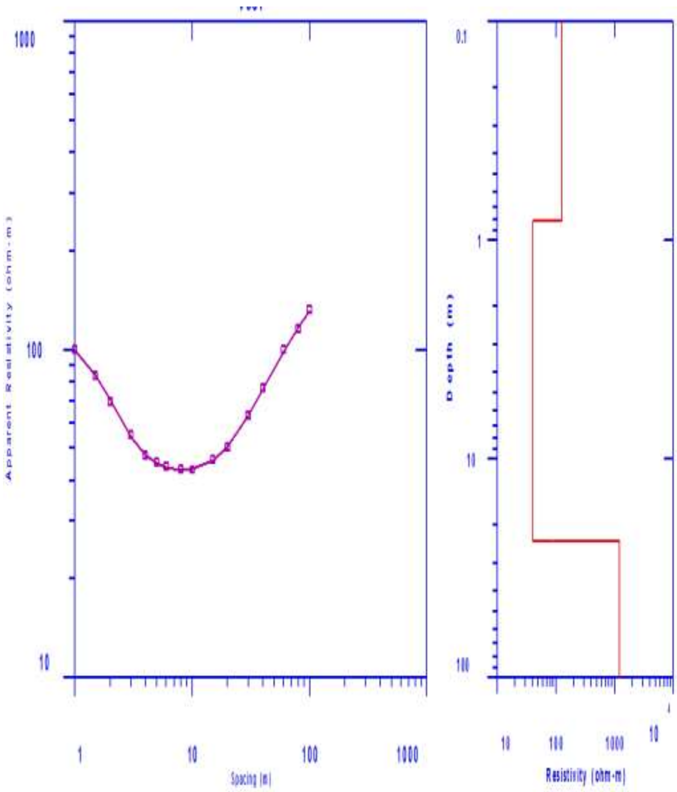
S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic (Ohm-m)	Values
1	1	0.2	39.30	39.02	
2	1.5	0.2	37.00	37.57	
3	2	0.2	33.00	33.46	
4	3	0.2	26.00	26.08	
5	4	0.2	21.20	21.52	
6	5	0.2	17.00	17.46	
7	6	0.2	14.91	14.52	
8	8	0.2	12.40	12.41	
9	10	0.2	11.70	11.19	
10	15	1.5	11.40	11.37	
11	20	1.5	12.05	12.02	
12	30	1.5	14.20	14.33	
13	40	1.5	17.50	17.58	
14	60	1.5	25.45	25.42	
15	80	1.5	34.00	33.76	
16	100	1.5	42.04	42.17	

VES 38

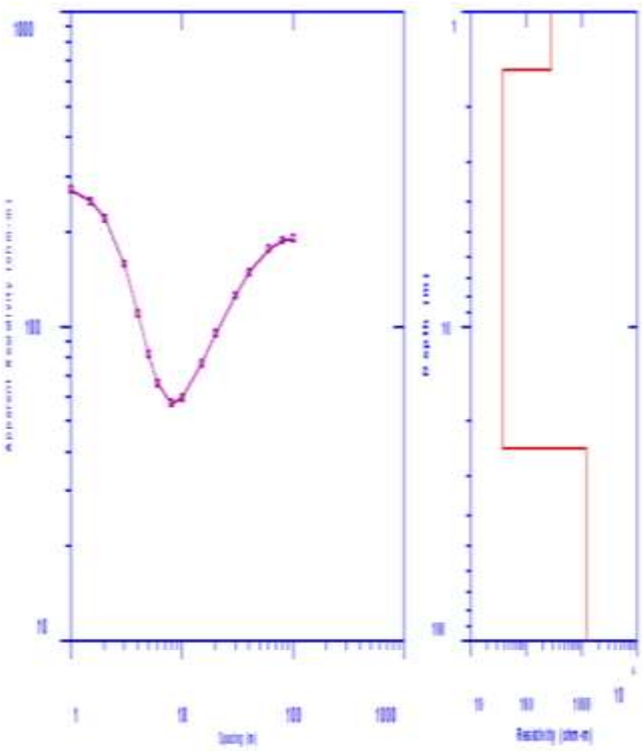
S/NO	AB/2 (M)	MN/2 (M)	Resistivity Data (Ohm-m)	Synthetic (Ohm-m)	Values
1	1	0.2	620.73	620.90	
2	1.5	0.2	580.00	444.40	
3	2	0.2	530.28	432.30	
4	3	0.2	430.94	430.80	
5	4	0.2	349.88	349.70	
6	5	0.2	300.42	300.70	
7	6	0.2	262.98	262.90	
8	8	0.2	229.83	229.10	
9	10	0.2	217.72	217.10	
10	15	1.5	223.82	223..90	
11	20	1.5	250.56	251.30	
12	30	1.5	330.16	334.00	
13	40	1.5	423.87	422.40	
14	60	1.5	605.21	409.40	
15	80	1.5	800.80	802.10	
16	100	1.5	1000.90	994.80	

Appendix 2: Smoothened Curve Types of the Study Area

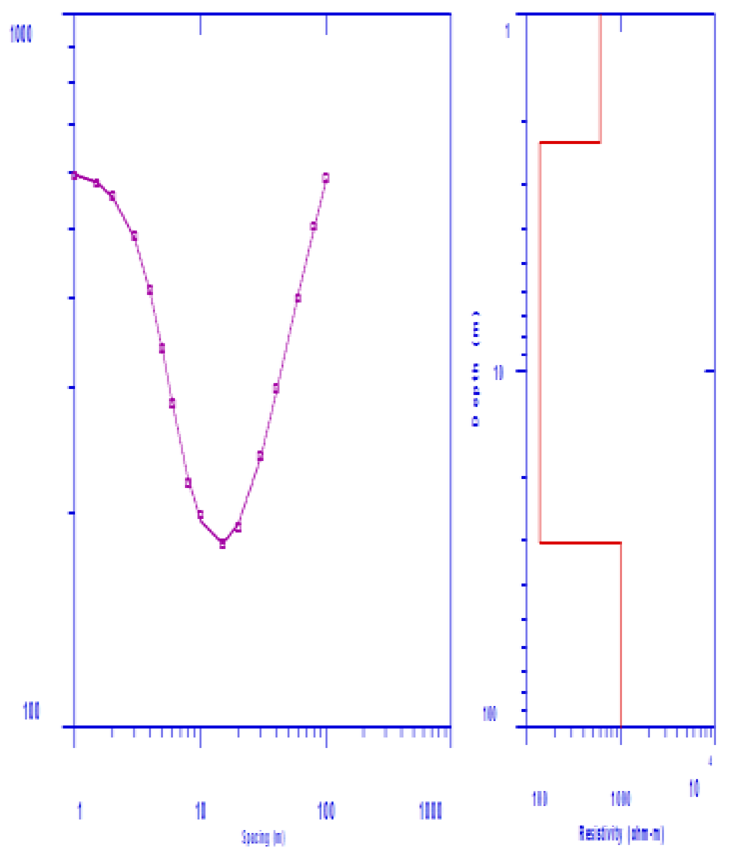
VES 1



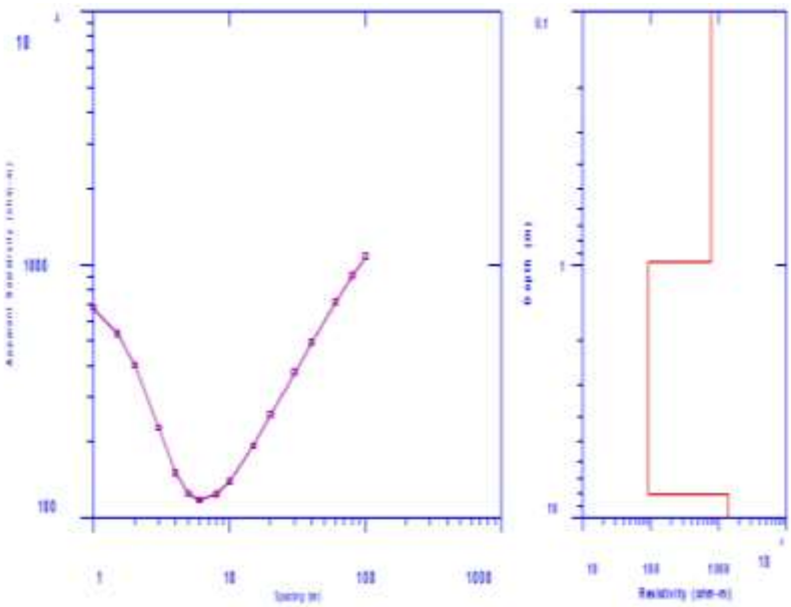
VES 2



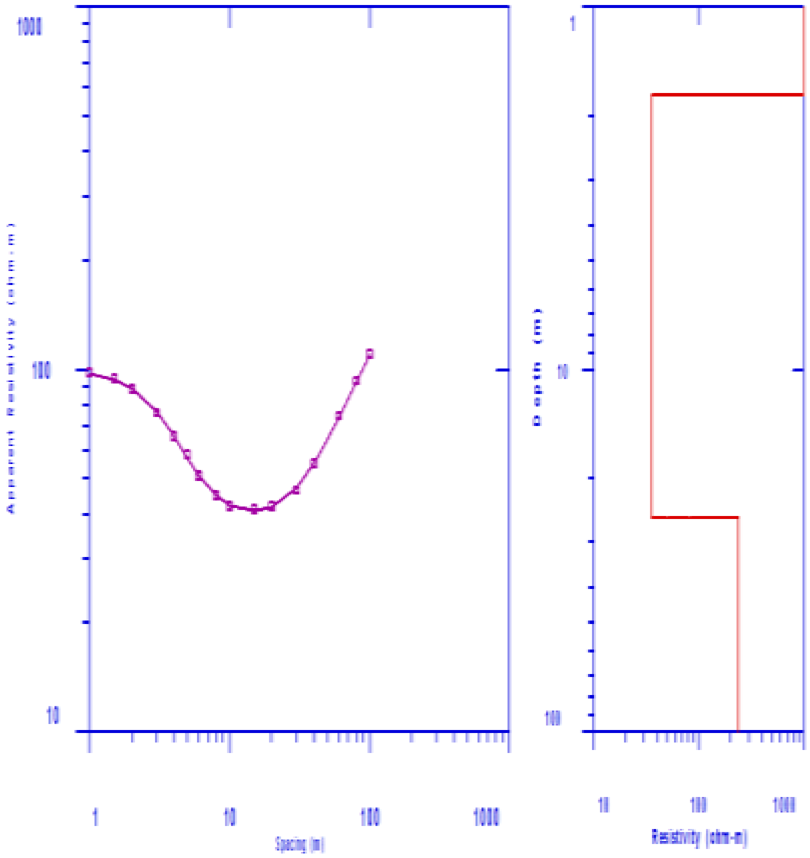
VES 3


1000
100
1
10
100
1000
Spacing (m)
Depth (m)
Resistivity (ohm-m)

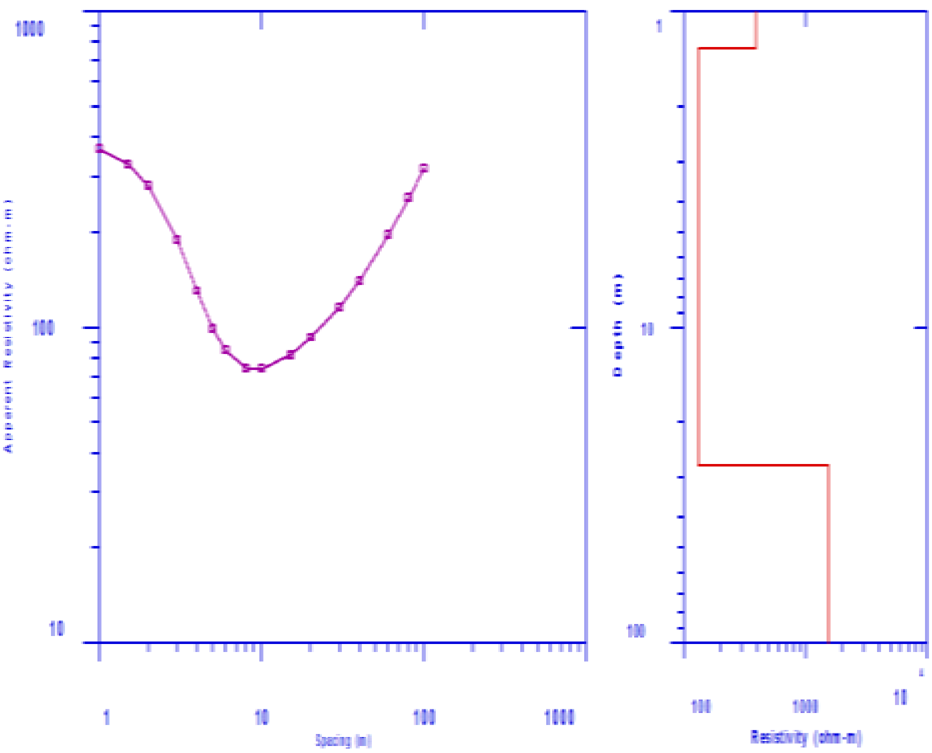
VES 4


1000
100
1
10
100
1000

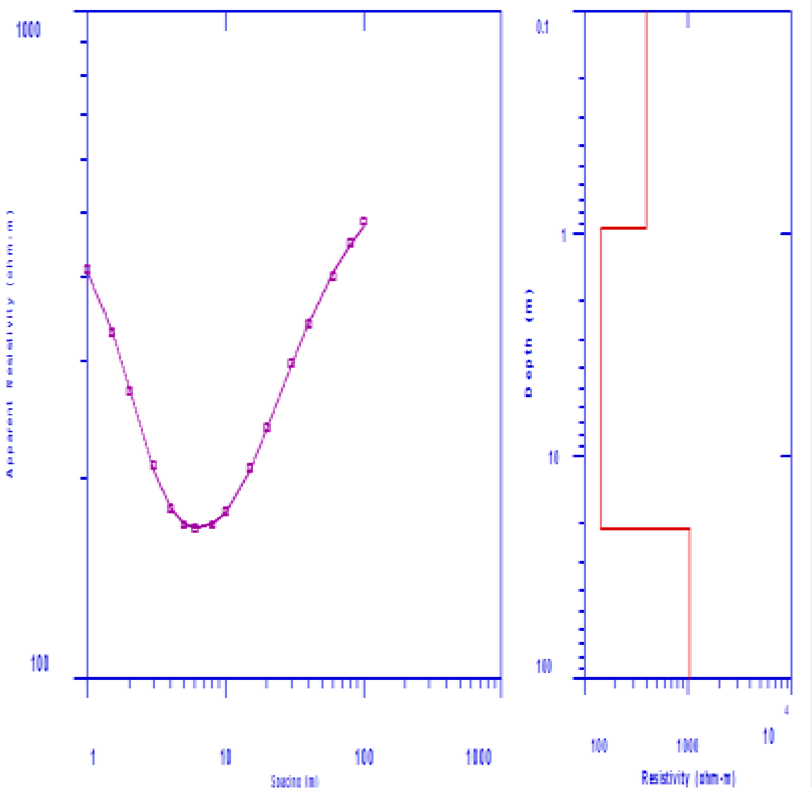
VES 5


1000
100
10
Apparent Resistivity (ohm.m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

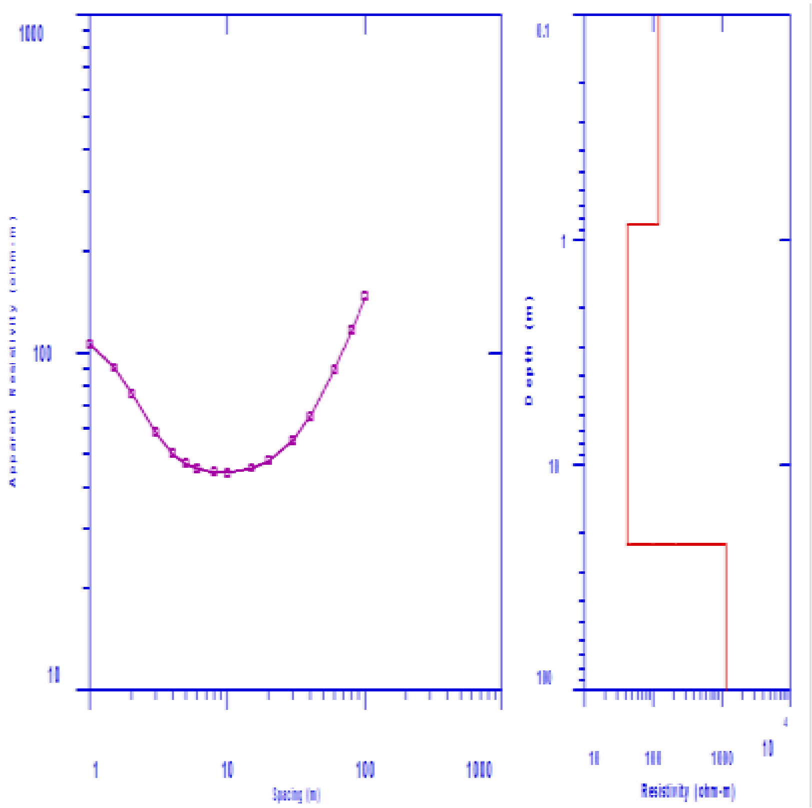
VES 6


1000
100
10
Apparent Resistivity (ohm.m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
100
1000
10
Resistivity (ohm-m)

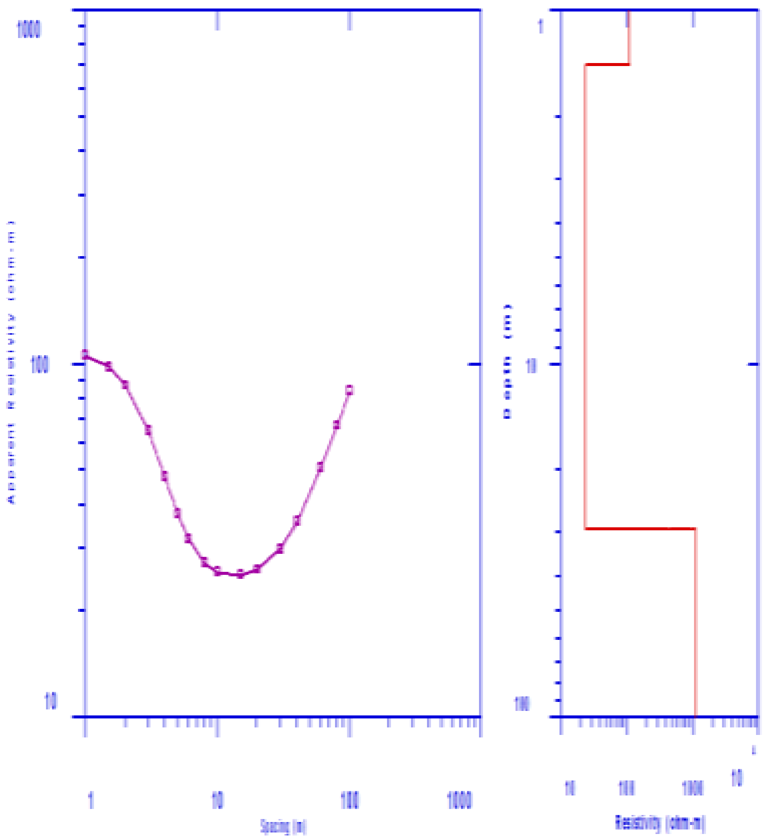
VES 7



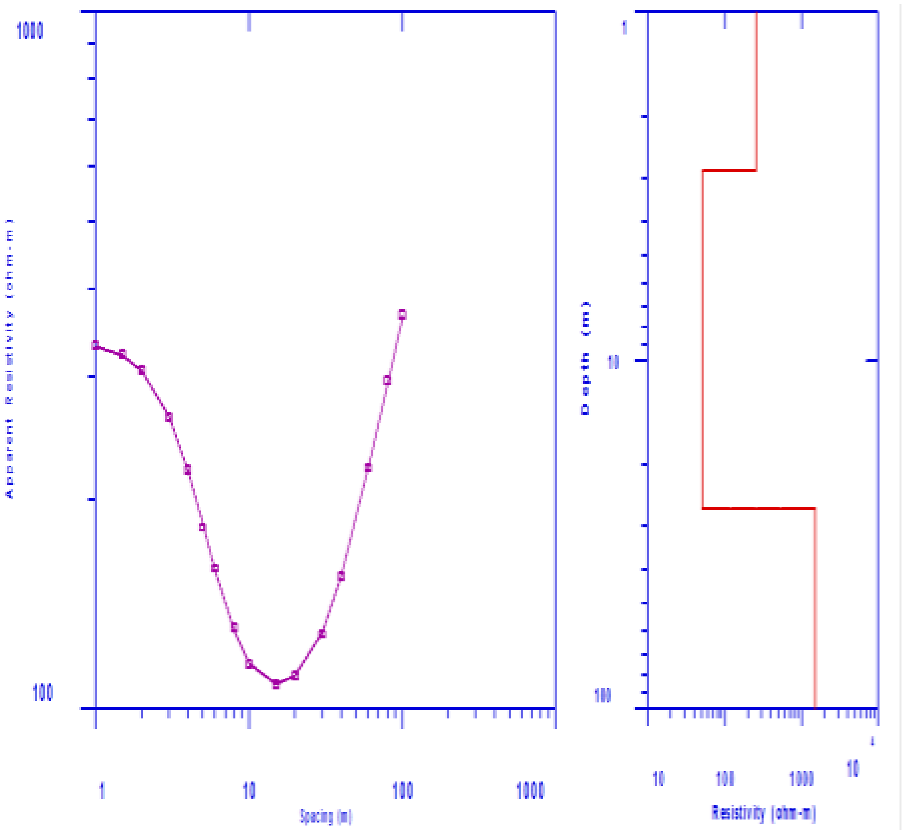
VES 8



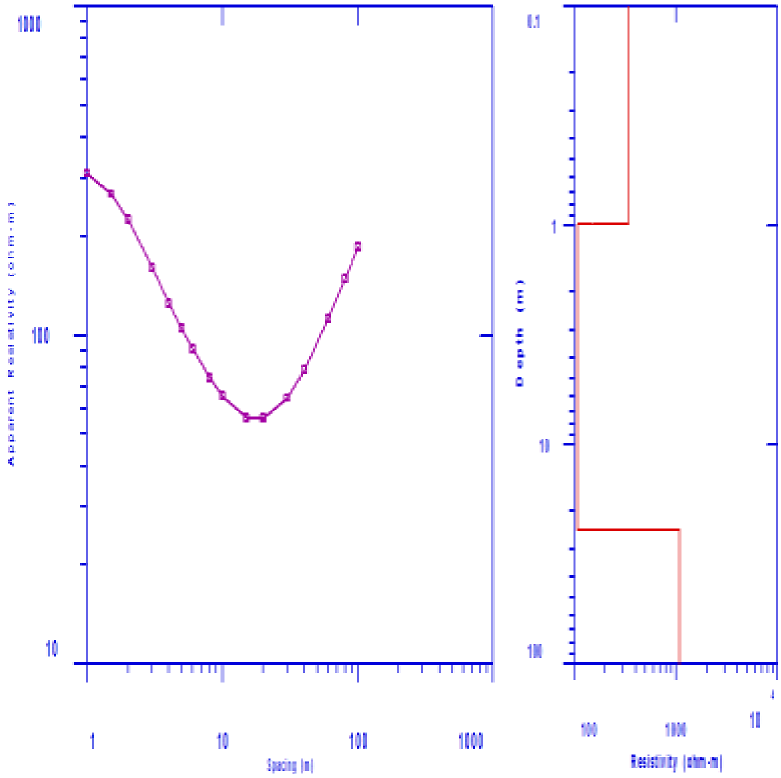
VES 9


1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
Depth (m)
Resistivity (ohm-m)

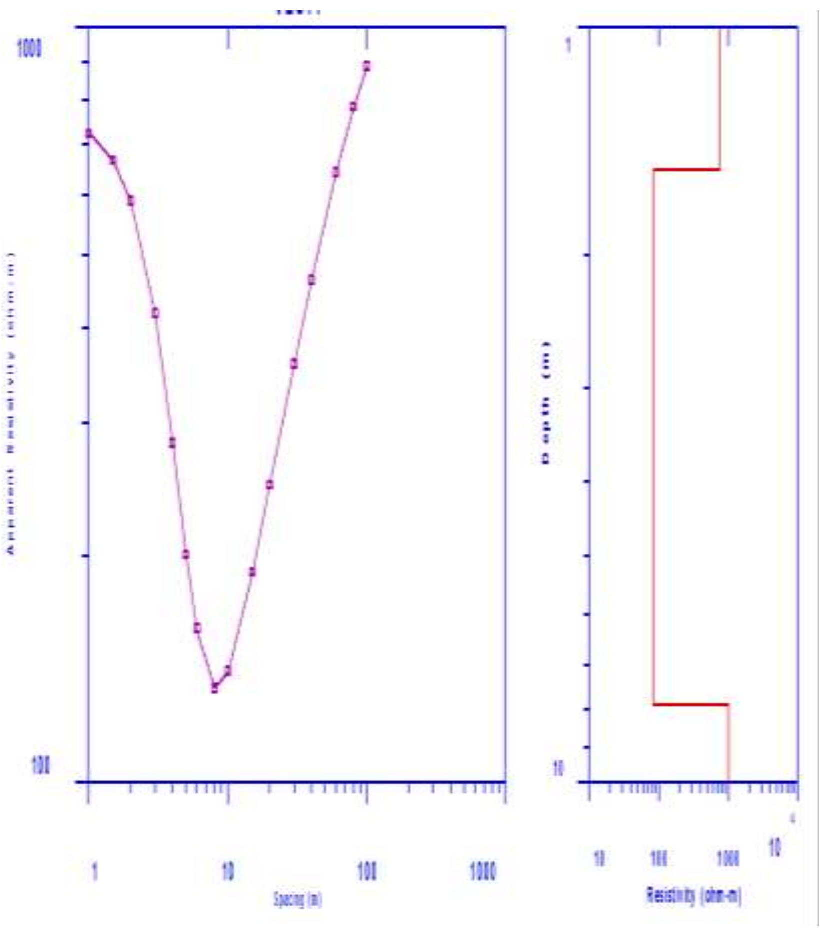
VES 10


1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
Depth (m)
Resistivity (ohm-m)

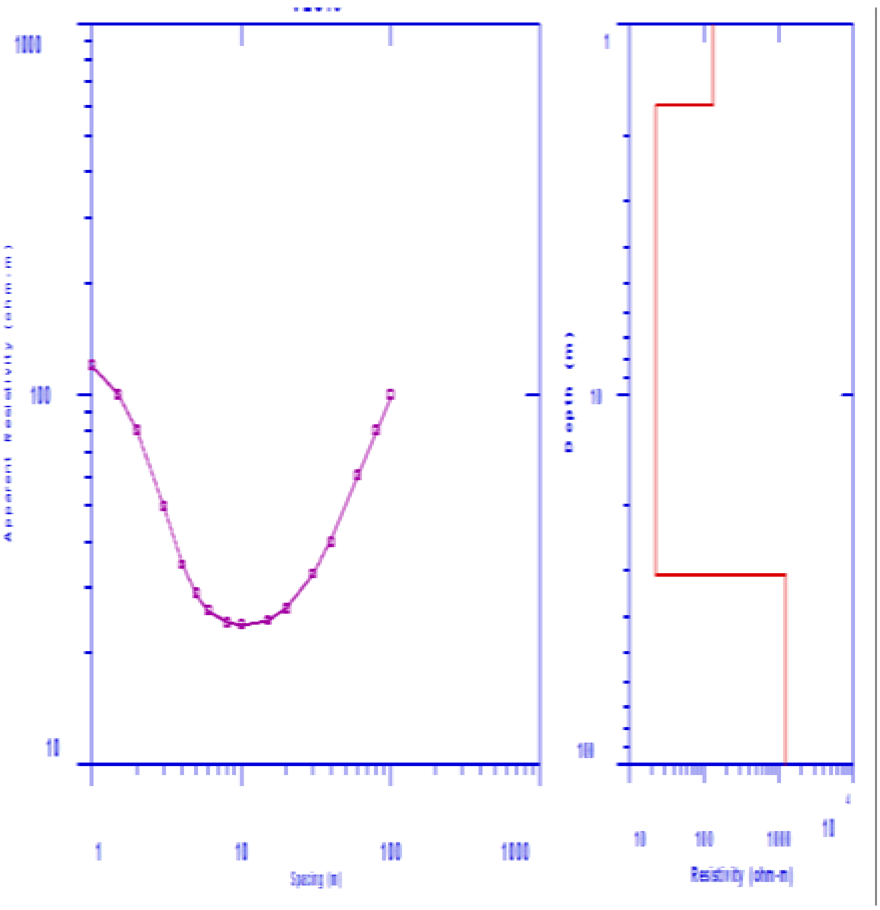
VES 11


1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

VES 14

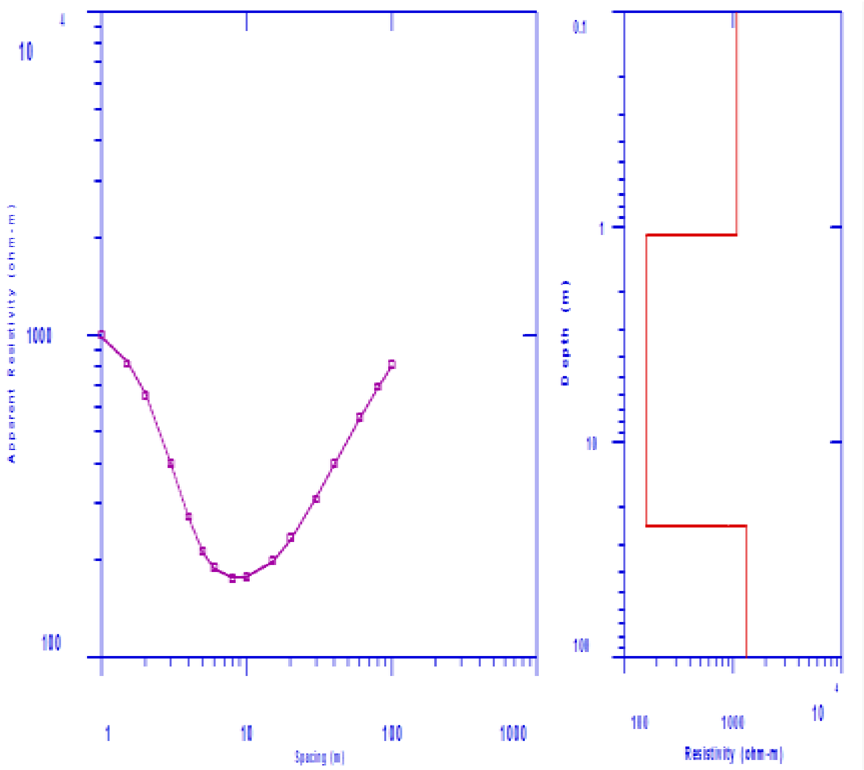

1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
Depth (m)
10
100
1000
Resistivity (ohm-m)

VES 15



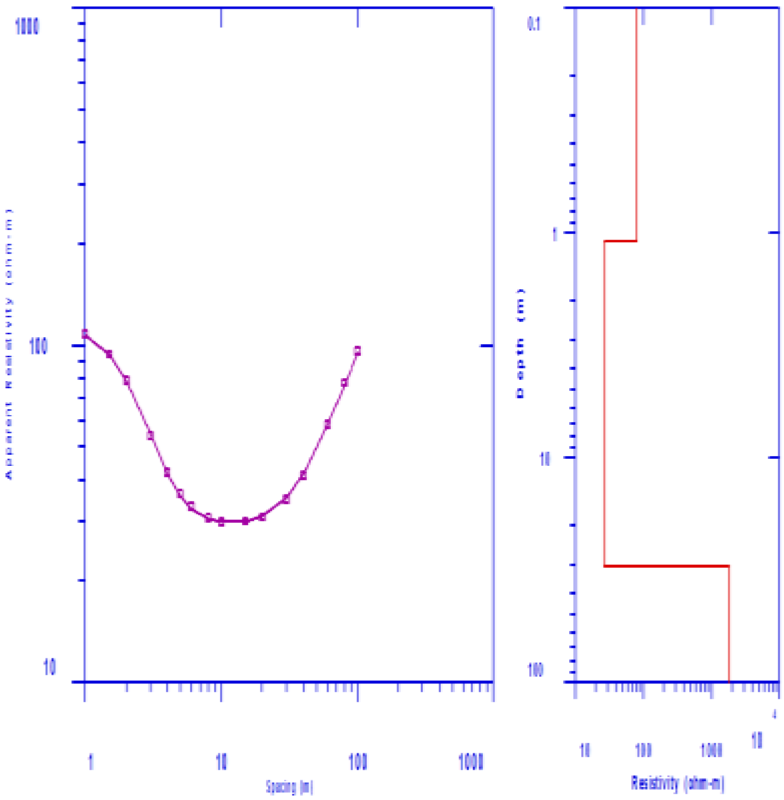
1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

VES 16



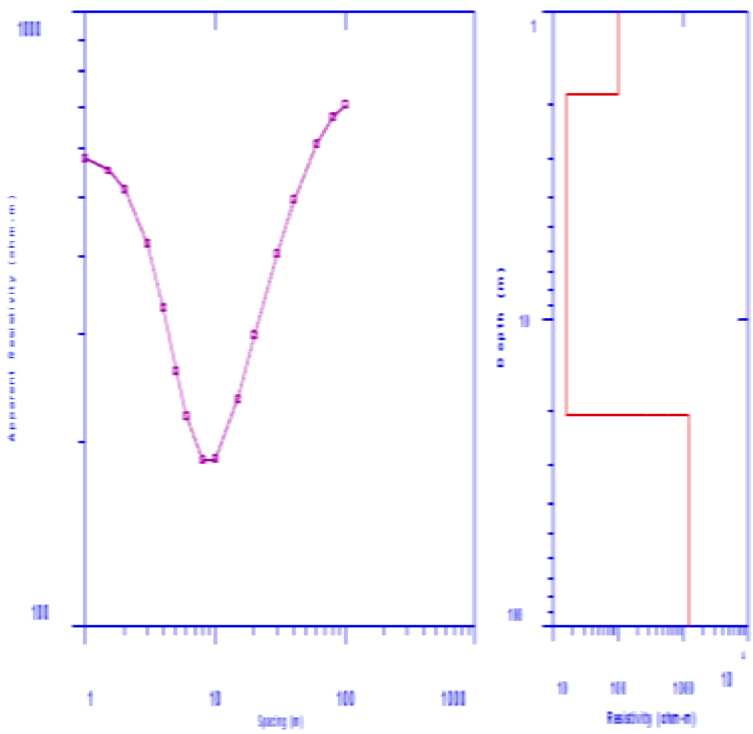
1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

VES 17



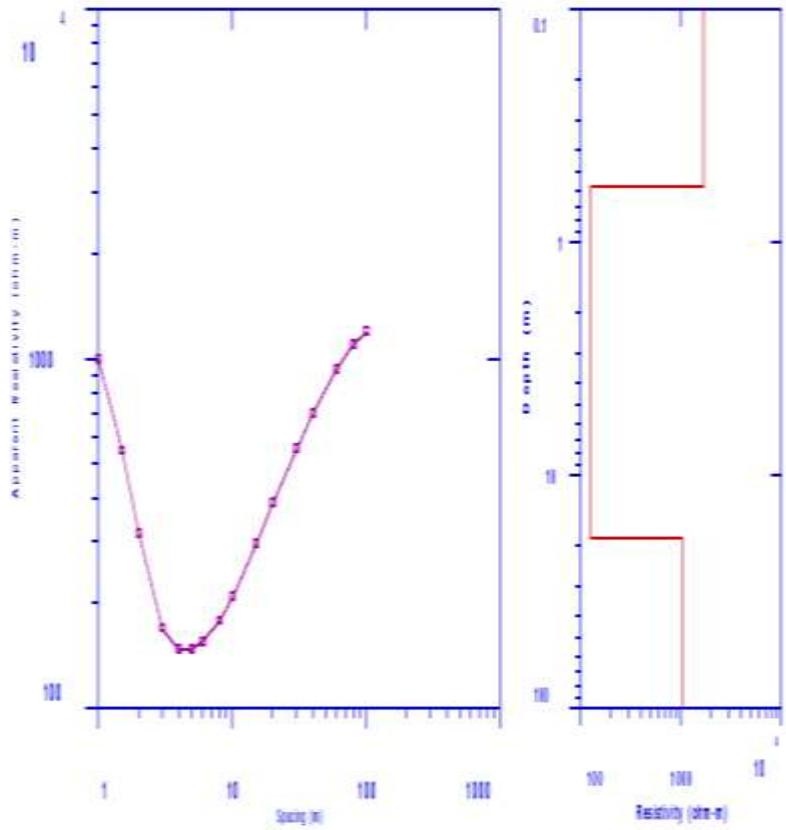
1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

VES 18



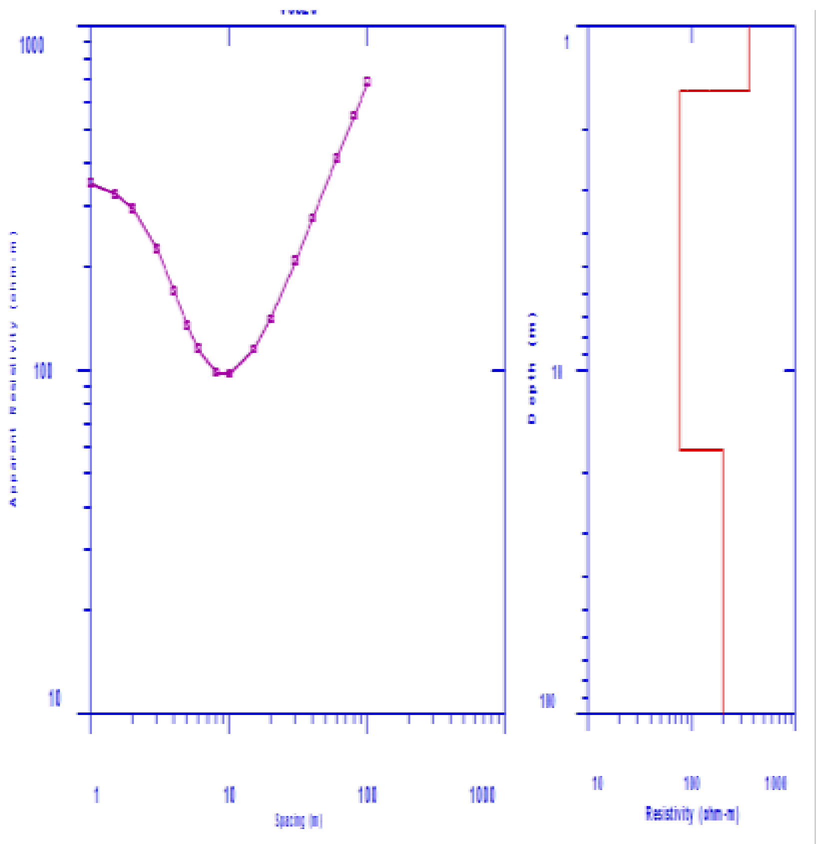
1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

VES 19



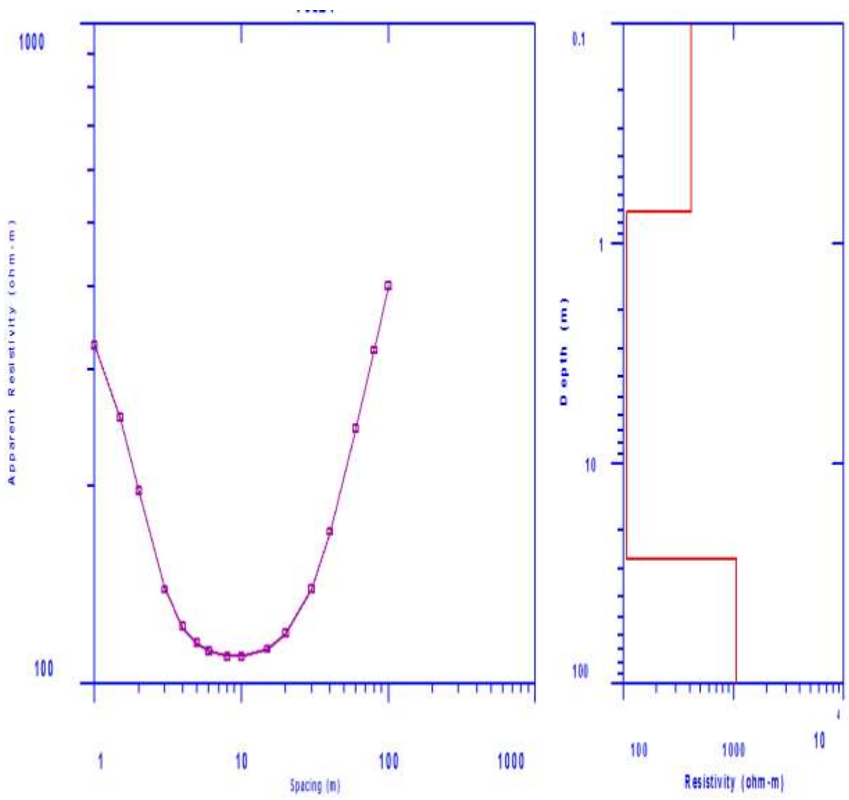
10
1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

VES 20



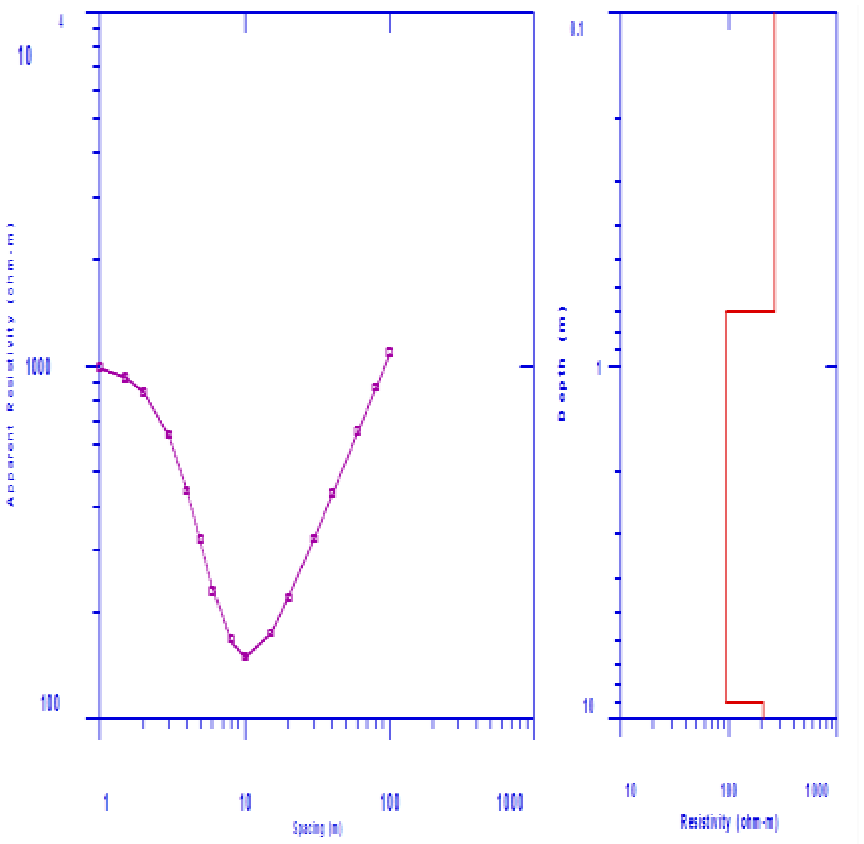
1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

VES 21



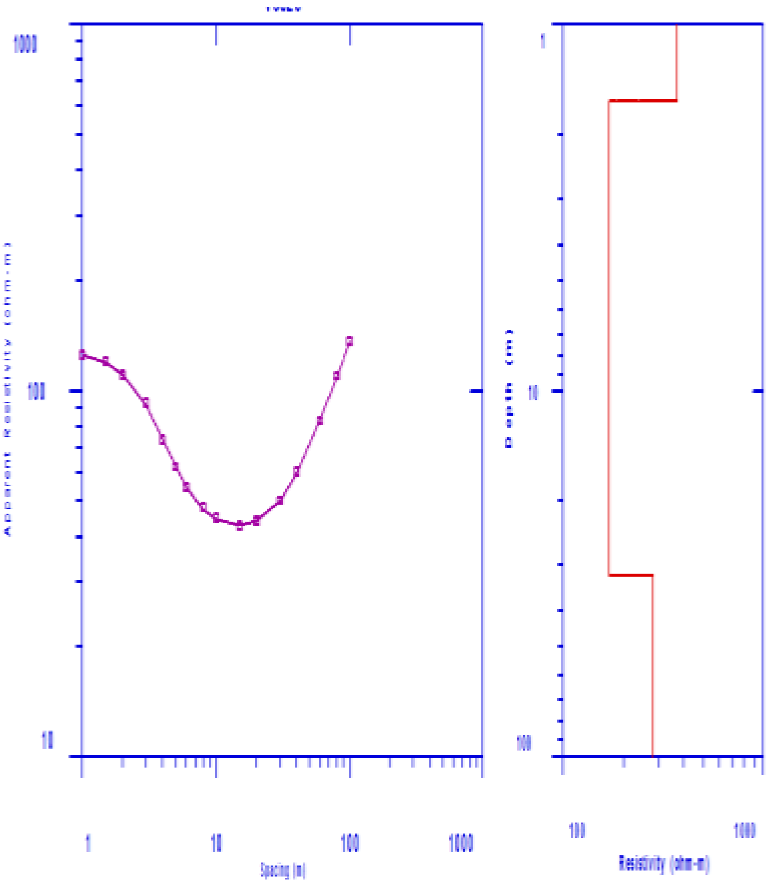
1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
100
1000
10
Resistivity (ohm-m)

VES 22

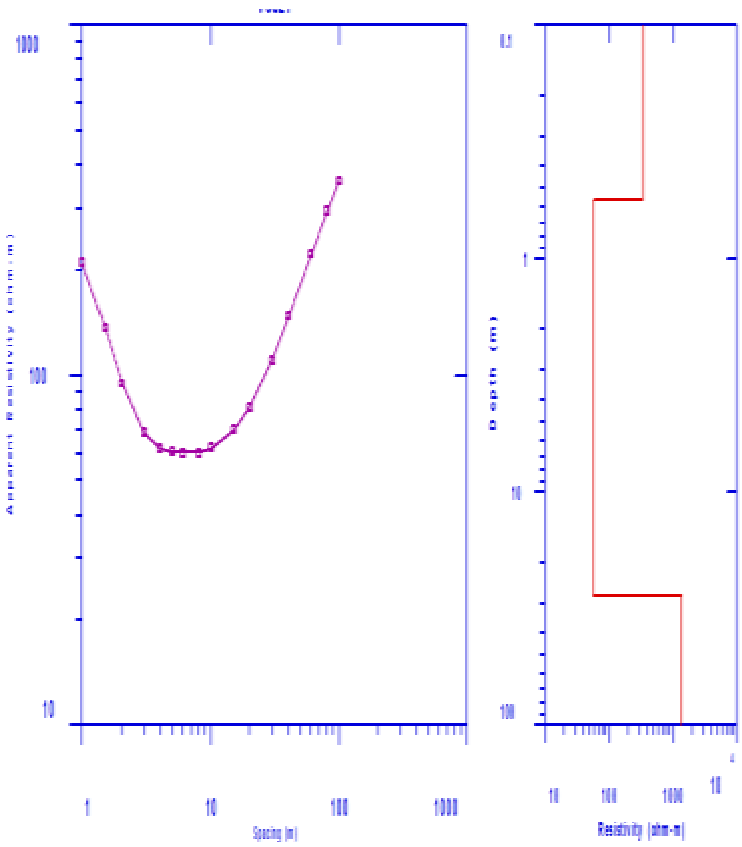


10
1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
Depth (m)
10
100
1000
Resistivity (ohm-m)

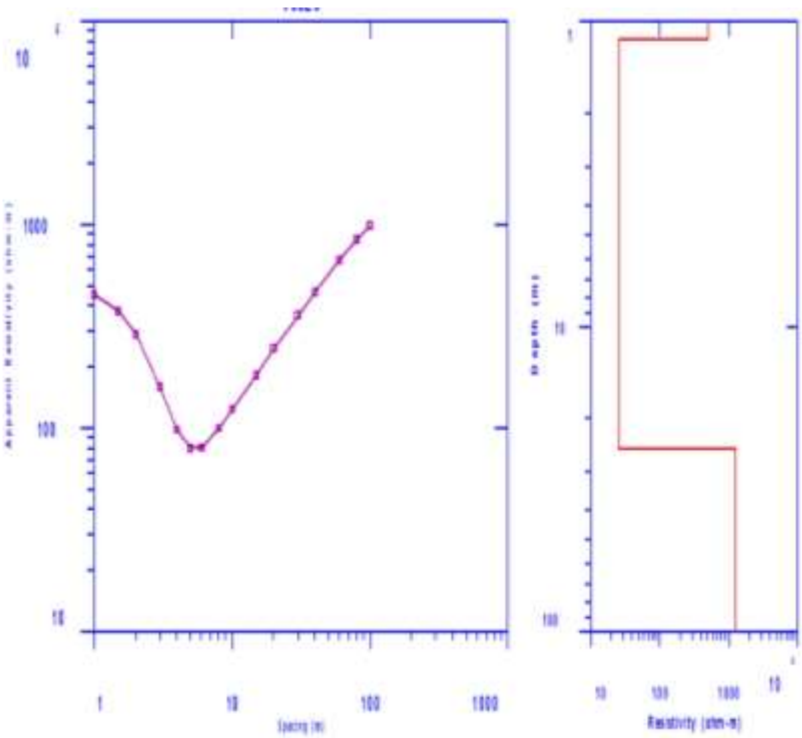
VES 23


1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

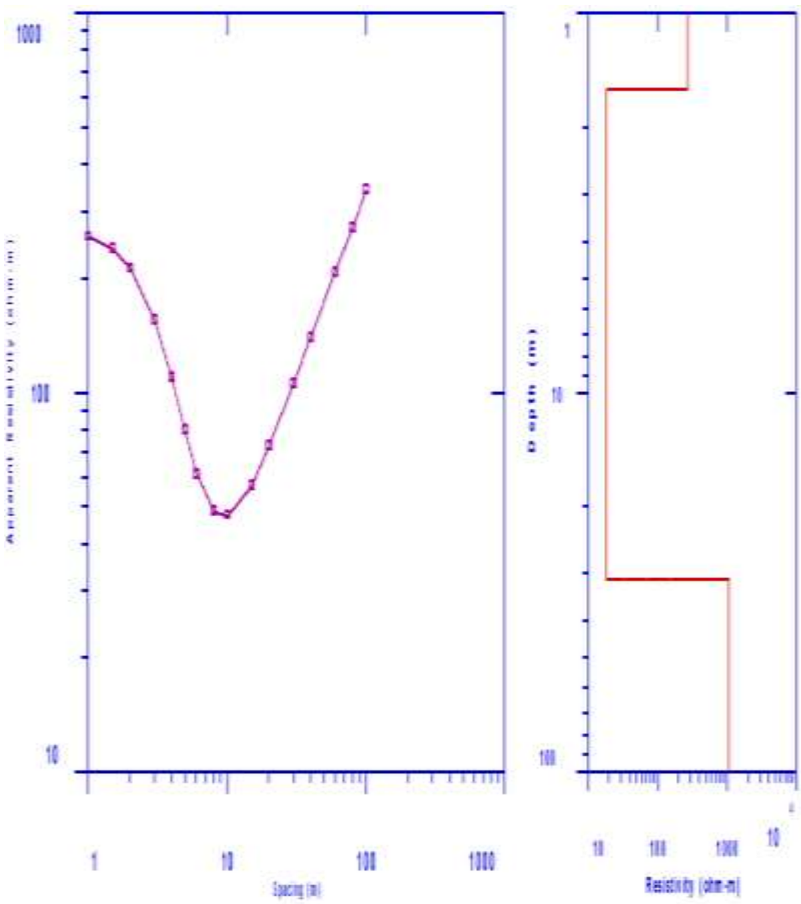
VES 27


1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

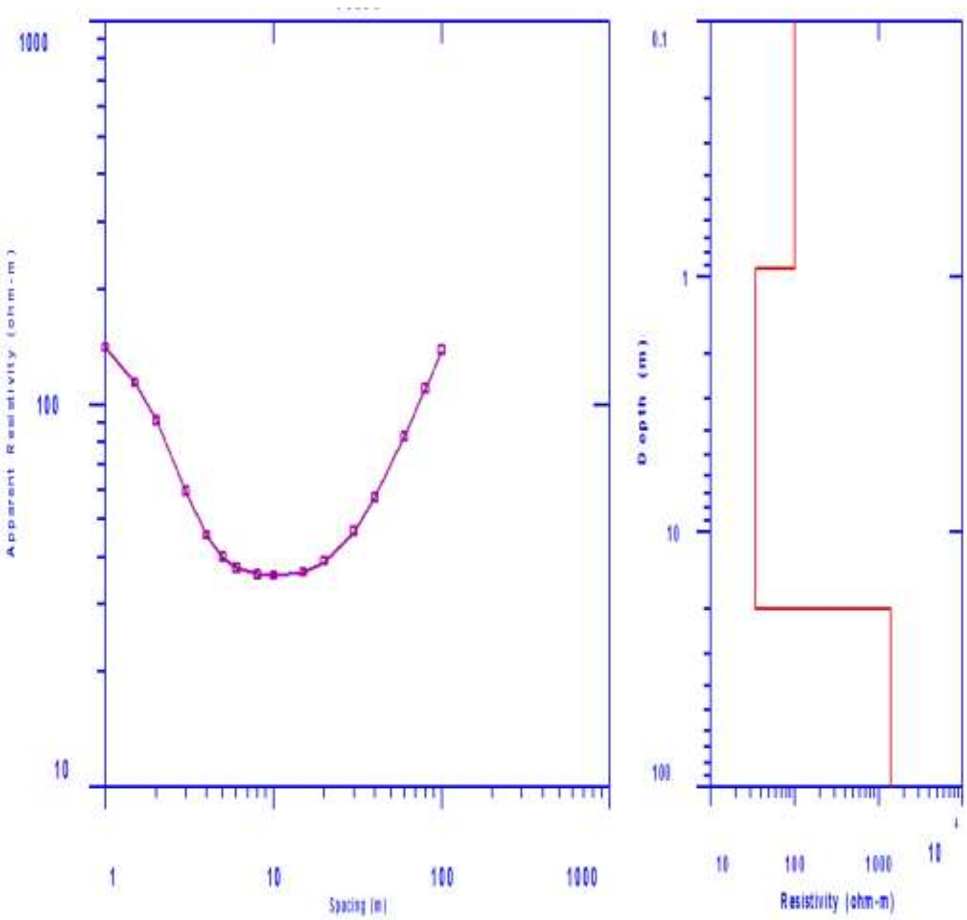
VES 26


Apparent Resistivity (ohm-m)
Spacing (m)
1
10
100
1000
Depth (m)
Resistivity (ohm-m)

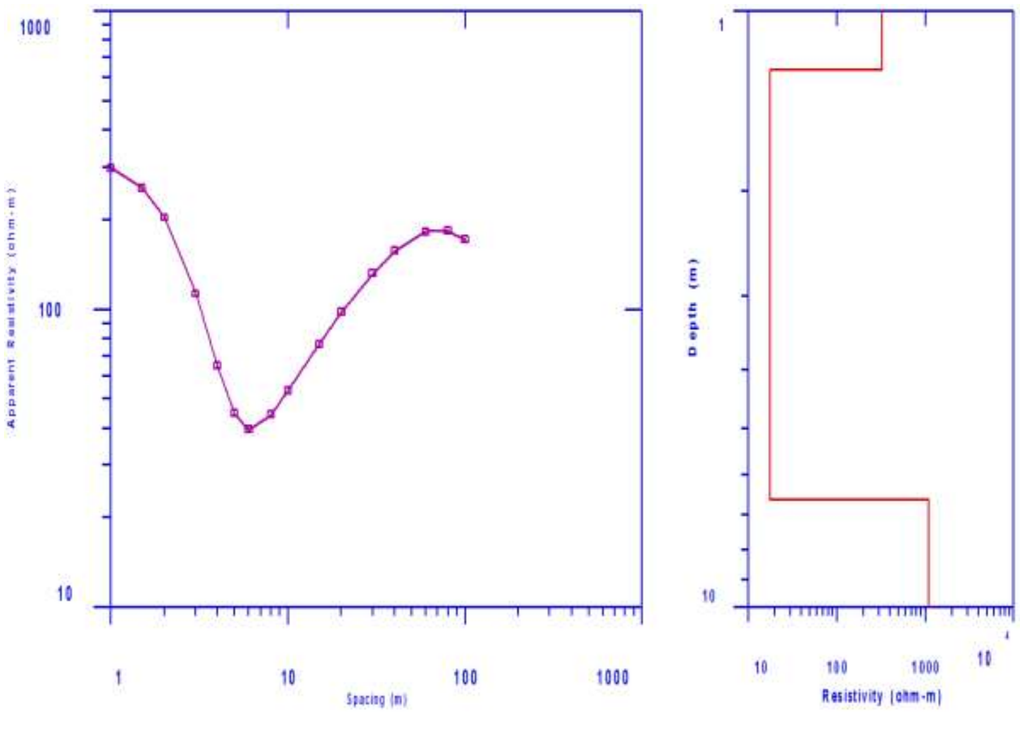
VES 28


Apparent Resistivity (ohm-m)
Spacing (m)
1
10
100
1000
Depth (m)
Resistivity (ohm-m)

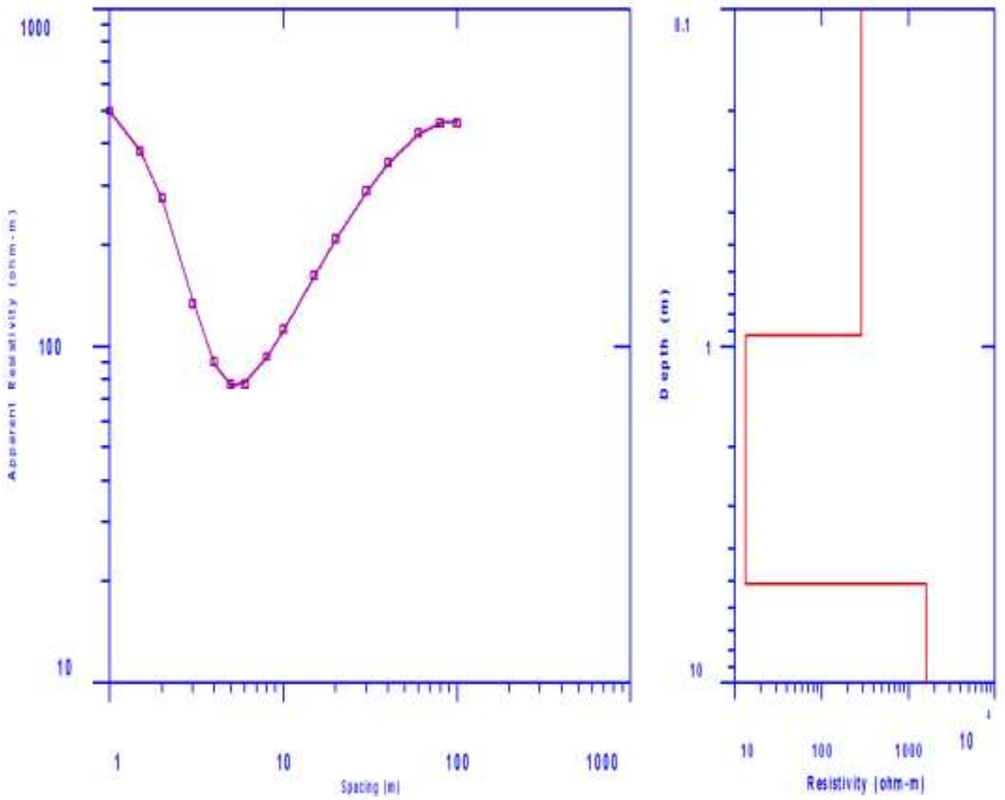
VES 30



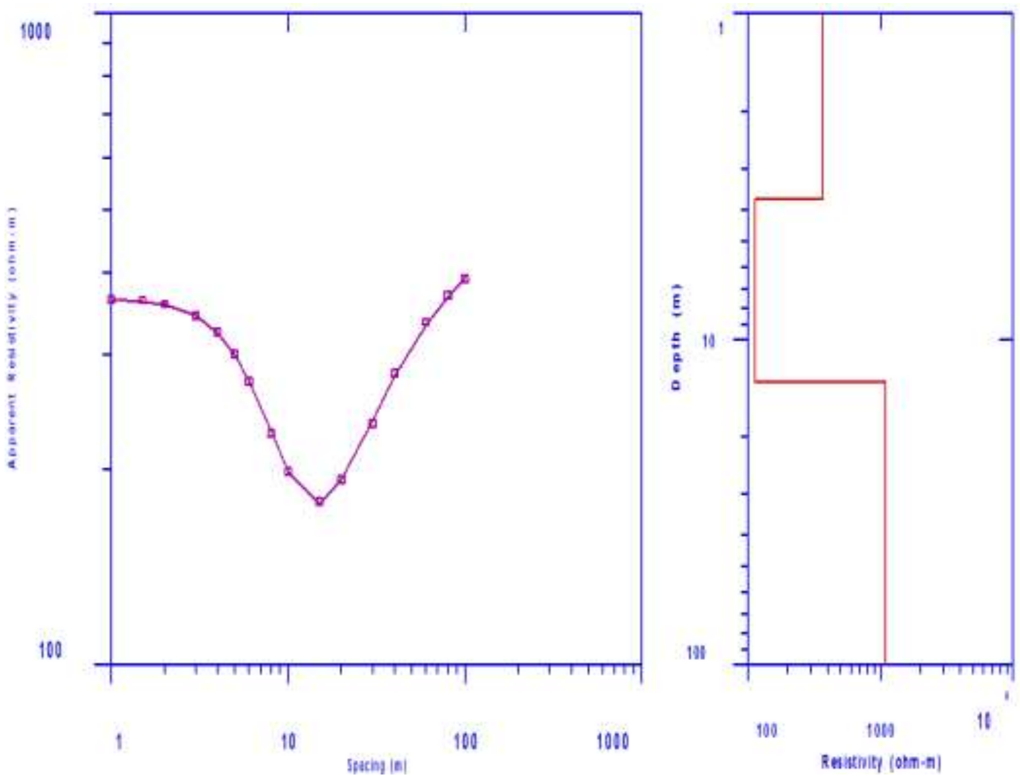
VES 33



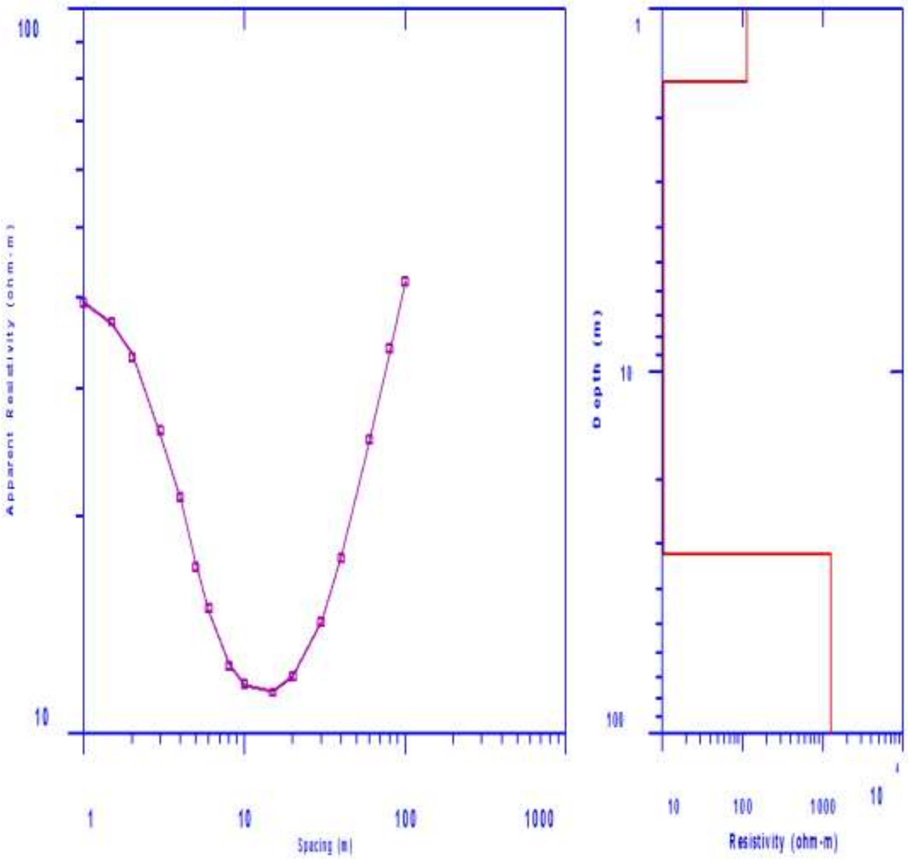
VES 32


1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
Depth (m)
10
100
1000
Resistivity (ohm-m)

VES 36

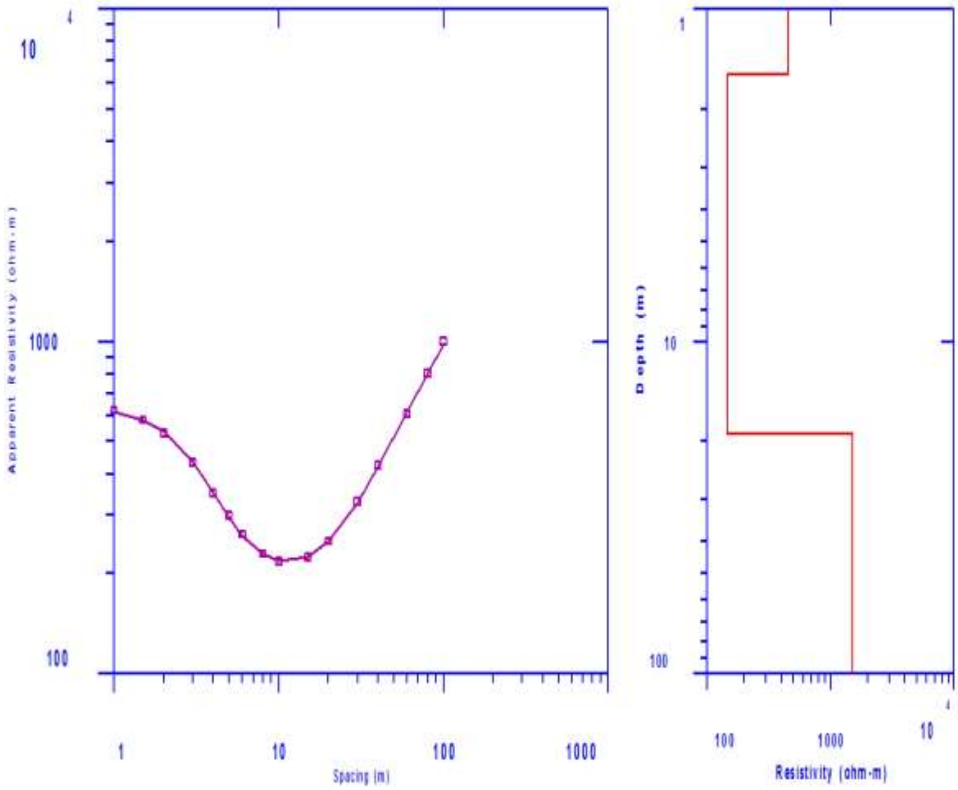

1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

VES 37



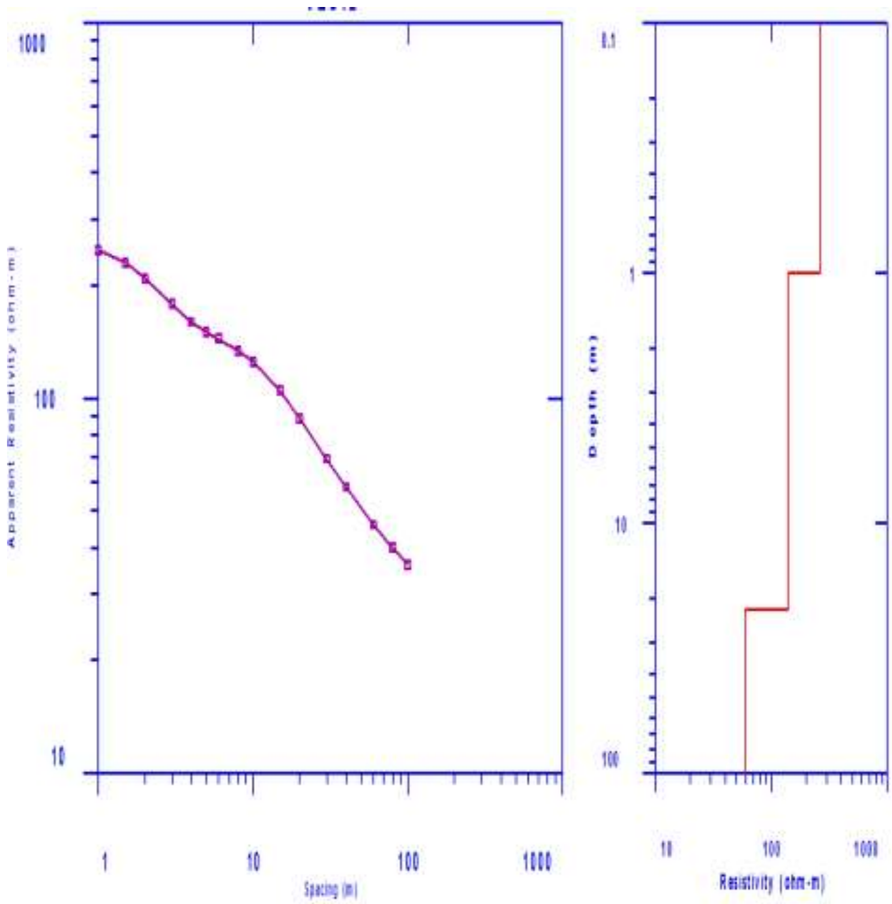
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
10
100
1000
10
4
Resistivity (ohm-m)

VES 38

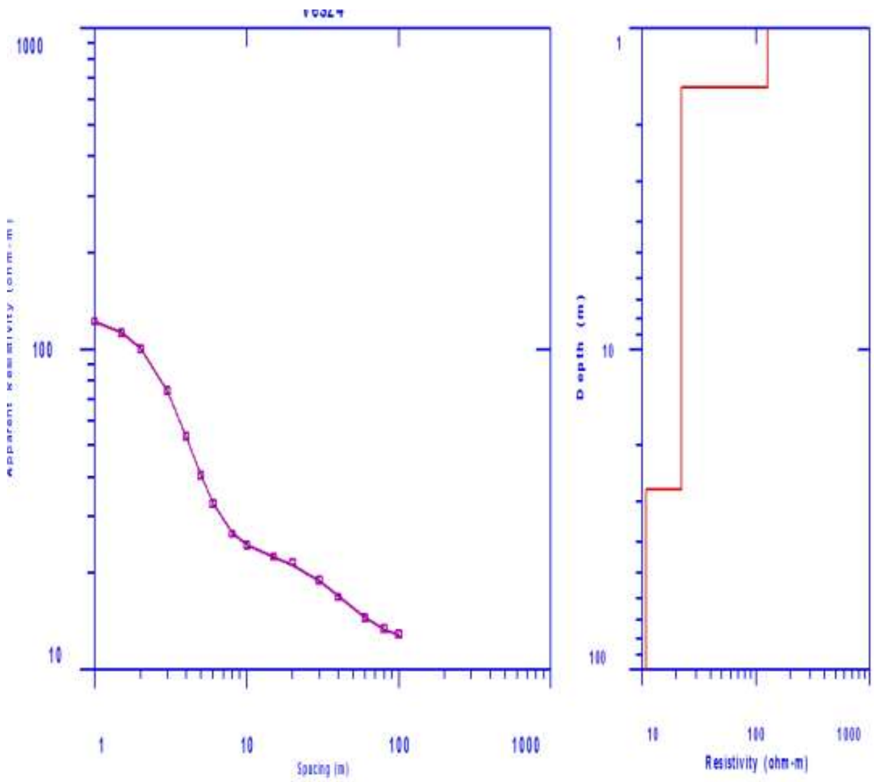


10
4
1000
100
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
100
1000
10
4
Resistivity (ohm-m)

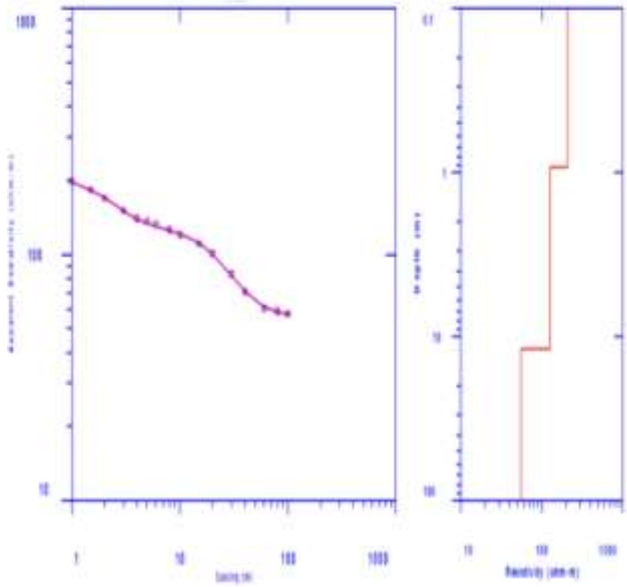
VES 12


1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
0.1
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

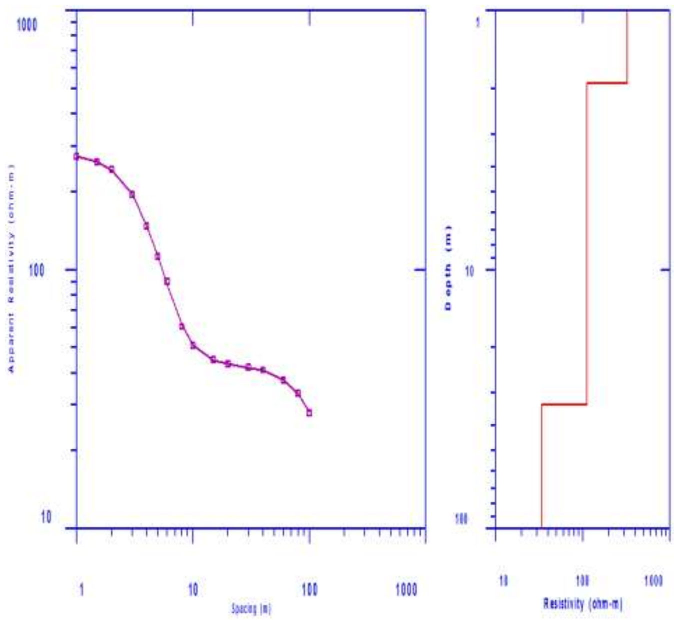
VES 24


1000
100
10
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
10
100
1000
Resistivity (ohm-m)

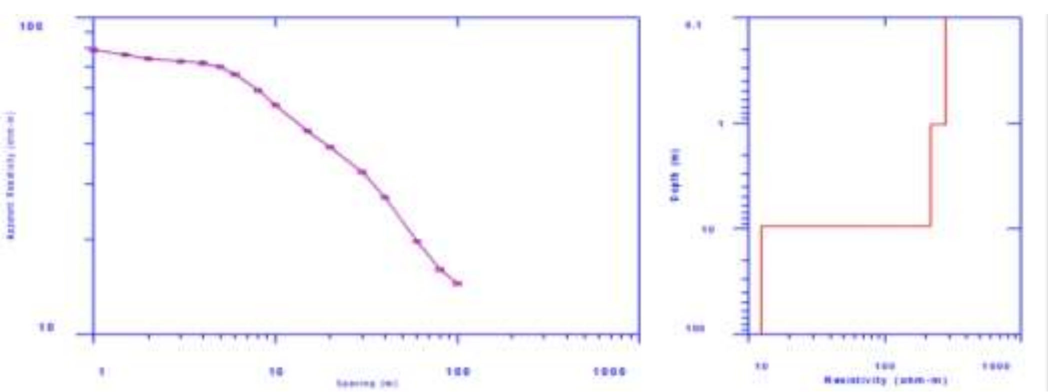
VES 29



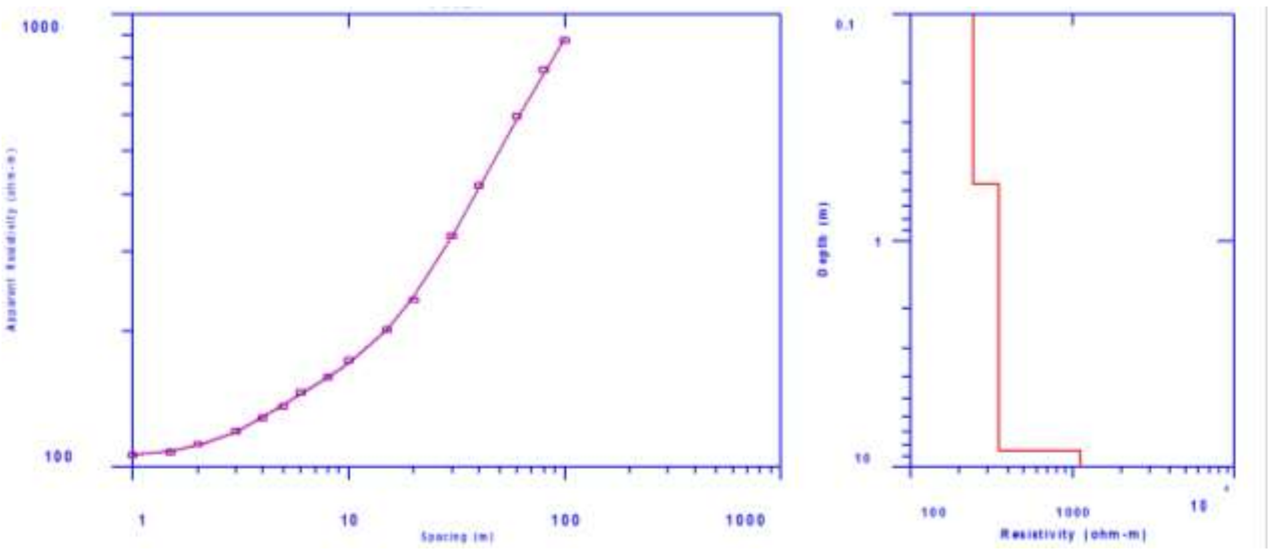
VES 31



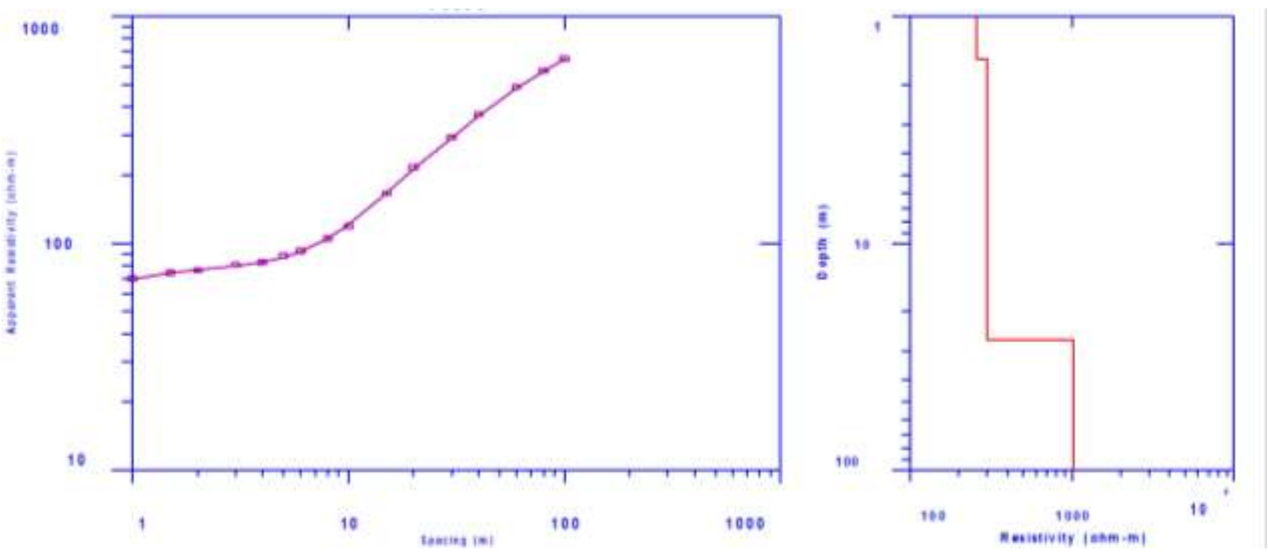
VES 34



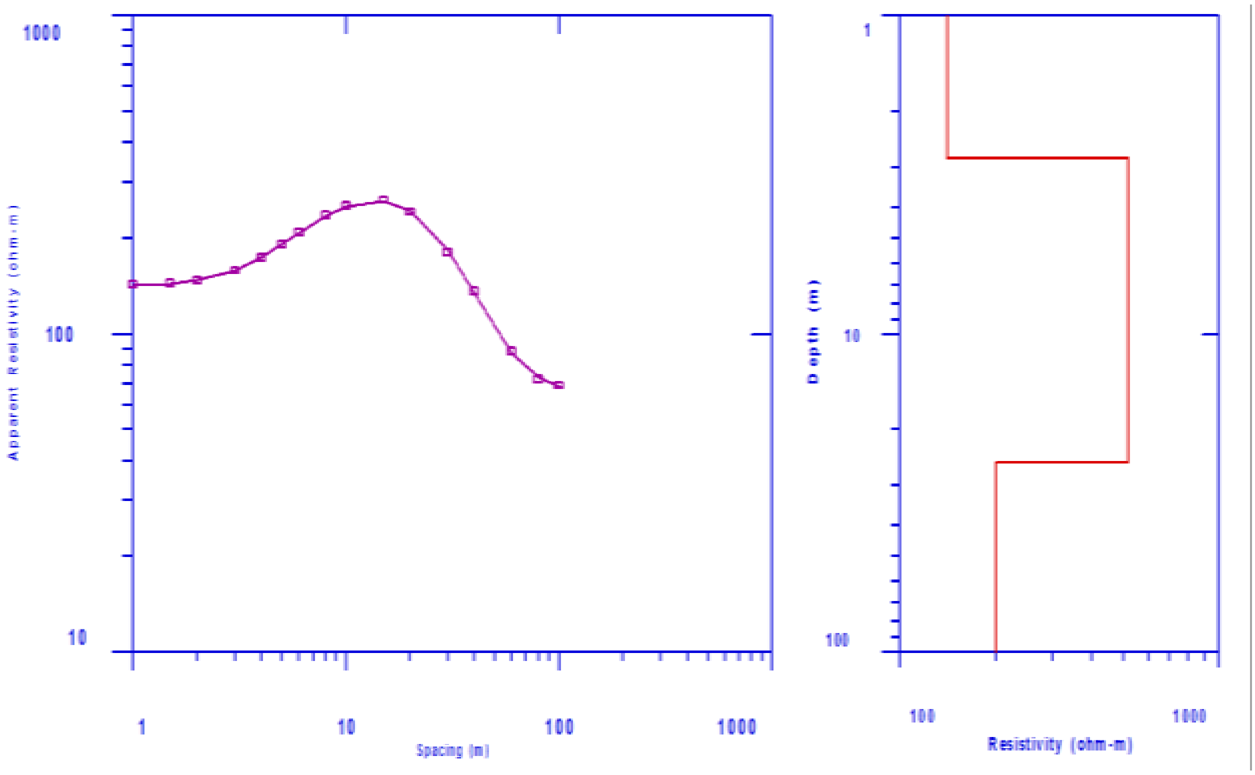
VES 25


1000
100
1
10
100
1000
Spacing (m)
0.1
1
10
Depth (m)
100
1000
Resistivity (ohm-m)

VES 35


1000
100
10
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

VES 13



1000
100
10
Apparent Resistivity (ohm-m)
1
10
100
1000
Spacing (m)
1
10
100
Depth (m)
100
1000
Resistivity (ohm-m)

Appendix 3 Results Obtained From Computed Output Of The Thirty Eight(38)Ves In Boi and Environs

VES	Coordinates	Thickness of Layers (meters)		Resistivity of Layers (Ohms-meter)			Longitudinal Conductivity (Siemens)		Transverse Resistance (ohms-meter)		Fitting Errors(%)
		H1	H2	ρ1	ρ2	ρ3	S1	S2	T1	T2	
1	N 9.61557 E 9.50278	0.70	23.70	128.96	40.10	1214.70	0.0054	0.59	90.27	950.37	0.77
2	N 9.60222 E 9.50278	1.53	24.45	284.07	37.61	1211.21	0.0054	0.65	434.63	919.56	0.28
3	N 9.58640 E 9.50116	2.28	30.42	601.26	138.16	1000.33	0.0038	0.22	1370.87	4202.83	0.88
4	N 9.57502 E 9.50556	0.98	8.05	775.84	92.99	1384	0.0013	0.087	760.32	748.57	0.29
5	N 9.55613 E 9.50029	1.70	25.67	999.71	35.52	238.85	0.0017	0.72	1699.51	911.80	0.83
6	N 9.53556 E 9.50500	1.31	27.31	592.23	130.65	1546	0.0033	0.21	513.82	3568.05	0.27
7	N 9.51722 E 9.50419	0.94	21.12	394.92	144.82	1043.75	0.0024	0.15	371.22	2058.60	0.93
8	N 9.51945 E 9.51891	0.86	22.53	119.80	42.51	1151	0.0072	0.53	103.03	957.75	0.36
9	N 9.53278 E 9.52780	1.43	29.26	111.58	23.75	1100	0.013	1.23	158.56	694.93	0.37
10	N 9.54722 E 9.52001	2.86	26.60	556	51	1331	0.011	0.52	724.78	1326	0.63
11	N 9.56419 E 9.52500	0.98	23.55	342.67	106.82	1096	0.0029	0.22	335.82	2526.29	0.39
12	N 9.58194 E 9.51889	0.99	21.31	263.40	139.35	59.79	0.0038	0.15	260.77	2968.48	0.34
13	N 9.59778 E 9. 53057	0.93	21.65	206	308.42	201	0.00058	0.070	1493.02	6677.29	0.73
14	N 9.61613 E 9.53001	1.55	6.35	758.72	83.87	1000.50	0.0020	0.076	1176.02	532.57	0.36
15	N 9.61641 E 9.54835	1.64	29.23	576.20	14.43	1231	0.0034	2.03	780.97	421.79	0.80
16	N 9.59169 E 9.54445	0.91	23.00	227.60	77.97	1327	0.00040	0.29	20056.60	1793.31	0.90
17	N 9.56947 E 9.55001	1.80	26.99	81	26.60	1821	0.0019	1.01	1674.52	717.93	0.81
18	N 9.55056 E 9.54445	1.84	16.64	100	15	1220.80	0.0031	1.12	1090.86	249.60	0.39
19	N 9.51778 E 9.54168	0.57	17.95	1679	126.60	1039.01	0.00034	0.14	957.03	2272.47	0.44
20	N 9.51969 E 9.55835	1.55	15.57	563.43	77.26	200	0.0043	0.20	563.32	1202.94	0.39
21	N 9.54723 E 9.56336	0.71	26.30	413.38	106.93	1060	0.0017	0.25	293.50	2812.26	0.35
22	N 9.55836 E 9.55807	0.70	8.29	265.34	93.60	208	0.0026	0.089	185.74	775.94	0.98
23	N 9.58362 E 9.55280	2.64	26.65	371.81	169.47	280	0.0071	0.16	981.58	4516.38	0.84
24	N 9.59446 E 9.56389	1.52	25.87	126.77	22.13	10.80	0.012	1.17	192.69	572.50	0.61
25	N 9.60280 E 9.56058	0.56	9.08	243.95	200	1118	0.0023	0.12	136.61	4816	0.90
26	N 9.61667 E 9.57502	1.14	27.51	507.87	25.59	1254	0.0022	1.08	578.97	614.42	0.47
27	N 9.60135 E 9 58278	0.57	28..60	323.43	55.24	1380	0.0018	0.51	184.36	703.98	0.77
28	N 9.58611 E 9.57502	1.77	29.30	264.21	18.45	1080	0.0067	1.05	467.65	356.09	0.70
29	N 9.57502 E 9.57529	0.85	10.00	211.13	129.66	55.32	0.0040	0.077	179.46	1296.60	0.89
30	N 9.55694 E 9.58002	0.93	18.94	100	34.23	1393	0.0057	0.55	151.50	629.83	0.37
31	N 9.53362 E 9.57808	1.19	31.08	526.97	112.04	33.91	0.0036	0.028	389.09	3482.20	0.95
32	N 9.51806 E 9.58612	1.34	4.30	590.86	13.43	1618	0.0046	0.32	389.75	57.75	0.97
33	N 9.53308 E 9.59751	1.25	5.36	326.86	17.64	1100	0.0038	0.30	408.58	94.55	0.37
34	N 9.53558 E 9.59722	1.03	8.44	281.97	217.68	12.38	0.012	0.039	84.43	1837.22	0.21
35	N 9.55417 E 9.59752	1.54	25.08	557	300	1019.2	0.052	0.084	45.85	7524	0.90
36	N 9.57503 E 9.59723	3.60	13.59	364.88	113.49	1094.	0.0099	0.12	1313.57	1542.33	0.65
37	N 9.59444 E 9.59919	1.03	30.34	113.35	10.62	1250	0.0090	2.86	116.75	322.21	0.70
38	N 9.61113 E 9.59946	2.47	17.37	455.20	147.11	1500	0.0054	0.12	1124.34	2630.33	0.90
Mean		1.37	20.85	363.35	96.07	12488.58	0.0061	0.48	1171.73	191722	0.67

4 Appendix 4 Geochemical Data of Ten Water Samples and Water Quality Standard Data

Coordinates	Sample Locations	Sample Sources	Physical Parameters						Chemical Parameters Cations (mg/l)							Chemical F
			Temperature (T^0)	PH	TDS (mg/l)	EC (ms/cm)	TB (NTU)	TH (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (Mg/l)	Mn^{2+} (mg/l)	Fe^{2+} (mg/l)	Cu^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	$SO4^{2-}$ (mg/
N 9.52325 , E 9.53046	Ndukum	B1	28.0	6.74	371	545	3.78	57	6.70	0.11	0.05	0.63	0.00	48.9	0.17	18
N 9.56126 E 9.50209	Boi	B2	28.2	6.30	445	980	2.61	74	13.10	0.13	0.11	0.72	0.00	50.2	0.19	23
N 9.5707 E 9.51737	Kubong	D1	28.6	6.70	220	441	2.06	80	14.01	0.01	0.07	0.73	0.00	50.8	0.16	6
N 9.59085 E 9.51380	Gyara	W1	27.0	6.92	338	670	3.78	67	8.50	0.13	0.01	0.83	0.03	23	0.10	2
N9.60283 E 9.57356	Gwaska	B3	28.2	5.83	471	987	2.71	70	12.01	0.17	0.17	0.42	0.01	50.8	0.14	14
N 9.58362 E 9.55280	Daram	W2	27.8	5.08	325	645	7.41	69	7.30	0.09	0.19	0.58	0.00	38	0.20	11
N 9.60998 E 9.59769	Lusa	B4	28.7	6.55	210	413	1.59	60	6.01	0.14	0.09	0.82	0.01	50.7	0.19	8
N 9.59444 E 9.59919	Lusa	W3	27.4	6.74	162	328	1.03	46	4.10	0.11	0.13	0.81	0.01	50.8	0.10	9
N 9.55055 E 9.55000	Kol	S1	27.4	6.60	233	466	1.33	27	3.93	0.06	0.11	0.65	0.00	55.4	0.17	20
N 9.55694 E 9.58002	Bonga	W4	29.0	6.45	354	707	1.08	22	2.30	0.04	0.18	0.67	0.00	49.2	0.18	12
Mean			28.03	6.39	312.5	618.2	2.74	57.2	7.80	0.10	0.11	0.69	0.015	46.78	0.16	12.3
Range			27-29	5.08-6.74	162-471	328-987	1.03-7.41	22-80	2.3-14.01	0.01-0.13	0.01-0.19	0.42-0.83	0.01-0.03	23-50.8	0.10-0.20	2-23
WHO(2011) Permissible Value (mg/l)			variable	6.5-8.5	1000	250	5	75	200	150	0.2	0.2	2	200	12	500
EU(2011) Permissible Value(mg/l)			variable	6.5-8.5	1000	250	3	75	200	150	0.05	0.2	2	200	12	250