INVESTIGATION FOR GROUNDWATER POTENTIAL AND ENGINEERING WORKS USING ELECTRICAL RESISTIVITY METHOD AT GIDAN KWANO CAMPUS, FUT, MINNA, NIGER STATE, NIGERIA

BY

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ABSTRACT

Vertical Electrical Sounding (VES), using Schlumberger array was carried out to investigate the subsurface layer parameters of a 500 x 500 m land area located between latitude 09º32′21.4″ N to 09º32′37.8″ N and longitude 06º27′29.2″ E to 06º27′45.5″ E at the northern part of Gidan Kwano Campus, Federal University of Technology, Minna, Niger State. A total of 36 VES points at 100 m interval were sounded with a 100 m maximum half inter current electrode spacing (ab/2). Result revealed that the study area is underlain by three (3) geoelectric layers which include: the top soil with 10.6 to 1679.8 Ωm, 0.5 to 4.2 m and 0.5 to 4.2 m as its range of resistivity, depth and thicknesses respectively; the weathered layer having resistivity of 4.8 to 61.5 Ωm, depth of 2.7 to 23.0 m and thickness of 2.1 to 21.1 m; and the fractured/fresh basement which has 158.7 to 1421.5 Ωm as its resistivity value with undefined depth and thickness. The observed curve types include: A (3%) and H (97%). Five (5) VES stations A_5, B_4, B_5, C_2, and F_3 were delineated as aquifer potentials of the study area, their resistivity, depth and thickness range from 24.2 to 34.4 Ωm, 9.2 to 23.0 m and 8.0 to 21.2 m respectively. The points delineated for civil engineering works are VES stations A6, B1, B6, C5 and F1 having shallow depth to basement.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Water is considered a basic component of life, all living things rely heavily on it for their existence. It is highly needed for domestic, agricultural and industrial use; its sources are mainly the surface and groundwater source. Presently, the use and sustainability of water is getting more complex due to population growth, urbanisation and industrialisation. For any developmental activity, both surface and groundwater sources are the main components depending on their quality and availability. In an area where surface water is not feasible for the desired activity, groundwater becomes the alternative, if it has the anticipated amount and quality (Shishaye & Abdi, 2016).

Groundwater is the water present in soil pore spaces beneath earth's surface and in the fractures of rock formations. It is available in different proportions, in various rock types and at various depths, in the subsurface layer of the earth. A unit of rock or an unconsolidated deposit that can yield a usable quantity of water is referred to as an aquifer (Salako & Adepelumi, 2018). The depth at which fractures or soil pore spaces in rock becomes fully saturated with water is called the water table. Groundwater is recharged from the surface and eventually flows to it naturally; natural discharge often occurs as springs. Groundwater constitutes 20% of the world's fresh water supply (Alhassan *et al.*, 2017). It is considered to be a less contaminable source of water which makes it suitable for drinking and agricultural purpose; though fairly dispersed all over the world, it cannot be found in good quantity everywhere (Alhassan *et al.*, 2015), hence the need for a careful investigation/survey beforehand.

Groundwater exploration can be carried out using different methods. The four major groundwater exploration methods are the surface method, esoteric methods, subsurface method and areal method (Al-Garni, 2009). Among these methods, esoteric method is mostly based on traditional indicators. Each of the above listed groundwater exploration methods have different sub-methods under them. Geophysical survey is therefore one of the sub-methods under the surface method of groundwater exploration.

Various geophysical methods have been employed successfully for ground water exploration in different parts of the world over the years. Some of these methods include magnetic, electrical, electromagnetic, gravity, seismic, remote sensing etc. Of all these methods, the electrical resistivity method has been the most widely used geophysical tool for groundwater investigation because of its advantage which include simplicity in field technique and data handling procedure (Anomohanran, 2013), and it is the most effective (Alhassan *et al.*, 2017).

The Vertical Electrical Sounding (VES) is an electrical resistivity method that is widely used for depth sounding due to its simplicity and reliability (Olawuyi and Abolarin, 2013). It is used to estimate the electrical resistivity variation of the earth subsurface vertically downward since the electrical resistivity of most rocks is dependent on the amount of water in the pore spaces within the rocks, the dissemination of these pores and the salinity of the water in the pore spaces. It provides the thickness and depth of the various subsurface layers and their relative water yielding capacities.

The vertical electrical sounding method can also be used to determine the depth to bedrock which constitute the basics for geotechnical survey, hence its choice for this study.

1.2 Statement of the Research Problem

The growing demand for water due to the increasing human population has been the major problem of the Gidan-kwano Campus of the Federal University of Technology, Minna. The University has relocated most of her faculties from Bosso Campus to Gidan-kwano Campus, consequently, there is a demand to compliment the already existing water supply sources in the campus hence the need to delineate the aquifer potential of the study area.

Also, due to lack of or improper site investigation and poor foundation, there have been several cases of building collapse in Nigeria for some decades now; according to Alamu and Gana, 2014, Nigeria recorded the highest report of structural failures between 1980 and 2014. It has resulted to the loss of several lives and valuables over the years. With the availability of relevant information about the sites competent for civil engineering works within the study area, such tragedy would be averted.

1.3 Aim and Objectives of the Study

This study is aimed at investigating groundwater potential and engineering work site(s) within the study area.

The objectives of this study are to:

i. determine the resistivity, depth and thickness of the subsurface layers

ii. produce isoresistivity, overburden thickness and geologic section maps of the study area

iii. delineate the aquifer potential and structural site of the study area

1.4 Significance of the Study

This work provides relevant information as regards the aquifer potential of the study area which will be of great importance to government or individuals who may wish to site borehole within the area as it will help save the cost of carrying out another survey.

Also, the parts most competent for civil engineering works within the study area were mapped out and the information will serve as a guide for civil engineers. Furthermore, this research work serves as future reference for other researchers who may wish to carryout related research work.

1.5 Scope of the Study

This study is focused on employing the vertical electrical sounding (VES) technique to investigate the subsurface structures of a 500 m x 500 m area of land defined by latitude $09^o32'21.4''$N to $09^o32'37.8''$N and longitude $06^o27'29.2''$E to $06^o27'45.5''$E located at the Gidan-kwano Campus, Federal University of Technology Minna, Niger State. A total of 36 VES points at 100 m apart with maximum half inter current electrode spacing of 100 m were probed to carefully delineate the most appropriate points for groundwater development and civil engineering works.

1.6 Location of the Study Area

The study area is located at the northern part of the Gidan-kwano Campus, Federal University of Technology, Minna. It is defined by latitude $09^o32'21.4''$N to $09^o32'37.8''$N and longitude $06^o27'29.2''$E to $06^o27'45.5''$E. The western end of the area is bounded by the Saint Malachy′s Chaplaincy church auditorium of the University; and its eastern end is about 645 m away from the Minna-Bida road.

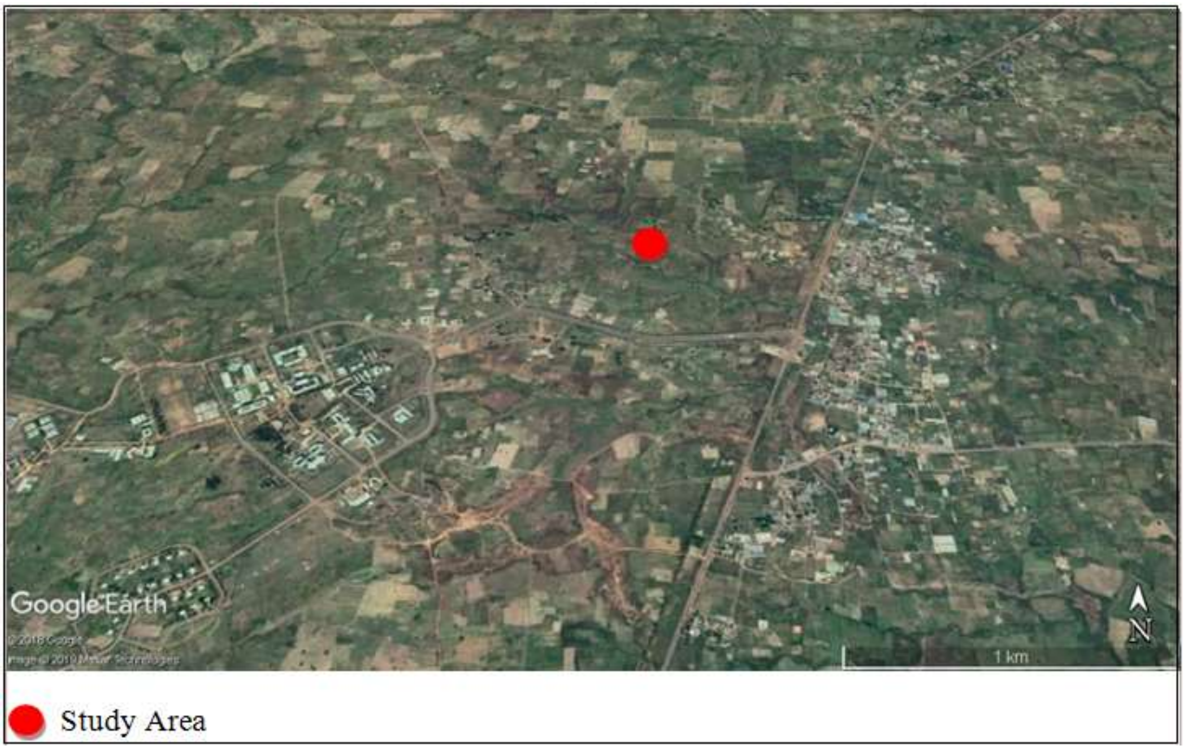

Figure 1.1: Satellite image of the study area (Google Earth).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geological Setting of Nigeria

Nigeria is situated in the West African sub-region and located between latitude 4^o and 14^o N and longitudes 3^o to 14^o E (Obaje, 2009), it is bounded by Niger republic to the north and the Atlantic Ocean to the south. Benin and Cameroun Republic flank it to the west and east respectively. A small strip borders the Chad Republic to the northeast. It has a landmass of 923,768 sq. km. The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex, Younger Granites, and Sedimentary Basins. The Basement Complex, which is Precambrian in age (Pan-African and older, greater than 600 million years), is made up of the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites.

The Younger Granites comprise several Jurassic (200 – 145 million years) magmatic ring complexes centred around Jos and other parts of north-central Nigeria. They are structurally and petrologically distinct from the Older Granites. The Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages (less than 145 million years), comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida-Nupe) Basin and the Dahomey Basin (Obaje, 2009). Solid mineral deposits of economic significance that including gold, iron ore, cassiterite, columbite, wolframite, pyrochlore, monazite, marble, coal, limestone, clays, barites and lead-zinc occur in the different geologic segments of Nigeria and indeed each of the 36 federating states and the Federal Capital Territory. Oil and gas on the other hand occur prolifically in the Niger Delta Basin with opportunities to add to the national reserve asset existing in the other sedimentary basins (Obaje, 2009).

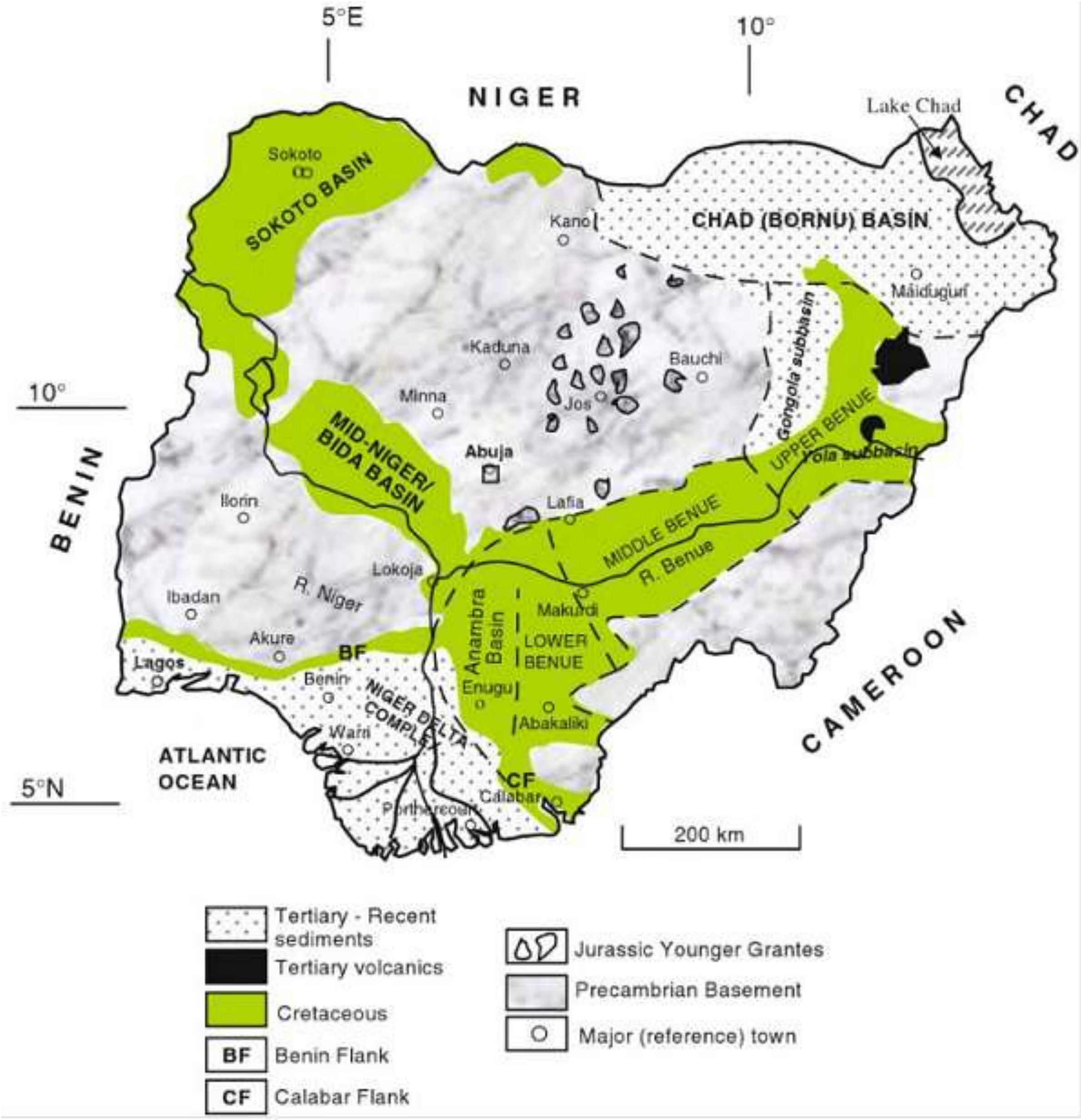

Figure 2.1: Geological sketch map of Nigeria showing the major geological components (Obaje, 2009)

2.2 Theoretical Framework of the Study

2.2.1 Electrical resistivity method

In the DC resistivity surveying, an electric current is passed into the ground through two outer electrodes (current electrodes), and the resultant potential difference is measured across two inner electrodes (potential electrodes) that are arranged in a straight line, symmetrically about a centre point. The ratio of the potential difference to the current is displayed by the Terrameter as earth resistance. A geometric factor ***K*** in metres is calculated as a function of the electrode spacing. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed. A and B are current electrodes through which current is supplied into the ground, **M** and **N** are two potential electrodes to measure the potential differences between the two electrodes. The potential difference between the two potential electrodes is measured. The apparent resistivity is given by

$$\rho_a = k\left(\frac{\Delta V}{I}\right) \qquad (2.1)$$

where k is a geometric factor which only depends on electrode spacing. For schlumberger array, it is given in equation 3.1.

Electrical resistivity method is defined by the frequency of operation, the origin of the source signals and the manner by which the sources and receivers are coupled to the ground. The method is generally governed by Maxwell's equations of electromagnetism. In the direct current (DC) frequency, the diffusion term is zero and the field is thus governed entirely by Poisson equation. Electrical methods of geophysical investigations are based on the resistivity (or its inverse, conductivity) contrasts of subsurface materials. The electrical resistance, R of a material is related to its physical dimension, cross-sectional area, A and length, $\boldsymbol{l}$ through the resistivity, ρ or its inverse, conductivity, σ by

$$\rho = \frac{1}{\sigma} = \frac{RA}{l} \qquad (2.2)$$

Low-frequency alternating current is employed as source signals in the DC resistivity surveys in determining subsurface resistivity distributions. Thus, the magnetic properties of the materials can be ignored so that Maxwell's equations of electromagnetism reduced to:

$$\nabla.\vec{E} = \frac{1}{\varepsilon}q \qquad (2.3)$$

$$\nabla \times \vec{E} = 0 \qquad (2.4)$$

where $\overrightarrow{E}$ is electric field in *V/m, q* is the charge density in *C/m*^{3} and ε is the permittivity of medium. These equations are applicable to continuous flow of direct current; however, they can be used to represent the effects of alternating currents at low frequencies such that the displacement currents and induction effects are negligible. Usually, a complete homogeneous and isotropic earth medium of uniform resistivity is assumed. For a continuous current flowing in an isotropic and homogeneous medium, the current density $\vec{J}$ is related to the electric field, $\vec{E}$ through Ohm's law

$$\vec{J} = \sigma\vec{E} \qquad (2.5)$$

The electric field vector $\vec{E}$ can be represented as the gradient of the electric scalar potential,

$$\vec{E} = \nabla\Phi \qquad (2.6)$$

The apparent resistivity is the ratio of the potential obtained in-situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1Ω m resistivity. The apparent resistivity measurements give information about resistivity for a medium whose volume is proportional to the electrode spacing. Resistivity is affected more by water content and quality than the actual rock material in porous formation while aquifers that are composed of unconsolidated materials, their resistivity decreases with the degree of saturation and salinity of the groundwater (Afuwai and Lawal, 2013).

Since the measured resistivity is usually a composite of the resistivity of several layers, the apparent resistivity may be smaller or larger than the real resistivity or in rare cases identical with one of the two resistivity values in a homogeneous surface. The apparent resistivity is the same as the real resistivity in a homogeneous subsurface but normally a combination of contributing strata. The value of the apparent resistivity obtained with small electrode spacing is called the surface resistivity.

2.2.2 Schlumberger array

The Schlumberger array consists of four collinear electrodes. The two outer electrodes (A and B) are current (source) electrodes and the inner two electrodes (M and N) are the potential (receiver) electrodes. The potential electrodes are installed at the center of the electrode array with a small separation, typically less than one fifth of the spacing between the current electrodes. The current electrodes are increased to a greater separation during the survey while the potential electrodes remain in the same position until the observed voltage becomes too small to measure (Emmanuel *et al.*, 2017).

The advantages of the Schlumberger array are that fewer electrodes need to be moved for each sounding and the cable length for the potential electrodes is shorter. Schlumberger soundings generally have better resolution, greater probing depth, and less time-consuming field deployment than the Wenner array. The disadvantages are that long current electrode cables are required, the recording instrument needs to be very sensitive, and the array may be difficult or confusing to coordinate amongst the field crew (Emmanuel *et al.*, 2017).

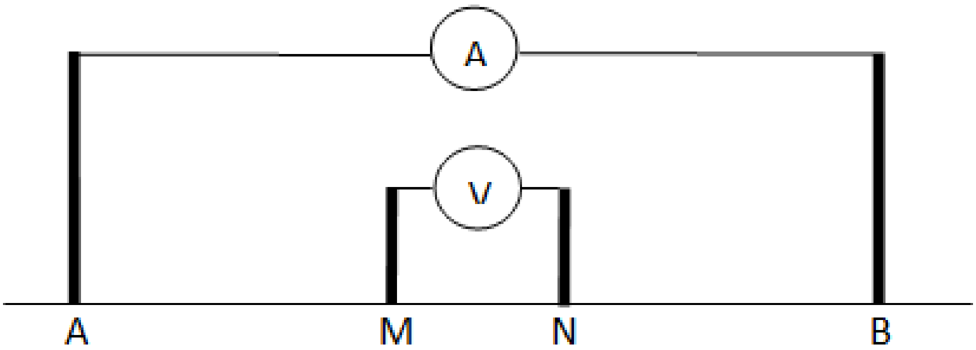

Figure 3.1: Schematic diagram of the schlumberger array used in the survey.

for schlumberger array, apparent resistivity (ρ_a) is given by

$$\rho_a = KR \quad (2.7)$$

$$K = \pi\left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right) \quad (2.8)$$

where R is the earth resistance,

K is the k-factor,

Π is pie,

AB is inter current electrode spacing and

MN is inter potential electrode spacing.

2.3 Geology of the Study Area

Niger State is unique in view of the occurrence of the two major components of Nigerian geology (Basement Complex and Sedimentary Basin). Approximately, one half of the land mass of Niger State is underlain by the basement complex rocks while the other is occupied by the Cretaceous sedimentary rocks of the Bida basin and part of the Sokoto Basin (Abdullahi *et al.*, 2015).

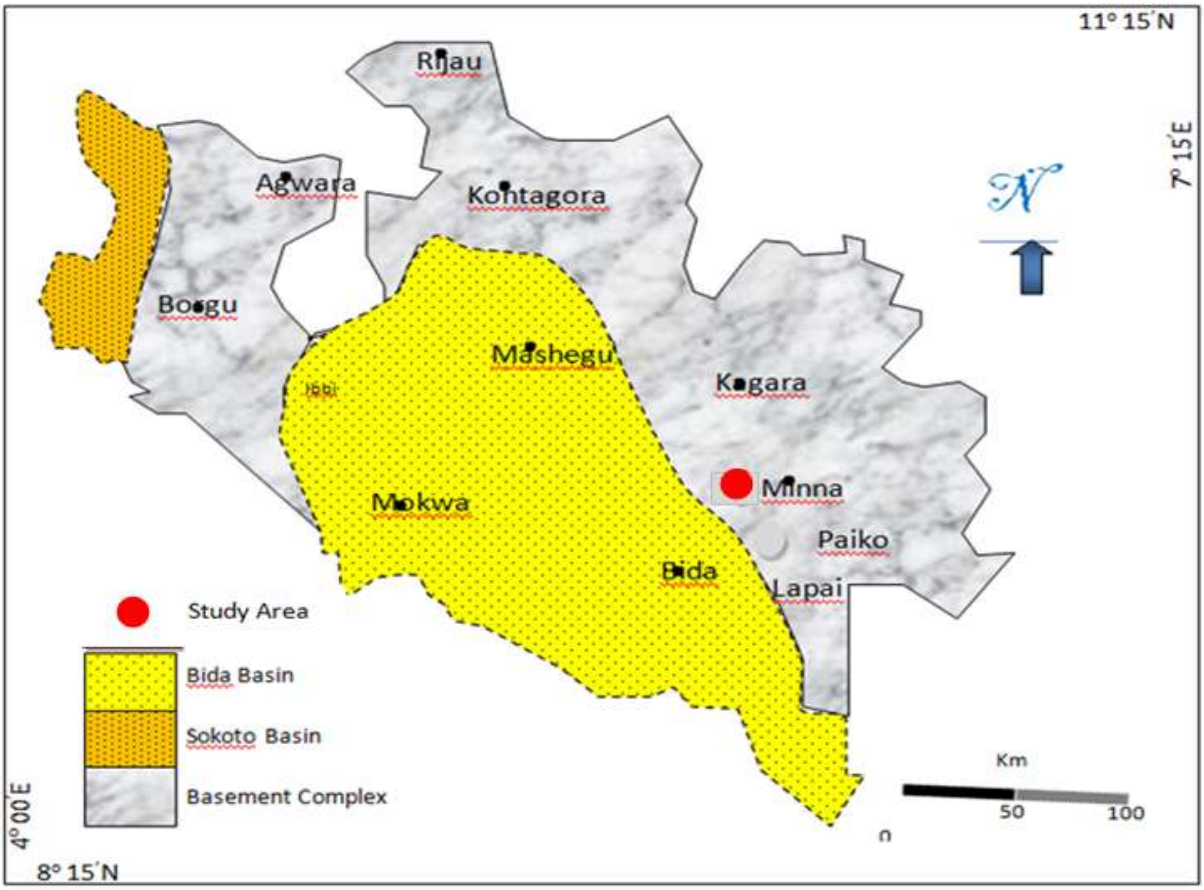

Figure 2.2: Geological map of Niger state (Amadi *et al.,* 2012)

The study area (Minna) is underlain by Basement Complex rocks consisting of medium-grained biotite granite interbanded with coarse-grained leucocratic granite and intruded in places by quatzo-feldspar pegmatite dykes. The dykes strike parallel to the strike of the foliation, and they range from 0.5 m to 3.5 m in diameter. Outcrops are found along the river valleys as flat-lying bodies. They range in sizes from 3x5 m to about 8x15 m. Pinkish feldspar (i.e potassium feldspar) is the dominant mineral in the granite gneiss and the pegmatite. This implies that its weathered product will be rich in clay.

The rock types present in the area are part of the old granitic suite which are mostly exposed along the stream channels (Udensi *et al.,* 1986). The major rock type is porphyritic, medium to fine grained granite (Adesoye, 1986 and Adeniyi *et al.*, 1988). The rocks are found in East-West (E-W) treading veins and joints which are sometimes filled by aplitic or quartz; this is in contrast to the porphyritic granite that are found in the North-South (N-S) trending quarts and aplitic veins ranging in length from 2 m to about 15 m. The medium to fine-grained granitic rocks are broken up into boulders in some places and they show the effect of weathering in the form of colour change, and loose rock fragments (Adesoye, 1986).

2.3.1 The basement complex

One of the three major litho-petrological components that make up the geology of Nigeria is the basement complex. The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006). The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian, the Eburnean, the Kibaran, and the Pan-African cycles.

Within the basement complex of Nigeria four major petro-lithological units are distinguishable, namely:

1. The Schist Belt (Metasedimentary and Metavolcanic rocks)
2. Undeformed Acid and Basic Dykes
3. The Migmatite – Gneiss Complex (MGC)
4. The Older Granites (Pan African granitoids)

2.4 Empirical Review of Previous Geophysical Work

Vertical Electrical Sounding (VES) survey was carried out by Shehu *et al*. (2019) at EL-Amin proposed University site, located along eastern bye pass Minna, Niger State, Nigeria. It lies in the basement complex region of northern Nigeria. The survey was carried out with the aim of determine the ground water potentials of the area and evaluate its aquifer protective capacity. The technique employed was the Vertical Electrical Sounding (VES) using Schlumberger array. A total of 48 VES points were sounded on grid profiles separated by 100 m apart with VES spacing of 100 m. Three to four layers were observed. The Stratigraphy of subsurface shows: topsoil with resistivity range from 0.4 to 277.89 Ωm, Weathered/Fracture basement layer having resistivity vary between 31.0 and 982.89 Ωm and Fresh basement with resistivity range from 19.1 to 79935.239 Ωm. The Weathered/Fractured layer was considered as aquiferous horizon. The Longitudinal Conductance and resistivity Contour maps were produced. Thirteen VES points were delineated as groundwater potential with resistivity ranging from 45.5 Ωm to 611.77 Ωm, thickness ranging between 3.5 m and 13.07 m and depth ranging from 8.8 m to 24.43 m which represent about 18.75 percent of the area. The south, south-east and north-west portions of the area are underlain by materials of moderate to good protective capacity while the western and central part of the area with thin overburden coincided with weak to poor protective capacity which will expose the groundwater in the area to pollution.

Alhassan *et al*. (2019) carried out a geoelectric survey in part of Three Arms Zone Minna, north central Nigeria. The aim of the survey was to evaluate the aquifer potential of the area and its protective capacity. Fourty eight vertical electrical sounding stations were investigated across the area. Schlumberger electrode configuration with maximum current electrode spacing (AB/2) of 100 m was employed. The area was gridded into six profiles with profile separations of 100 m and VES spacing of 100 m apart. Two to four geologic layers were delineated from the interpreted results. The geoelectric layers of the subsurface shows topsoil with resistivity range from 2.1 to 434.4 Ωm, Weathered/fractured basement layer resistivity range from 20.4 to 4491.1 Ωm and fresh basement resistivity ranging between 1,021.4 and 19,418.4 Ωm. The weathered/fractured layer is considered as the major aquiferous zone. Iso-resistivity and longitudinal conductance maps were produced. Eight VES points were consider as the aquifer potential of the area having weathered/fractured resistivity varying between 108.5 Ωm and 647.1 Ωm with thickness range from 11.8 m to 30.7 m. The longitudinal conductance value ranged from 0.002642 Siemens to 2.340909 Siemens. The protective capacity evaluated shows that about 50% of VES points are poorly protected, 14.48% are weakly protected, 22.92% are moderately protected and 12.50% have good protective capacity.

Ndanusa *et al*. (2019) conducted a geotechnical survey involving Atterberg limit, CBR, Compaction and Sieve analysis at part of London Road, Minna, Niger State. The aim of the study was to investigate the causes of road failure. The CBR ranged between 54.1% to 64.2%, the liquid limit of the soil ranged from 16% to 17.90%, the plastic limit was zero. The percentage passive sieve ranged from 29.4% to 99.5%. Based on the 80% minimum CBR, 35% maximum percentage passing sieve, 12% maximum plastic index and 35% maximum liquid required for a material to be used as a based course material for road construction as specified by Nigeria general specification for road and bridge work. All the samples tested do not meet the requirement highlighted above. According to them, the samples cannot be used as base course material of the studied location.

Markus *et al*. (2018) combined the methods of Electrical Resistivity Profiling (ERP) and Vertical Electrical Sounding (VES) to investigate the groundwater potential of part of Rafin-Yashi, Minna, North central Nigeria. 15 out of the 200 VES points probed were chosen as priority locations suitable for groundwater development. Also, it was established that the area was characterized by three to four discrete geoelectric layers, namely, the top layer, the weathered layer, the fractured/fresh layer, and the fresh basement layer.

Shehu *et al*. (2018) carried out Vertical Electrical Sounding at Union Site, Gidan-kwano Campus, Fedral University of Technology, Minna, Nigeria. Their objective was to delineate areas suitable for structural development and to determine the soil corrosivity of the study area. A total of sixty (60) Vertical Electrical Sounding points were covered and their result revealed the existence of three (3) distinct geologic layers, the layers include topsoil, fractured basement and the fresh basement. The topsoil has resistivity and thickness values ranging from 11.41 – 1009 Ωm and 1 – 6 m respectively. The fractured basement has its own resistivity value and thickness ranging between 11 – 963 Ωm and 1 – 45 m respectively indicating high fracture and/or water saturation. The resistivity value of the fresh basement ranged from 12 – 2983 Ωm. A, H and Q curve types were observed and seventeen (17) Vertical Electrical Sounding stations having depths to basement varying between 2 – 5 m were delineated for high rise building.

Alhassan *et al*. (2017) carried out Vertical Electrical Sounding (VES) in northern part of Paiko, North Central Nigeria to determine the subsurface layer parameters (resistivities, depths and thickness) employed in delineating the groundwater potential of the area and established three to four distinct geoelectric layers, namely, the top layer, the weathered layer, the fractured/fresh layer, and the fresh basement layer. Eight VES stations were delineated as ground water potentials of the area, with third and fourth layer resistivities ranging from 191 Ωm to 398 Ωm. Depths range from 13.60 to 36.60 m and thickness varies from 9.23 m to 30.51 m.

Akande *et al*. (2016) employed the Vertical Electrical Sounding (VES) technique to investigate the groundwater potential of Chanchaga area, Minna, North-central Nigeria with a view to delineating the suitable aquifer for groundwater development. It concluded that the central and northern parts of the study area have meagre to marginal groundwater potential, and this is supported by the occurrences and concentration of fractures which can constitute weathered/fractured aquifers around these regions.

Alhassan *et al*. (2015) assessed the aquifer potential and vulnerability of southern Paiko, North Central Nigeria, using geoelectric method. A total of 66 VES points were investigated and the result showed that three to four geoelectric layers exist in the study area. The layers include: the top layer with 194-4582 Ωm, 0.5-47.9 m and 0.5-47.9 m as its resistivity, depth and thickness respectively; the weathered layer having a resistivity value of 11-8475.2 Ωm, depth of 1.33-59.6 m and thickness of 0.13 - 55.7 m; the fractured layer has a resistivity range of 42-9730.9 Ωm while its depth and thickness were not defined; and the fresh basement which has 50.2-9145.7 Ωm as its resistivity value and an undefined depth and thickness. Also, the result revealed that 18 VES stations are good sites for viable boreholes and that the southeast and northwestern parts of the study area were best for structural development.

Ejepu and Olasehinde (2014) made use of the Vertical Electrical Sounding (VES) method to provide information about the lithology and subsurface structure of the Gidan-kwano Campus, Federal University of Technology Minna, with the aim of evaluating its groundwater potential. 48 VES points were made out of which 8 VES stations were selected as priority locations for the development of groundwater resources.

Ismail and Yola (2012) carried out a vertical electrical sounding survey at Dawakin Tofa Local Government Area of Kano State. They indicated that dynamic water levels from open wells were collected and these were used as guides for the selection of the electrode spread distance; further, they pointed out that the Schlumberger array with a maximum electrode spread of 100 m was employed at all points. The authors reported that the results from the sounding data of their investigation indicate that the area is generally underlain by five geoelectric or geologic section as follows: lateritic top soil or lateritic sand, silty sand or sandy clay, weathered basement or clayey sand, fractured basement, and fresh basement. Based on the results obtained, the authors concluded that the fractured and the weathered basement constitute the aquiferous zone within the study area and that the resistivities of these zones varies from 7.3 to 772 Ωm with an average value 178 Ωm, while the thickness varies from a value of 1.66 to 28 m with an average value of 14.33 m. Depth to this zone varies from 5 to 31 m with an average value of 16 m.

Okolie and Akpoyibo (2012) investigated subsurface lithology and aquifer distribution using the Vertical Electrical Sounding (VES) method at Edjekota, Ughelli North Local Government Council, Delta State, Nigeria; the authors remarked that this community is prone to annual flooding that result in massive deposition of materials over many years, thereby polluting sources of potable water. The authors acquired ten VES sounding points tha t were then plotted on bi-log graphs to obtain the associated sounding curves; the result obtained by the authors showed that Edjekota has homogeneous subsurface stratification with AAK, KHAA, AKHA and KQHQ curve types. The authors concluded that the generated geoelectric sections have five to six sub-layers to a depth of over 70 m with a lot of loose sand deposits; however, the aquifer zone is between the 30 and 50 m depth.

Okiongbo and Odubo (2012) investigated aquifer transmissivity in parts of Bayelsa State, south Nigeria, where nineteen Vertical Electrical Sounding (VES) stations were occupied using a maximum current electrode separation ranging from 300 to 400 m with the aim of estimating the transmissivity of the alluvial aquifer in areas where no pumping test has been carried out; the authors reported that four of the soundings were carried out near existing boreholes in which pumping test had been carried out. Further, the VES data obtained was interpreted, and layer parameters, such as true resistivities and thicknesses, were determined; the geoelectric parameters were used to generate the Dar Zarrouk parameters, and correlating a Dar Zarrouk parameter (e.g. longitudinal unit conductance) with transmissivity derived from pumping test data, a constant was found which translate longitudinal unit conductance to transmissivity in a hydrogeological setting where effective porosity is the primary control on resistivity and hydraulic conductivity. The authors reported that transmissivity determined from the pumping test data ranged between 1634.0 and 5292.0 m^2/day while transmissivity values estimated from the longitudinal unit conductance (*Lc*) ranged between 721 and 8991 m^2/day. The conclusion drawn from this survey was that the transmissivity estimated from the pumping test (*Tp*) data and transmissivity estimated from the longitudinal conductance (*Lc*) on comparison show excellent correlation (R_2 = 0.92). Finally, the authors noted that the high transmissivity values agree with the geology of the Benin Formation (Coastal Plain sands) consisting of fine-medium-coarse sands, and that the results give a useful first approximation of the transmissivity and could be used to site exploratory boreholes

Mogren *et al*. (2011) discussed a geoelectrical survey using the vertical electrical sounding (VES) on the Eastern Red Sea coast in Jazan area, Southwest Saudi Arabia, to delineate aquifer boundaries. The authors set out to principally map the Quaternary sediments in areas where little is known about the subsurface geology, to infer shallow geological structure, and to identify formations that may present fresh aquifer waters. A further objective was the estimation of the relationship between groundwater resources and geological structures. The authors reported that data were collected at nine locations and were initially interpreted with curve-matching techniques, using theoretically calculated master curves; further, the initial earth models were double checked and reinterpreted using a one-dimensional inversion program in order to obtain final earth models. The result of the VES measurements showed four zones with different resistivity values, corresponding to four different bearing formations, namely: a resistive surface layer at the top; a basalt flow layer in the northern parts; strata saturated with fresh to brackish groundwater; and a water-bearing formation containing Red Sea saltwater.

Amadi *et al*. (2011) used the Vertical Electrical Sounding technique to study the groundwater potential of Pompo Village in the neighbourhood of Gidan-kwano Campus of Federal University of Technology, Minna. Out of the 12 VES points probed, 5 VES stations were chosen as the most viable locations for the development of groundwater resources. Two types of aquifers, which are the weathered basement and fractured basement aquifer, were delineated in their study. These aquifer units may have significant groundwater potential.

Badmus and Olatinsu (2010) reported on a geophysical survey involving thirty four Vertical Electrical Sounding (VES) that was carried out at Federal College of Education, Osiele, Abeokuta, southwestern Nigeria using Schlumberger electrode array.

The authors pointed out that the locations were selected based on existing boreholes. According to their report, the results revealed a maximum of five geoelectric layers, viz: topsoil, sandy clay, clayey sand, shale/clay, sandstone, fractured basement and fresh basement. Furthermore, the authors recognized that three probable aquifer units and one aquitard were delineated with clayey sand occurring in 50%, sandy clay constitutes 24%, fractured basement 24% and shale/clay 2%. The authors concluded that VES 10, 26 and 30 with weathered layer (shale/clay) of thicknesses 14.7, 23.5 and 9.9 m respectively revealed very low yield (not productive). The authors recommended that borehole drilling in the study area should be executed in the peak of the dry seasons during which groundwater level is expected to be low because recharge of the existing boreholes in the study area is largely due to falling precipitation. They expatiated by pointing out that existing boreholes located within the study area characterized by unconfined aquifer while some are confined under pressure between relatively impermeable materials, thus problems of recharging and drying up of borehole can be solved.

Omosuyi (2010) discussed the geoelectric assessment of groundwater prospect and vulnerability of overburden aquifers at Idanre, southwestern Nigeria by noting that the area of study is characterized by extensive outcrops of crystalline basement rocks, largely of granite gneiss origin, and because of inadequate municipal water supply, coupled with the hydrogeologically complex nature of the terrain, individuals and corporate bodies indiscriminately sink tube wells and boreholes within the unconsolidated overburden materials, with glaring lack of concerns for the vulnerability status of aquifers, and possible environmental risk. The author reported that this study involved collecting sixty-five VES depth sounding data from the area of study; of particular interest was the use of resistivity parameter of the geoelectric topmost layer across the area of study to assess the vulnerability of the underlying aquifers to near-surface contaminants. The result of this study indicated that the thickness of the unconsolidated overburden varies from 0.5 m to 15.8 m, where about 81.5% falls within the 1 to 5.9 m brackets, and this shows that unconsolidated materials are generally not significantly thick and hence of apparently low groundwater prospect; further, the author showed that the topmost geoelectric layer has resistivity mostly within the range of 1-100 Ωm (77%) across the area, meaning that resistivity values within these brackets tend to indicate silt or clay sequence, which can constitute effective protective geologic barriers for the underlying aquifers. The author concluded that aquifers within the unconsolidated overburden at Idanre are mostly capped by impervious or semi-pervious materials, thereby geologically protecting the underlying aquifers from near-surface contaminants.

Salako *et al.* (2010) used electrical and seismic refraction methods to investigate the western part of Gidan-kwano Campus, Federal University of Technology, Minna, Niger State. The aim of the survey was to determine the ground water potential of the area and to locate the areas that could be useful for civil engineering purposes. The results obtained from both methods shows that the area appropriate for groundwater development were found in the north-east and north-central part of the survey area having aquifer systems of 100 m width and between 3.8 m and 25 m depth. Also, it was established that the southern part of the survey area, having shallow fresh basement, was the most competent area for civil engineering works.

Salako *et al*. (2009) Investigated Groundwater at the South-western Part (Site A) of Nigerian Mobile Police Barracks (MOPOL 12), David Mark Road, Maitumbi, Minna, using the vertical electrical sounding (VES) technique. A total of thirty-six (36) VES stations were surveyed and the result suggested the existence of three (3) geoelectric layers. The first layer has resistivity values between 20 Ωm - 200 Ωm which corresponds to lateritic topsoil, fadama loam, sandy-clay and gravel. The second layer has resistivity ranging from 200 Ωm - 900 Ωm which is typical of weathered and fractured basement. While the third layer has resistivity value above 1000 Ωm indicating the fresh basement. The result showed that 15 out of the 36 VES points surveyed are viable for groundwater exploitation; and that the north-eastern and southern parts of the study area are best for civil engineering works.

Mohammed *et al*. (2007) employed the Vertical Electrical Sounding (VES) to investigate the land mass covering Minna and its environ in Nigeria aimed at assessing the lithology underneath the area, delineate the aquiferous formations and its depths and thicknesses. The weathered/fractured layers along the transitional zones form the aquiferous formations in the area with a maximum thickness of about 45 m.

Udensi *et al*. (2005) employed vertical electrical sounding (VES) method to carry out hydro geological and geophysical surveys for groundwater at designated locations of the Gidan-kwano main campus of the Federal University of Technology, Minna and reported that the thickness of the weathered zone appears to be too thin to sustain a productive borehole by itself . It was concluded that, the prospect of exclusively exploiting the aquifer of the weathered zone is not realistic and stated that there was no other option than to consider the fracture aquifer system.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials

The materials used for this survey include:

i. ABEM SAS 4000 Terrameter
ii. handheld Global Positioning System (GPS) device
iii. measuring tapes
iv. electrodes
v. current cables
vi. potential cables
vii. ribbons
viii. pegs
ix. geologic hammer

3.2 Method

This study used the electrical resistivity method to investigate the parameters of the subsurface structures of the study area. The Terrameter Signal Averaging System (SAS) model 4000 and its accessories were used to carry out the vertical electrical sounding (VES). Six (6) traverses (A, B, C, D, E and F) with six (6) VES points on each were made, a total of thirty six (36) points (A_1-A_6, B_1-B_6, …, F_1-F_6) were sounded; the inter traverse and inter VES point spacing were 100 m and the Schlumberger array pattern with half inter electrode spacing (AB/2) ranging from 1-100 m was adopted. Through a pair of current electrodes A and B, direct current (DC) was supplied into the ground and the potential difference was measured by means of another pair of electrodes M and N called the potential electrodes.

To increase the depth of investigation, the current electrode separation was increased while the potential separation remained constant.

The geometric factor, K, was first calculated for all the electrode spacing using the formula: $K = \pi\left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right)$ (3.1)

Then the apparent resistivity (ρ_a) values were obtained by multiplying K by the resistance(R) values

$\rho_a = KR$ (3.2)

Also, the apparent resistivity values obtained were plotted against AB/2 using winResist software and from the plots; the resistivity, depth and thickness of each of the subsurface layer were deduced.

Table 3.1: Ranges of resistivity of various rocks component in basement complex (Esimai, 2017).

Rock Type	Range of Resistivity (Ω m)
Clay	1-100
Famada loam	30-90
Weathered basement	20-500
Alluvium and sand	10-800
Weathered laterite	150-900
Fresh laterite	900-3500
Granite	$300\text{-}10^5$
Sand	500-5000
Quartzite (various)	$10 – 2 \times 10^8$
Gravel	100-5000
Fractured basement	500-1000
Fresh basement	> 1000

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Geoelectric Section

The Geoelectric section (VES curve) as shown in Figure 4.1, provides information about the subsurface layer resistivity, depth and thickness as summarised in table 4.1.

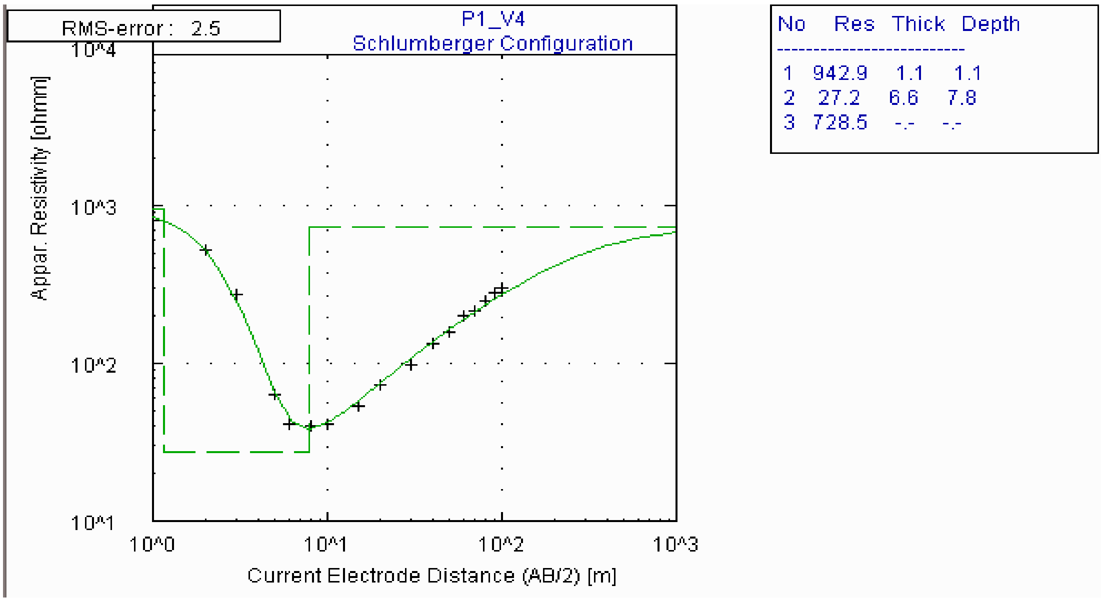

Figure 4.1: Geoelectric section of VES point A_4

Table 4.1 shows the summary of results obtained from each geoelectric section across profile A to F which reveals that the study area is underlain by three (3) geoelectric subsurface layers. The first layer which is the top layer has resistivity value ranging from 10.6 – 1679.8 Ωm, its depth and thickness varies between 0.5 – 4.2 m and 0.5 – 4.2 m respectively which corresponds to the geoelectrical parameters of fadama loam, weathered laterite and fresh laterite (table 3.1). The second layer has resistivity value of 4.8 – 61.5 Ωm, depth of 2.7 – 23 m and thickness of 2.1 – 21.2 m; this layer refers to the weathered/fractured basement. The resistivity of the third layer ranged from 158.7 – 1,421.5 Ωm, its depth and thickness are undefined.

4.2 Iso-Resistivity Contour Maps

4.2.1 Iso-resistivity contour map of the first layer

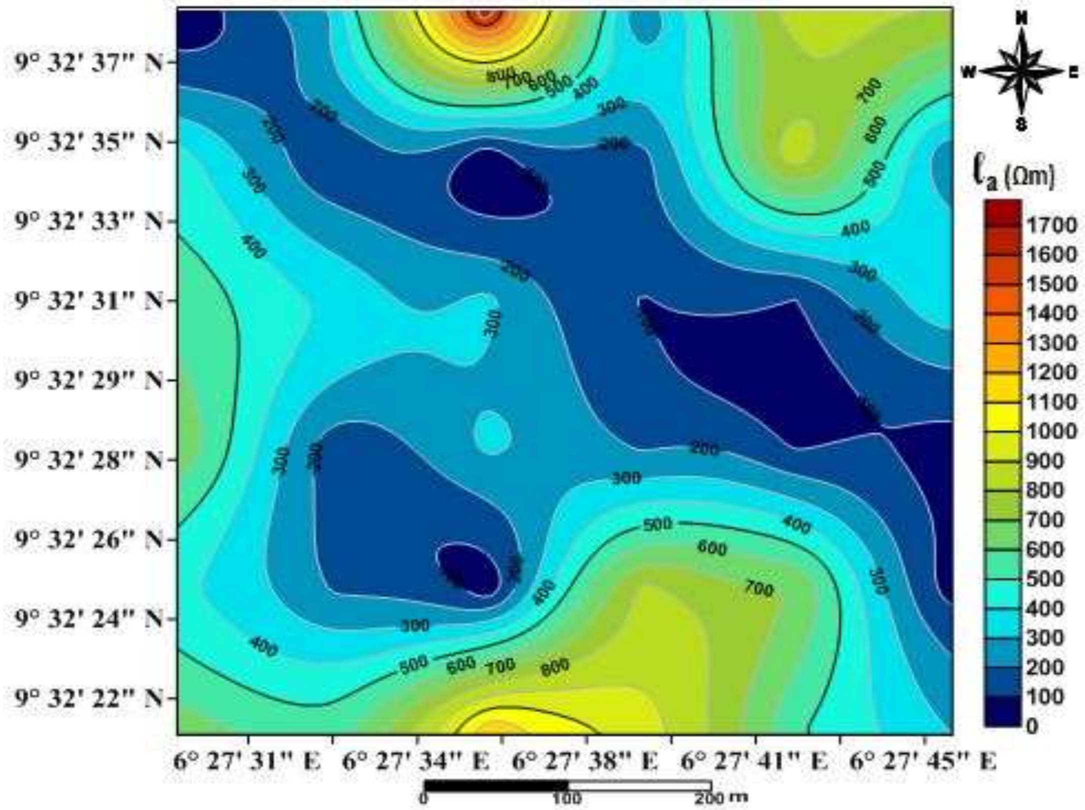

Figure 4.2: Iso-resistivity contour map of the first layer.

An interval of 100 Ωm was used to generate the iso-resistivity contour of the first layer (Figure 4.2). The range of the resistivity values is 10.6 to 1,679.8 Ωm. The areas with the lowest resistivity value trends from northwest to southeast with an extension towards southwest, it is characterised by fadama loam, sand and gravel; while those with high resistivity value are at the northern and southern parts.

4.2.2 Iso-resistivity contour map of the second layer

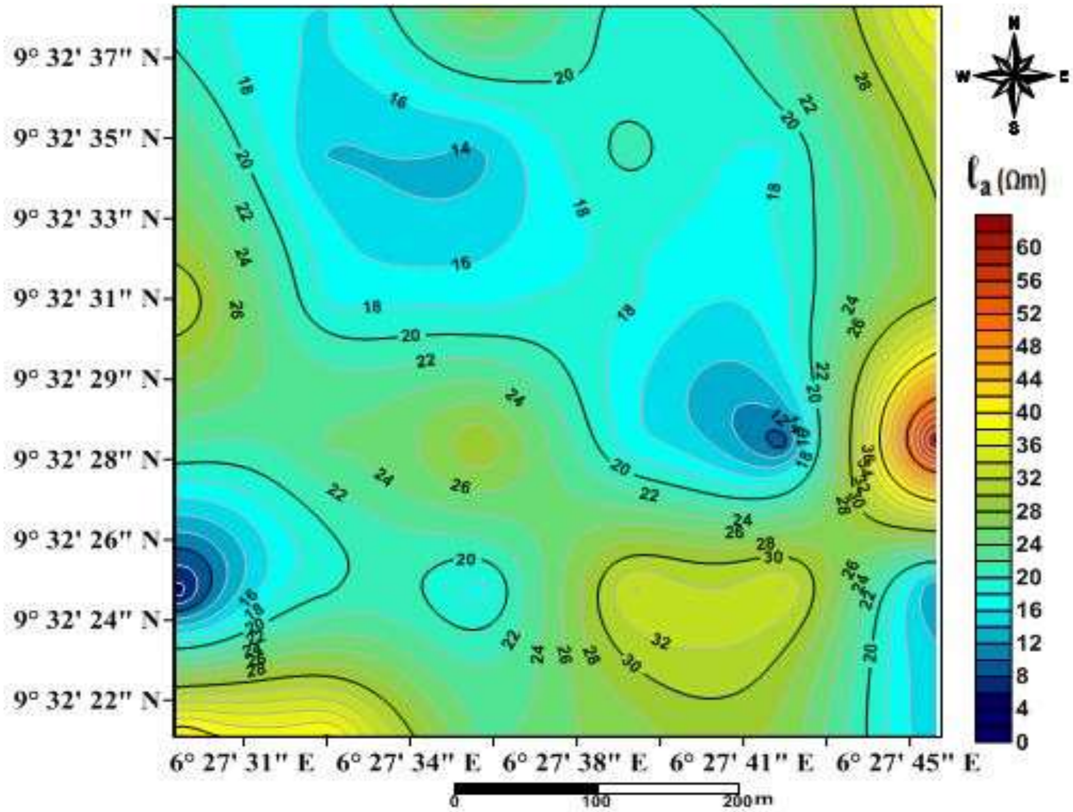

Figure 4.3: Iso-resistivity contour map of the second layer

The iso-resistivity contour of the second layer (Figure 4.3) was generated at an interval of 4 Ωm. The contour shows that the resistivity of the weathered/fractured zone is higher at the northeastern, eastern and southern part of the study area while the northern and central part are characterised by lower resistivity value.

4.2.4 Iso-resistivity contour map of the third layer

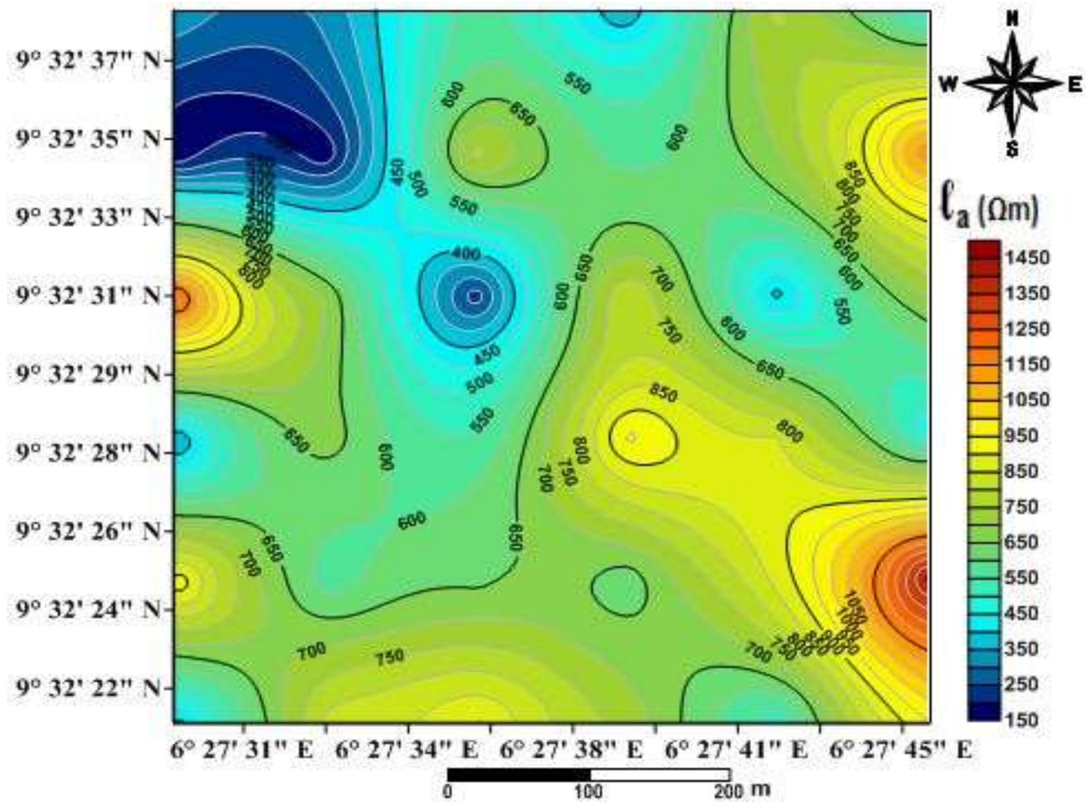

Figure 4.4: Iso-resistivity contour map of the third layer

The iso-resistivity contour of the third layer (Figure 4.4) reveals that the study area is highly weathered/fractured. The contour was generated at 100 Ωm interval with resistivity values ranging from 158.7 to 1421.5 Ωm. The third layer has its lowest resistivity value majorly at the north-western part of the study area while those of high resistivity occupy the north-eastern, south-western and south-eastern parts.

4.3 Isopach Contour Map of the Study Area

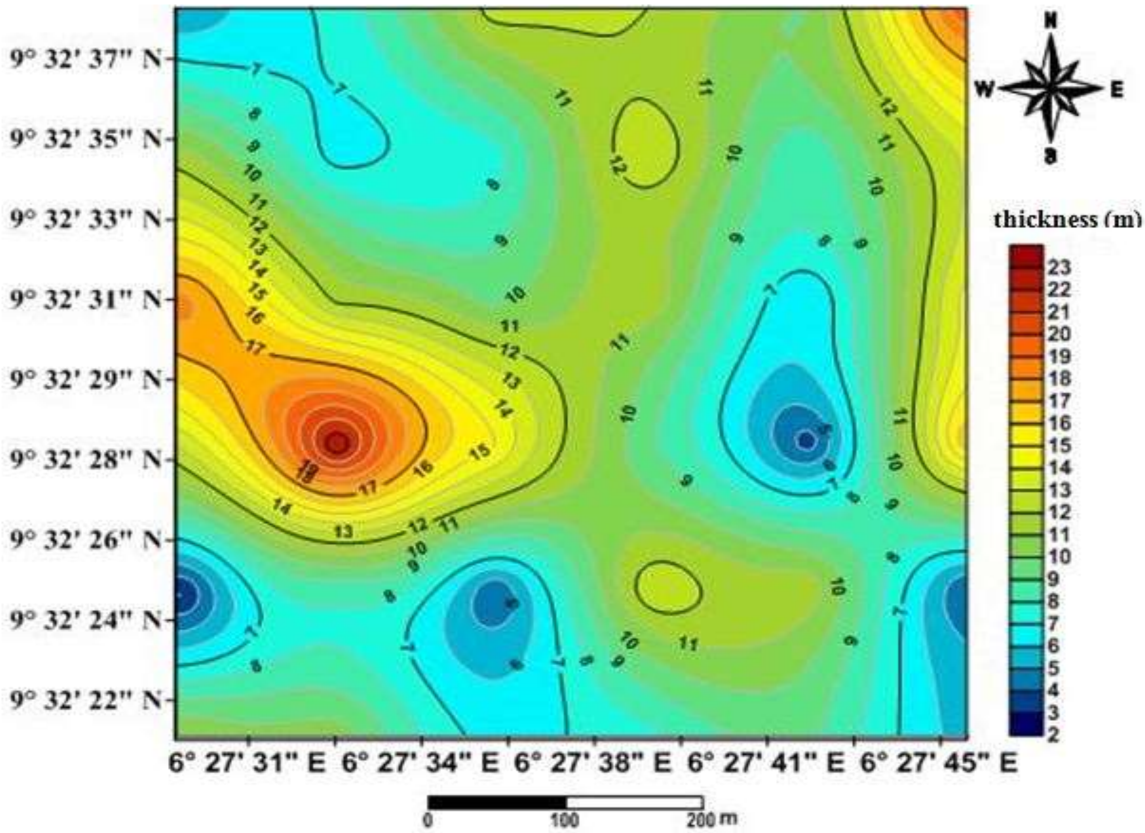

Figure 4.5: Isopach (Overburden) contour map of the study area

The Isopach (overburden contour map) was generated at an interval of 1 m, the values range from 2.7 to 23 m as shown in Figure 4.5. The contour reveals that overburden thickness is higher at the north-eastern and west-central parts of the study area while the north-western, southern, south-eastern and south-western parts are of lower overburden thickness.

4.4 The Curve Types

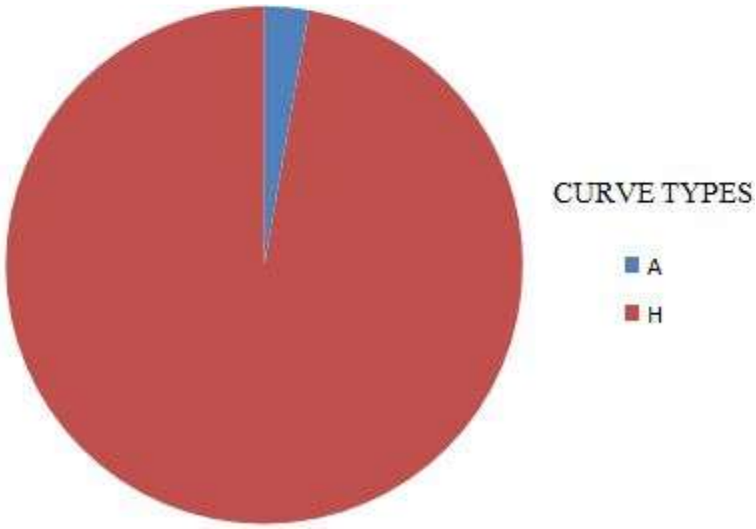

Figure 4.6: Curve type distribution

The curve distribution (Figure 4.6) indicates two (2) types. The H-type is the dominant curve with 97% of the area. The weathered/fractured layer in the H-curve type is usually characterized with low resistivity value made up of clayey or sandy clay, and it is usually water saturated and highly porous (Olorunfemi *et al*. 1999). The A-curve type consistitute 3% of the area.

4.5 Geologic Sections of the Study Area

Figure 4.7 to 4.12 reveals the vertical geologic section through profile A – F showing the layers of the subsurface structure, their depth and thickness.

4.5.1 Geologic section of profile A

The geologic section through profile A (Figure 4.7) reveals that the profile is characterised by three layers. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 294.1 – 1188.8 Ωm, 0.7 – 1.2 m and 0.7 – 1.2 m respectively.

The second layer is a weathered layer, its resistivity, depth and thickness varies between 14.0 – 42.5 Ωm, 5.5 – 11.2 m and 4.8 – 10.2 m respectively; it spreads across the entire profile. The third layer underlies the second layer, it is the fractured/fresh basement, it has a resistivity range of 379.6 – 956.7 Ωm and undefined depth and thickness. The fresh basement is uplifted towards the surface at VES A_6 which suggest that the point is competent for

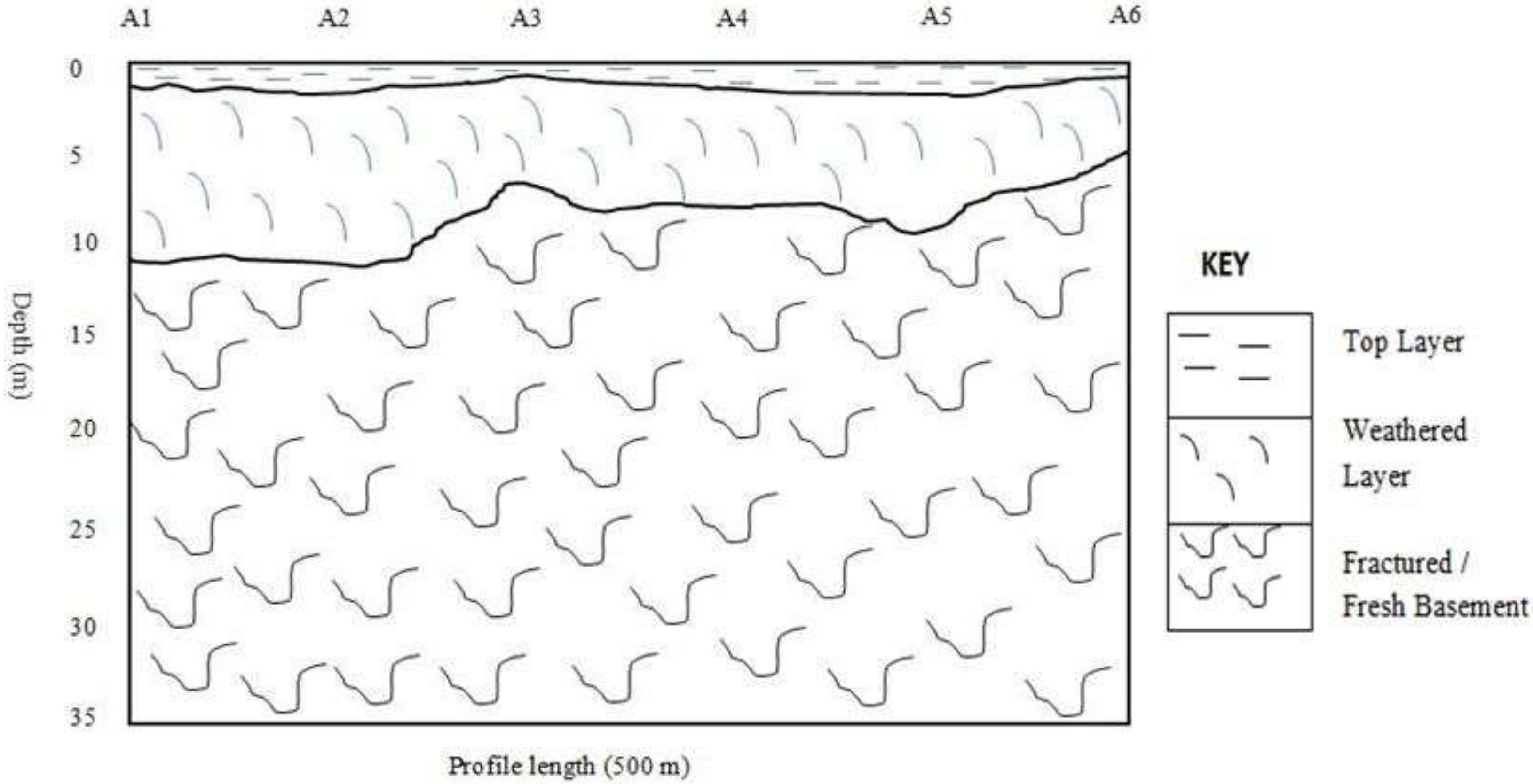

Figure 4.7: Vertical geologic section through profile A

civil engineering activities. The section also reveals a reservoir of about 9.2 m depth and 8m thickness at VES A_5

4.5.2 Geologic section of profile B

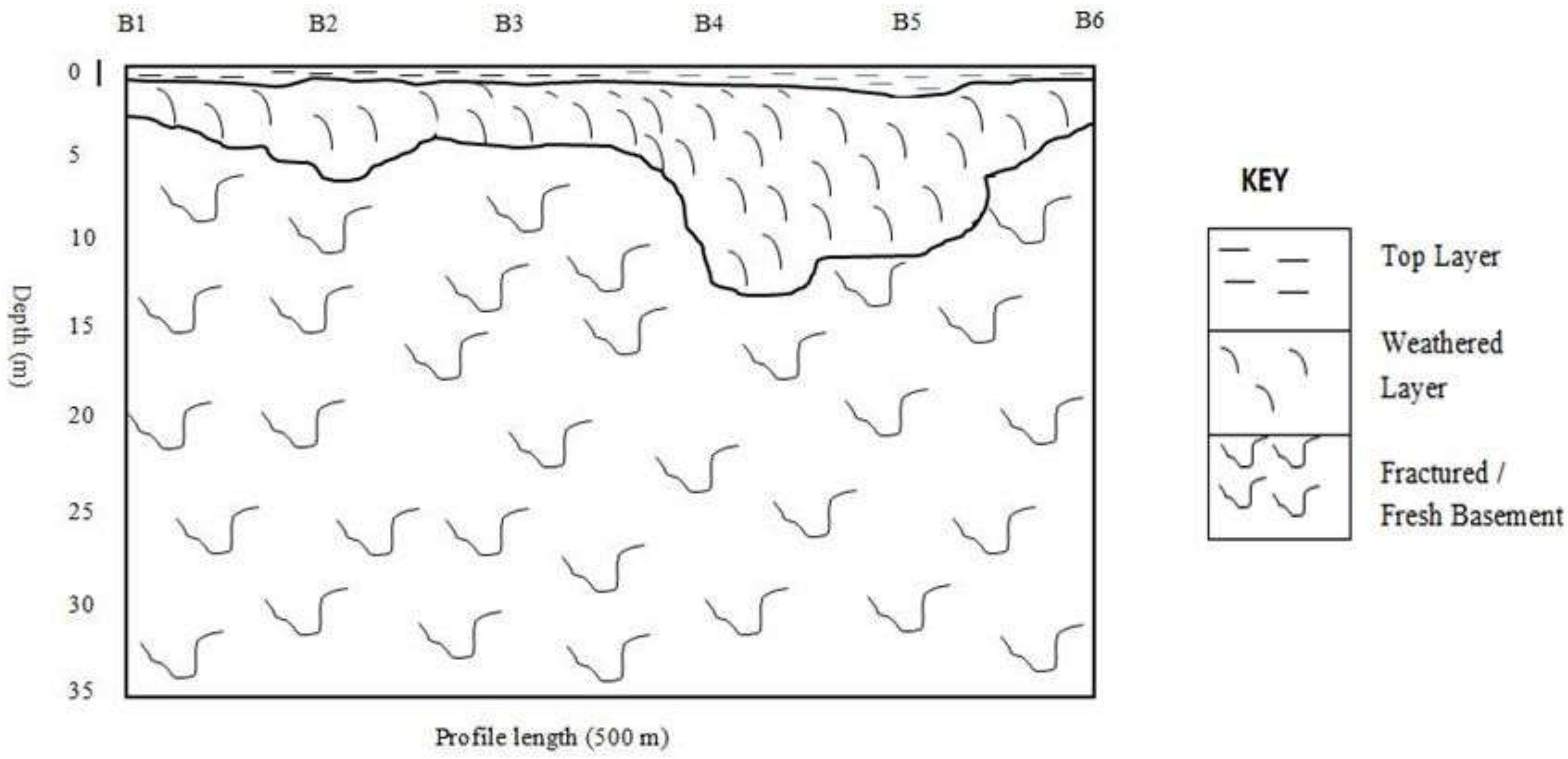

Figure 4.8: Vertical geologic section through profile B

The geologic section through profile B (Figure 4.8) shows that the profile is characterised by three layers. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 38.1 – 822.1 Ωm, 0.5 – 1.6 m and 0.5 – 1.6 m respectively. The second layer is a weathered layer, its resistivity, depth and thickness varies between 4.8 – 34.4 Ωm, 2.7 – 13.0 m and 2.1 – 12.1 m respectively; it spreads across the entire profile. The second layer is underlain by the third layer which is the fractured/fresh basement, it has a resistivity value of 572.9 – 1,421.5 Ωm and undefined depth and thickness; also, the profile has an aquifer spreading from VES B_4 to VES B_5 with average depth and thickness of 12.4 m and 11.1 m respectively. The section also reveals that the best points for civil engineering activities are VES B_1 and VES B_6

4.5.3 Geologic section of profile C

Figure 4.9 shows the geologic section through profile C, it reveals that three distinct layers exist therein. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 68.9 – 675.3 Ωm, 0.5 – 2.8 m and 0.5 – 2.8 m respectively. The second layer is a weathered layer which also spreads across the entire profile, its resistivity, depth and thickness varies between 8.7 – 61.5 Ωm, 3.4 – 23.0 m and 3.0 – 21.2 m respectively. The third layer which is the fractured/fresh basement has a resistivity range of 341.0 – 963,0 Ωm and undefined depth and thickness. VES C_5 will be favourable for civil engineering works as depth to fresh basement is shallow at the point; also VES C_2 will be a good point for groundwater development.

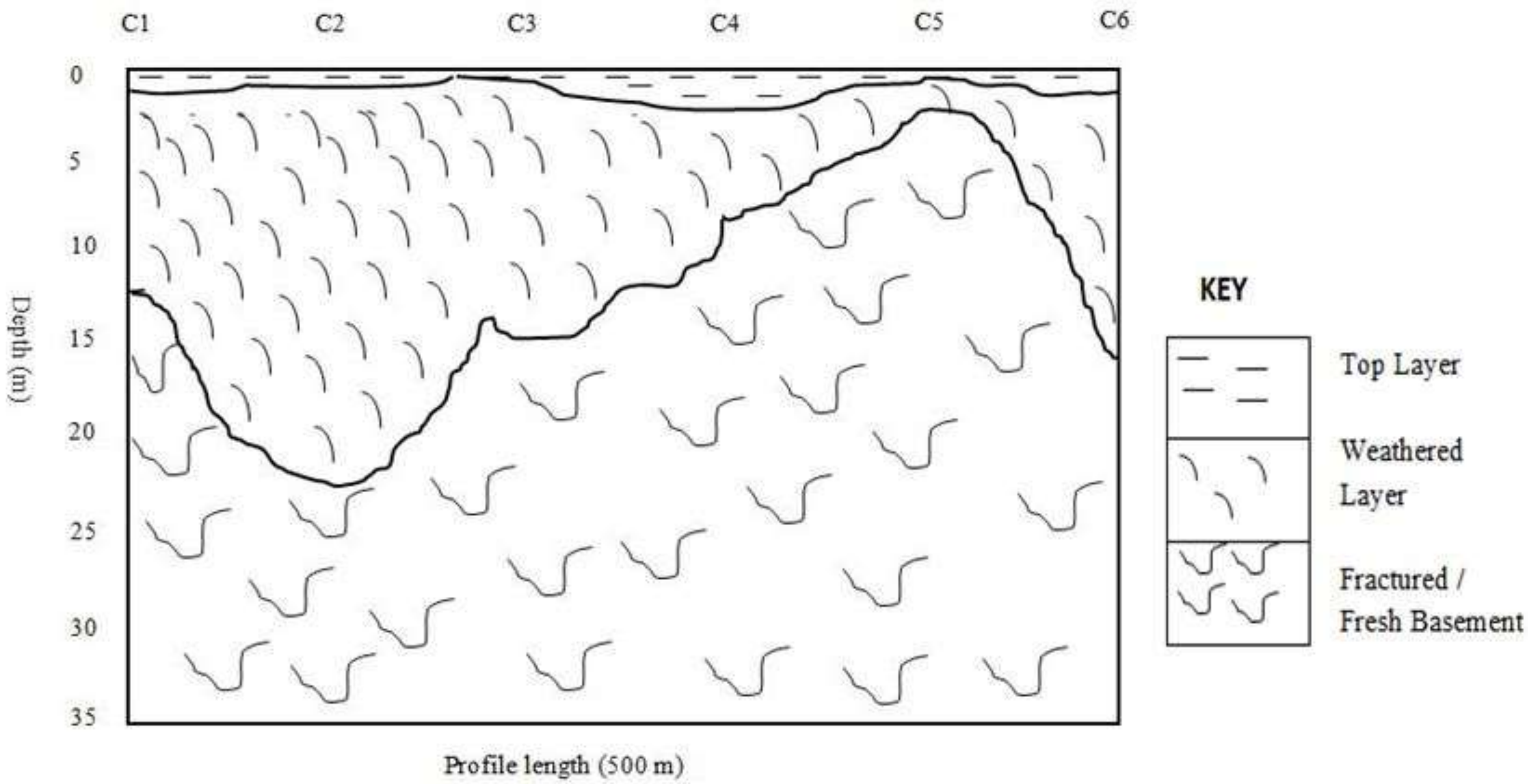

Figure 4.9: Vertical geologic section through profile C

4.5.4 Geologic section of profile D

The geologic section through profile D (Figure 4.10) reveals that the profile is characterised by three layers. The first layer which is the top soil spreads through the entire profile; its resistivity, depth and thickness range from 97.1 – 581.5 Ωm, 0.9 – 3.5 m and 0.9 – 3.5 m respectively. The second layer which is the weathered layer has resistivity, depth and thickness of 17.3 – 32.8 Ωm, 6.0 – 18.6 m and 5.2 – 16.1 m respectively; it spreads across the entire profile. The fractured/fresh basement which is the third layer underlies the second layer, it has a resistivity range of 219.2 – 1236.5 Ωm with depth and thickness undefined.

4.5.5 Geologic section of profile E

Figure 4.11 shows the geologic section through profile E, it reveals that three distinct layers exist therein. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 18.5 – 871.2 Ωm, 0.5 – 2.8 m and 0.5 – 2.8 m respectively. The second layer is a weathered layer which also spreads across the entire profile, its resistivity, depth and thickness varies between 13.5 – 31.3 Ωm, 6.6 – 13.2 m and 6.1 – 12.2 m respectively. The third layer which is the fractured/fresh basement has a resistivity range of 158.7 – 1138.8 Ωm with an undefined depth and thickness.

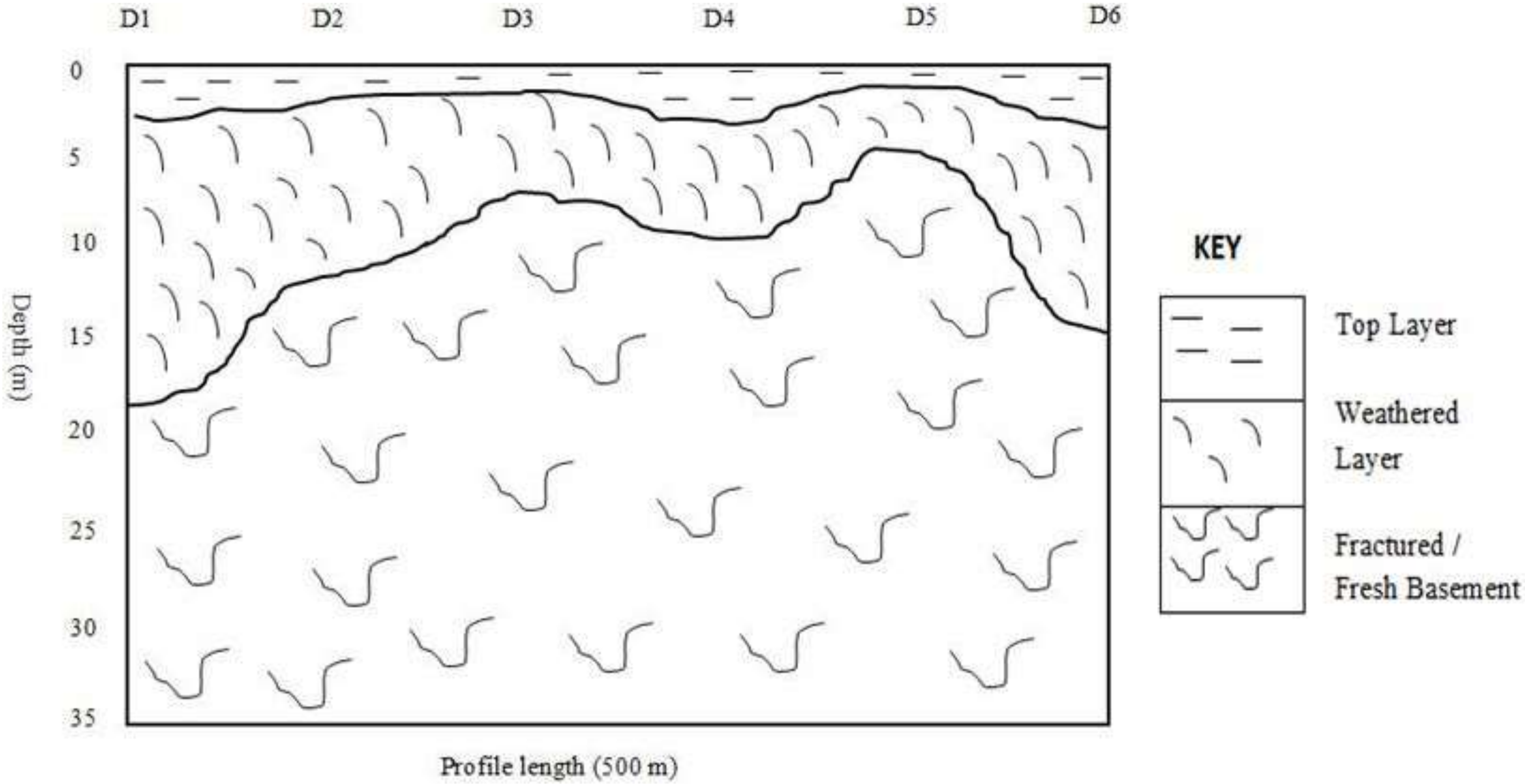

Figure 4.10: Vertical geologic section through profile D

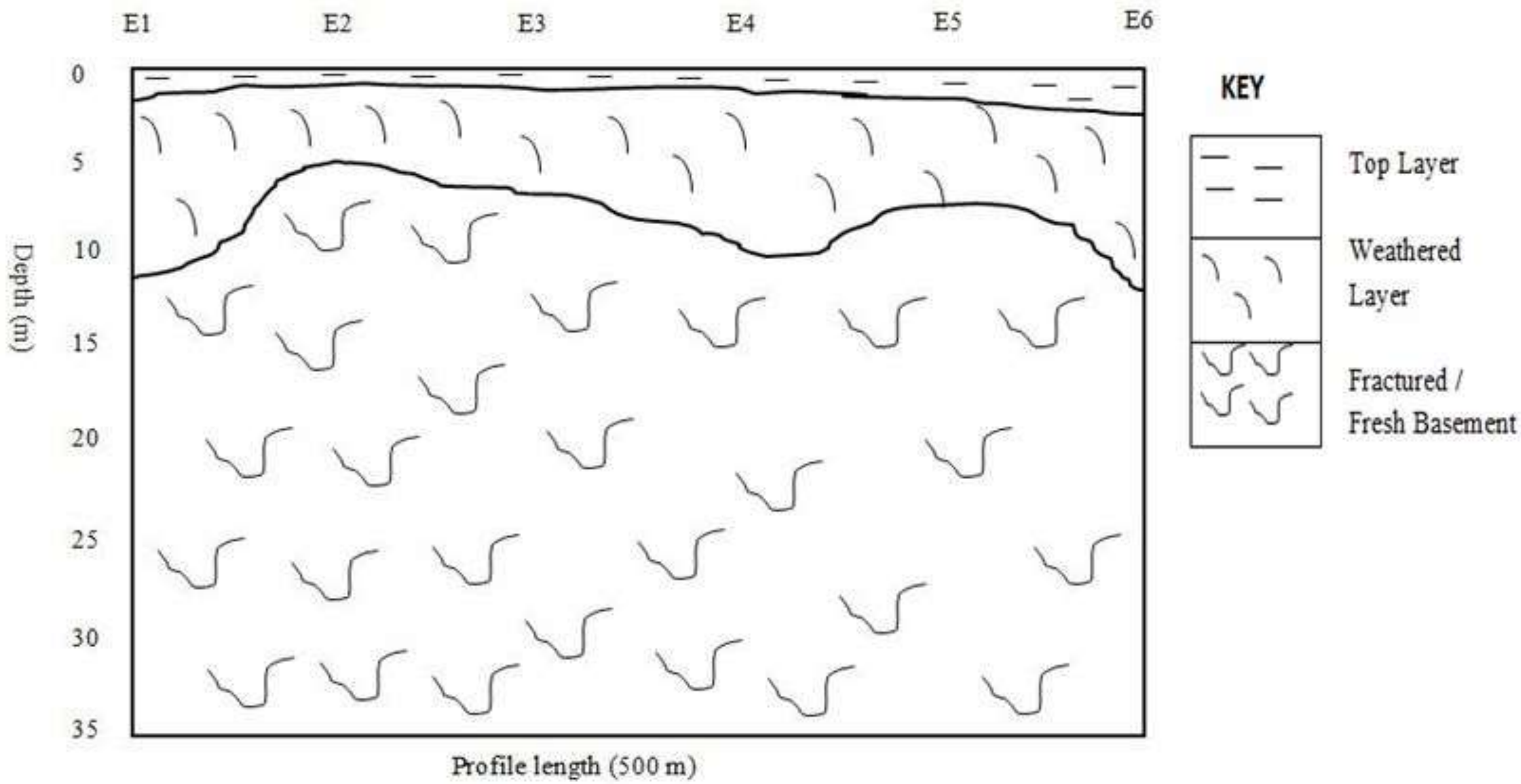

Figure 4.11: Vertical geologic section through profile E

4.5.6 Geologic section of profile F

Figure 4.12 shows the geologic section through profile F, it reveals that three distinct layers exist therein. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 10.6– 1679.8 Ωm, 0.6 – 4.2 m and 0.6 – 4.2 m respectively. The second layer is a weathered layer which also spreads across the entire profile, its resistivity, depth and thickness varies between 15.8 – 39.2 Ωm, 5.2 – 20.0 m and 4.2 – 15.8 m respectively. The third layer which is the fractured/fresh basement has a resistivity range of 312.2 – 763.5 Ωm with an undefined depth and thickness. VES F_1 will be favourable for civil engineering works as depth to fresh basement is shallow at the point; also VES F_3 will be a good point for groundwater development.

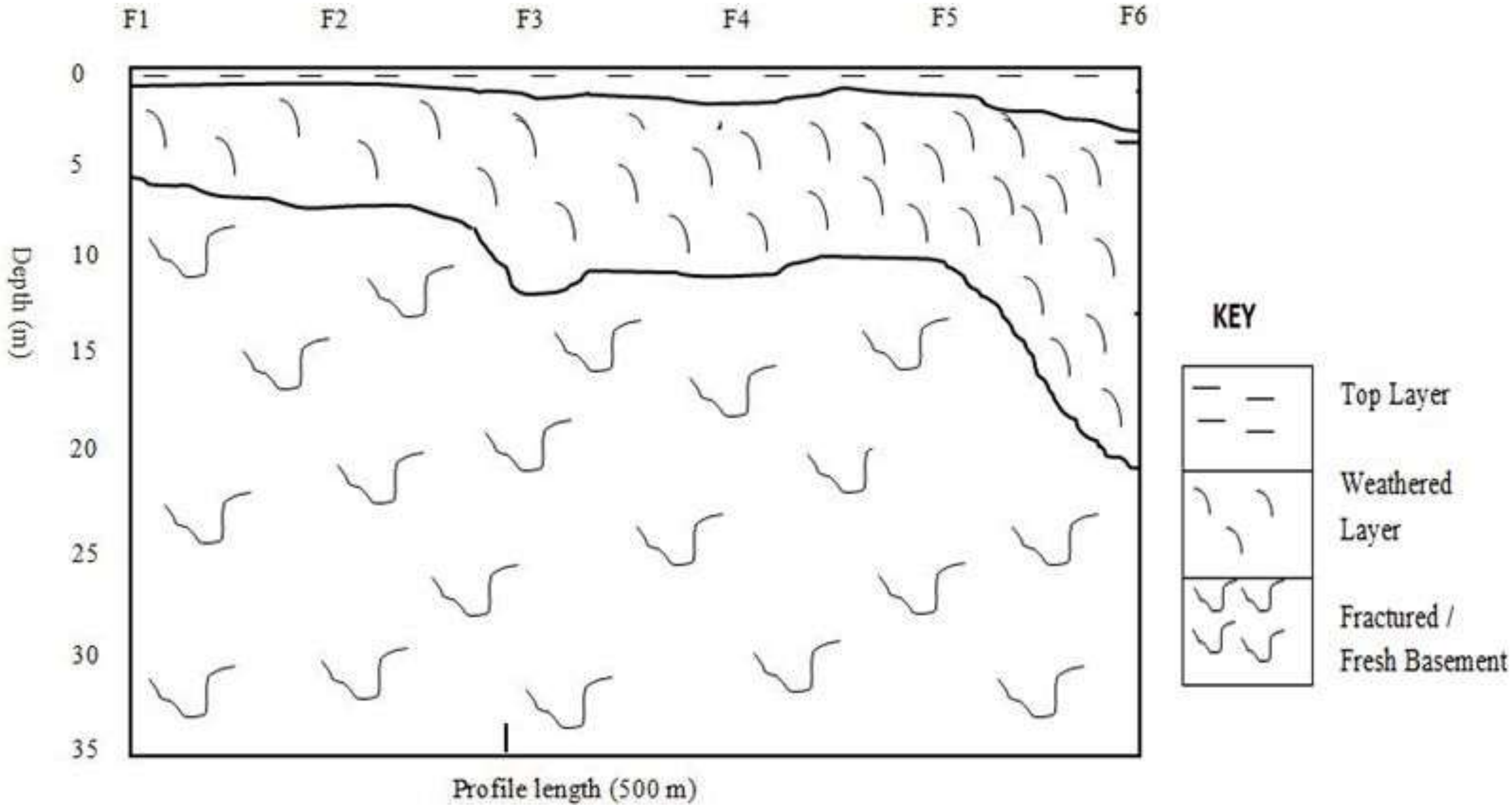

Figure 4.12: Vertical geologic section through profile F

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results obtained from the analysis of the data acquired in field of survey clearly showed that the electrical resistivity method is suitable for and very efficient in investigating the parameters of the subsurface structures. The study area is characterised by three (3) geoelectric layers as clearly revealed by the result, they are: the top layer which consist of fadama loam, sand and gravel; weathered layer and the fractured/fresh basement layer.

The resistivity of the top layer, weathered layer and fractured/fresh basement layer varies from 10.6 to 1,679.8 Ωm, 4.8 to 61.5 and 158.7 to 1,421.5 Ωm respectively across the entire study area; the depth of the top layer ranges from 0.5 to 4.2 m, that of the weathered layer varies from 2.7 to 23.0 m while that of the fractured/fresh basement layer is undefined across the six(6) profiles investigated; also, the study area has 0.5 to 4.2 m and 2.1 to 21.2 m as the thickness of its the top layer and weathered layer respectively, the fractured/fresh basement layer has an undefined thickness.

Isoresistivity maps were produced for the top layer, weathered layer and the fractured/fresh basement layer. An interval of 100 Ωm was used to generate the isoresistivity contour of the first layer (figure 4.2). The areas with the lowest resistivity value trends from northwest to southeast with an extension towards southwest while those with high resistivity value are at the northern and southern parts; similarly, The iso-resistivity contour of the second layer (Figure 4.3) was generated at an interval of 4 Ωm. The contour shows that the resistivity of the weathered/fractured zone is higher at the northeastern, eastern and southern part of the study area while the northern and central part are characterised by lower resistivity value; also, The iso-resistivity contour of the third layer (Figure 4.4) was generated at 100 Ωm interval, the contour reveals that the third layer has its lowest resistivity value majorly at the north-western part of the study area while those of high resistivity occupy the north-eastern, south-western and south-eastern parts.

Also, The Isopach (overburden contour map) was generated at an interval of 1 m, the contour reveals that overburden thickness is higher at the north-eastern and west-central parts of the study area while the north-western, southern, south-eastern and south-western parts are of lower overburden thickness.

The parameters (resistivity, depth and thickness) of the layers were employed to delineate the aquifer potential of the study area, five VES points A_5, B_4, B_5, C_2, and F_3 were delineated as groundwater potential points of the area, their weathered layer has resistivity value varying from 24.2 to 34.4 Ωm while its deph and thickness ranged from 9.2 to 23.0 m and 8.0 to 21.2 m respectively as indicated in table 4.2.

Also, the sites suitable for structures within the study area were delineated after careful consideration was given to the resistivity, depth and thickness of the subsurface layers, five VES points having depth to fresh basement varying between 2.7 to 5.5 m were chosen; the points are: A_6, B_1, B_6, C_5 and F_1 (table 4.3).

5.2 Recommendations

1. Government or individuals who wish to site boreholes within the study area should consider VES stations A_5, B_4, B_5, C_2, and F_3.
2. Quality excavation work should be carried out if structures must be built anywhere within the study area aside VES points A_6, B_1, B_6, C_5 and F_1 .
3. Another geophysical method like Seismic refraction should be employed for further research work in this area.

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