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ELECTRICAL RESISTIVITY INVESTIGATION FOR GROUND WATER EXPLORATION OF THE BASEMENT COMPLEX OF MALUMFASHI, NIGERIA

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ABSTRACT Twenty four Vertical Electrical Soundings (VES) were conducted along predetermined profiles situated on latitude 11°7.6′N to 11°7.7′N and longitude 7°6.2′E to 7°6.3′E at Malumfashi, Nigeria. The survey was carried out to investigate the fractured zones of the area and to map out the subsurface layers along the profiles. Terrameter SAS 300 system was used for the data acquisition at station intervals of 100m using Schlumberger array. Maximum current electrode separation (AB) of 200m was used. Interpretation was performed using computer software (IPI2win and Sufer11.0). The interpreted result was used to produce geoelectric and geologic sections and specialized maps (Iso-resistivity map, Aquifer thickness map, Depth to the basement map) were also drawn from which conclusion was drawn. The result of the study indicates that the area is underlain by three to four subsurface layers. The resistivity of the first layer ranges from 14 ohm-m to 273 ohm-m with an average thickness of 2.0m. This layer is the superficial cover composed of sand, clay and silt. The second layer has resistivity value between 15 ohm-m to 567 ohm-m which is the weathered basement and lateritic sand in some places. The third layer has 109 ohm-m to 799 ohm-m. This layer is the fractured basement with varying thickness of 4.0m to 38.9m. The fourth layer is the crystalline basement rock with resistivity values greater than 1000 ohm-m and infinite thickness. The investigations show that the aquifer in the area which is confined occurs in the weathered and fractured basement. From the maps analyzed and other information in the survey area, the fractured regions around VES 04,11,12,16 and 17 are the most promising for groundwater exploration.

Keywords: Vertical electrical sounding (VES), Geoelectric, Groundwater, Aquifer, Borehole

INTRODUCTION

Geophysical investigations of the earth involve studying the physical properties of the earth, thereby providing vital information on subsurface material conditions for numerous practical applications. By taking measurements near the earth's surface that are influenced by the properties of the earth's interior vary vertically and laterally that reflect the subsurface geology. Alternatively, another method of investigating subsurface geology is by pitting and drilling which provide information only at discrete locations and are expensive. Many geophysical investigations are non – intrusive and non – invasive, thus, avoiding the disruption caused by intrusive investigations such as pitting and drilling. Geophysical investigations cover large site areas, rapidly and optimize the targeting of necessary intrusive inspections. In environments where intrusive investigations are not permissible, only geophysics is the answer. Geophysical techniques are often useful for discovering unknown subsurface conditions; most of these techniques are classified as non – invasive, requiring only minimal disturbance of surface cover of the earth. The methods employed are electrical, gravity, magnetic, seismic, electromagnetic methods e.t.c. The methods are cost effective and capable of detecting and delineating local features of interest (Kearey and Brooks, 1988).

All resistivity methods employ an artificial source of current, which is introduced into the ground through point electrodes or long line contacts; the latter arrangement is rarely used nowadays. The procedure is to measure the potential difference between two other electrodes in the vicinity of the current flow. It is possible to determine an effective or apparent resistivity of the subsurface, because the current is measured as well. The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From the interpretation of these measurements, the true resistivity is related to various geological parameters such as the minerals and fluid contents, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. It is routinely used in hydrogeological and engineering investigations to investigate the subsurface geology (Kearey and Brooks, 1988).

In geotechnical applications, resistivity surveys are used for dam stability studies, bedrock strength, mapping of overburden, faults and fractures. While, in environmental applications, resistivity surveys are capable of mapping overburden depth, fractured rock units, waste dumps, faults, stratigraphy, saltwater intrusion, contamination plumes and voids.

LOCATION OF THE STUDY AREA

The study area is in Malumfashi, Katsina State, Nigeria.

Malumfashi is situated within the northern Nigerian Basement Complex, in the southern tip of Katsina State and is about 150 kilometres from Katsina City. Malumfashi in particular has its boundary with Kano State in the east and Bakori Local Government in the southwest, Kankara in the northwest and Musawa Local Government in the north respectively all in Katsina State. In the south it is bounded by Kafur Local Government about 18 kilometers away from Malumfashi. The study area is situated on latitude 11°44/N to 11°48/N and longitude 7°35/E to 7°38/E, with an average elevation of 630m above sea level (see Fig.1).

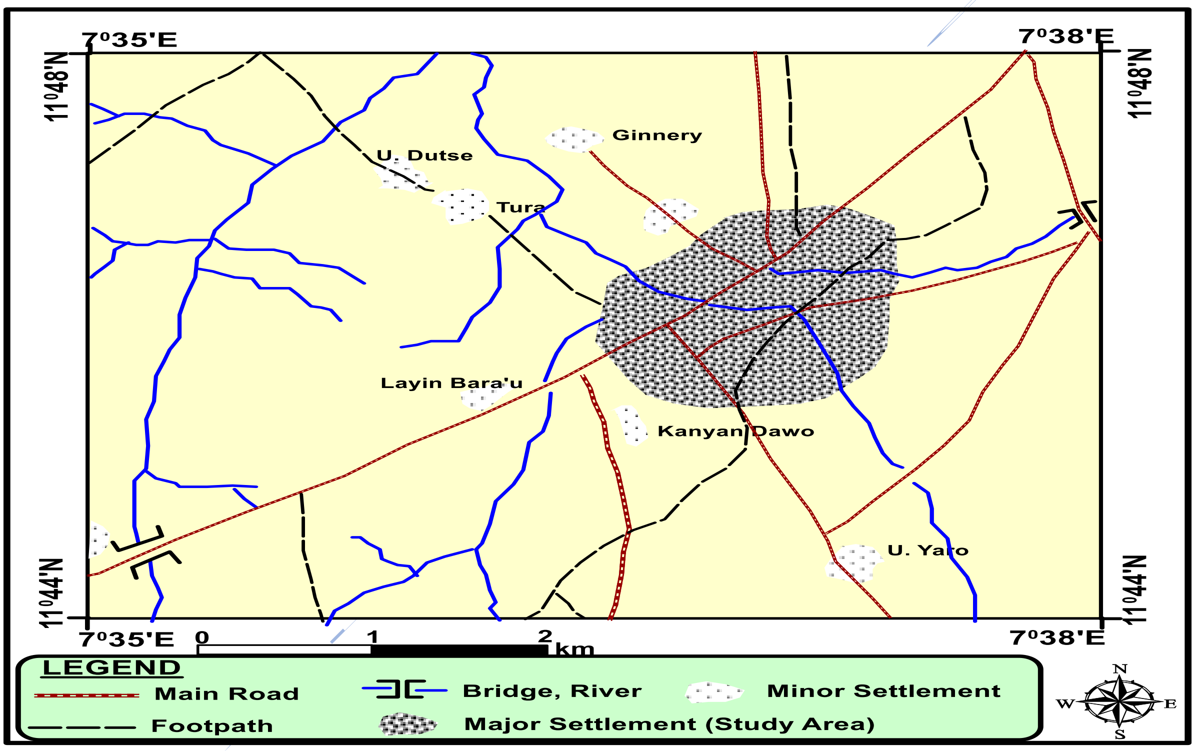

Fig.1: Location map showing the study area (Adopted from Geography Department Umaru Musa Yar'adua University, Katsina, 2011).

GENERAL GEOLOGY OF THE STUDY AREA

The study area is located within the Nigerian basement complex which is within the gneiss rock of northern Nigeria. The rock is bounded by the older granite in the south – east and late Proterozoic metasediments to the northern part (McCurry, 1970).

Oyawoye (1964) grouped the rocks within the Nigerian basement complex into three categories as, older metasediments, and older granite, gneiss, migmatites and younger metasediments (see Fig.2).

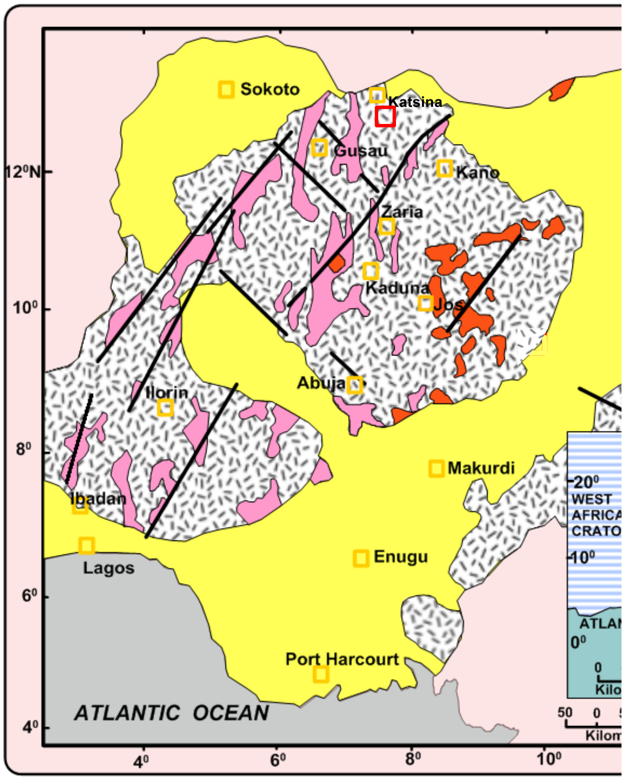

Fig. 2: Simplified geological map of Nigeria (Modified after Garba, 2003)

PRINCIPLE OF RESISTIVITY METHODS

The principle of the electrical resistivity method is the measurement of an earth resistance by passing low frequency current into the ground through two metal stakes or electrodes and measuring the potential difference resulting across another two electrodes. If the distances between the four electrodes are known then the current and potential difference measurements may be used to calculate a "resistivity" value of the earth (Thomas, 1986). All resistivity methods employ an artificial source of current which is introduced into the ground through point electrodes or long line contacts. The latter arrangement is rarely used nowadays. The procedure is to measure potential difference at other electrodes in the vicinity of the current flow. Because the current is measured as well, it is possible to determine an effective apparent resistivity of the subsurface. In this regard the resistivity technique is superior at least theoretically to all the other electrical methods because quantitative results are obtained by using a controlled source of specific dimension (Telford *et al*., 1990).The resistivity of rocks usually depends on the amount of groundwater present and upon the amount of salt dissolved in it. It decreases by the presence of many ore minerals and by high temperature (Alan et al., 2000). Conduction of electricity through rocks is of three types; electronic conduction which occurs when the mineral grains are electrically conductive as with minerals such as pyrite, and magnetite. Most common mineral grains such as quartz, feldspar and calcite are non-conductive and conduction is ionic or through ions in the interstitial fluid and the third type of current conduction is dielectric in poor conductors or insulators having very few charge carriers or even none.

THEORY OF D.C. RESISTIVITY METHODS

The resistivity methods are based on measuring the electric potential differences between one electrode pair, while transmitting direct current (DC) between another electrode pair. The depth of penetration varies with the separation between the two current electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground.

The principle underlying the resistivity method is embodied in Ohm's Law, which states that the current density at a given point is proportional to the electric field intensity at that point. Thus, Ohm's law gives the relationship between current density **J** (amperes/m^2) and electric field intensity **E (V/m)** as:

$$\mathbf{J} = \sigma \mathbf{E} \qquad (2.1)$$

where σ is the conductivity of the medium.

E is also the gradient of a scalar electric potential u (volts),

J is the magnitude of the current density. Thus,

$$\mathbf{E} = -\nabla \mathbf{u} \qquad (2.2)$$

Now, putting equation (2.2) into equation (2.1)

$$\mathbf{J} = -\boldsymbol{\sigma} \nabla \boldsymbol{u} \qquad (2.3)$$

From the divergence condition,

$$\nabla . \mathbf{J} = \mathbf{0} \qquad (2.4)$$

Thus, from equation (2.3)

$$\nabla . \mathbf{J} = -\nabla . (\boldsymbol{\sigma} \nabla \boldsymbol{u}) = \mathbf{0} \qquad (2.5)$$

or

$$\nabla \boldsymbol{\sigma} . \nabla \boldsymbol{u} + \boldsymbol{\sigma} \nabla^2 \boldsymbol{u} = \mathbf{0} \qquad (2.6)$$

For a homogeneous earth, σ is a constant and since the derivative of a constant is equal to zero, then the first term in equation (2.6) vanishes and hence,

$$\nabla^2 u = 0 \qquad (2.7)$$

By applying boundary conditions, Equation (2.7) can be solved for specific cases. For a single current electrode at the surface of a homogeneous earth, Equation (2.7) can be expressed in spherical polar coordinates as:

$$\nabla^2 u = \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 \frac{\partial u}{\partial r}\right] + \frac{1}{r^2 Sin\theta}\frac{\partial}{\partial \theta}\left[sin\Theta \frac{\partial u}{\partial \theta}\right] + \frac{1}{r^2 Sin^2\theta}\left[\frac{\partial^2 u}{\partial \emptyset^2}\right] = 0 \qquad (2.8)$$

For the single current source, there is complete symmetry of current flow with respect to θ and $\emptyset$ directions and the derivatives with respect to these directions are zero. Therefore, Equation (2.8) becomes

$$\frac{d}{dr}\left(r^2 \frac{du}{dr}\right) = 0 \qquad (2.9)$$

Equation (2.9) can be solved further by differentiating twice to arrive at

$$\frac{du}{dr} = \frac{IP}{2\pi}\left(\frac{I}{r}\right) \qquad (2.10)$$

Generally, the potential difference between two arbitrarily located points on the surface of a homogeneous isotropic ground is given by the expression

$$\Delta u = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right) \qquad (2.11)$$

where ρ is the resistivity, I is the current and r_1, r_2, r_3, r_4, are the inter electrode distances,

For a real earth which is not homogeneous ρ becomes the apparent resistivity ρ_a

and hence,

$$\rho = \rho_a = \frac{\Delta u}{I} \frac{2\pi}{\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)} \qquad (2.12)$$

The result is independent of the position of the electrodes and is not affected when the current electrodes and the potential electrodes are interchanged. The resistance is calculated using Ohm's Law.

$$R = \frac{u}{I} \qquad (2.13)$$

where R is the resistance in ohms, u is the potential difference in volts, and I is the current in amperes.

The material parameter ρ which is the inverse of electrical conductivity σ is related to the resistance via a geometric factor k_f. The apparent resistivity ρ_a of the ground can be calculated using, the relation,

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$$k_f = \frac{\Delta u}{I} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad (2.14)$$

$$\text{where } k_f = \frac{2\pi}{\left(\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}\right)} \quad - \quad - \quad - \quad - \quad (2.15)$$

Over uniform earth or homogeneous isotropic medium this calculated resistivity is constant for different electrode separation and for any current. However, if the ground is inhomogeneous, the calculated resistivity varies as the electrode spacing is varied. This calculated resistivity is called "apparent resistivityρ_a", since the measured resistivity is usually a composite of the resistivities of several layers. The apparent resistivity may be larger or smaller than the real resistivities or in rare cases identical with one of the two resistivity values in a homogeneous subsurface. The value of the apparent resistivity obtained with small electrode spacing is called the surface resistivity.

This is equal to the true surface resistivity only if the ground is uniform over a volume roughly of the dimension of the electrode separation. In any resistivity layout, current and potential electrodes can be interchanged and by the principle of reciprocity the apparent resistivity will be the same (unchanged) in either case.

Materials and Methodology

In this survey the instruments used for data collection are; Terrameter SAS300 system and its components, magnetic compass, field hammers, cutlass, pegs, electrodes, cables and reels, measuring tapes, global positioning system (GPS), and other accessories (Fig. 3). The Term SAS stands for Signal Averaging System.

When the human operator presses the measure button, the micro-processor runs through and checks circuit and electrodes positions, it also checks the battery condition and usability of selected parameters. This check–up takes only one second and if necessary, information comprising beeper signals and error codes tell the operator to check circuit or change parameter. When satisfied the micro-processor automatically starts the measurement cycle and after all the readings have been taken it puts the instrument in a standby mode with the final result displayed.

Vertical Electrical Soundings (VES) using D.C resistivity method were carried out in the study area. The data were acquired using Schlumberger array. Six Profiles of about 400m length that are not necessarily parallel to each other were established at different locations to cover the whole area under study, Fig. 4

Fig. 3 Terrameter SAS300 System and other accessories

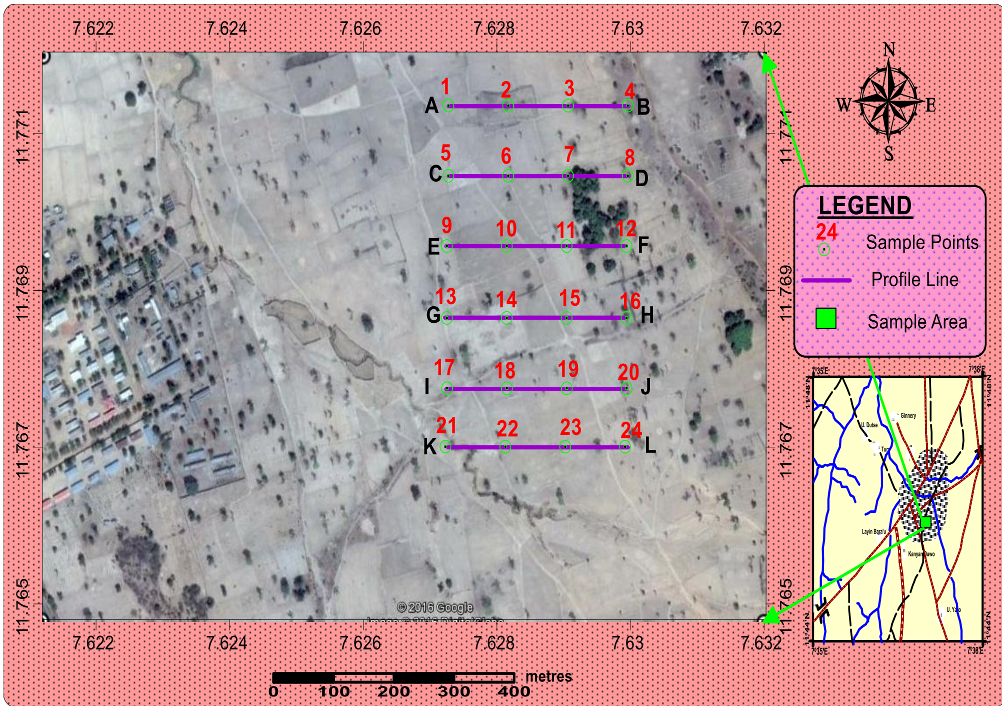

Fig. 4: A profile layout map of the study area (adopted from Google earth map)

RESULTS AND DISCUSSION

Available geological controls such as borehole data (Fig 5.), hand dug wells, exposed sections of the rock formations and resistivity values of earth materials compiled are used in order to have a meaningful interpretation (Saleko Ltd., 2013). Assumption has been made in the interpretation of Vertical Electrical Sounding (VES) data that: (a) the various geoelectric layers encountered are electrically homogeneous and isotropic. However, because of the existence of lateral variation in resistivity within a layer, possibility of error in interpretation is present, (b) the principle of equivalence that is, non-unique solution for a number of types of a typical three layer curve which are only distinguished by the resistivity value of their second layer in a relation to the value of either the first or third layer. Typical examples are type A ($P1<P2<P3$) and type H ($P1>P2<P3$) curves.

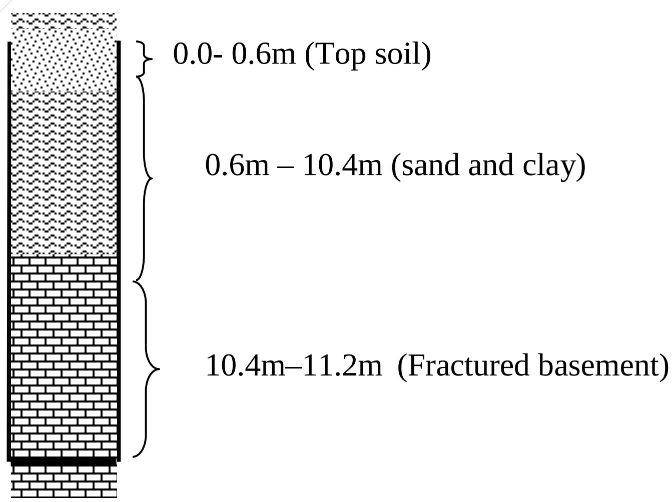

Figure 5: Borehole log data drilled near the study area (After Saleko Nig. Ltd., 2013)

The data analysis for the Vertical Electrical Sounding (VES) was performed using computer software (IPI2win) as stated before. Borehole lithological logs near the area, exposed cross section of rock formation in the area and hand dug wells around the area were considered in order to arrive at the resistivity values used for the interpretation of this present work and also resistivity values given by Telford *et al.*, (1990) are considered.

Table 1 Resistivity values adopted from Telford *et al.*, (1990) for this study.

ROCK TYPE	RESISTIVITY VALUE (Ωm)
Fadama Loam	30 - 90
Clay, Sandy silt, Sandy clay,	100 - 200
Fresh Laterite	850 - 3000
Weathered Laterite	30 - 300
Weathered basement	20 - 300
Weathered basement (lateritic)	300 - 1500
Fractured basement	500 - 1000
Fresh basement	>1000

The Geoelectric Section of Profile AB

Figure 6 shows a geoelectric section obtained for VES stations along profile AB. The profile consist of five subsurface layers; the first layer, which is the superficial cover, has resistivity values ranging from 21ohm-m around VES 02 and 03 to 1471ohm-m around VES 03 and 04. This layer has an average thickness of 2m.The underlying layer has resistivity values of 90ohm-m to 285ohm-m which probably consist of weathered basement. Around VES 03 the resistivity value is 567 ohm-m this area is likely made up of lateritic sand. The third layer has resistivity value 57ohm-m around VES 01 the layer is absent around VES 01 and 03, it continues around VES 04. This layer is probably the weathered basement with an average thickness of 19.5m. The fourth layer has resistivity value ranging between 1471ohm-m to 40519ohm-m which is probably a fresh basement.

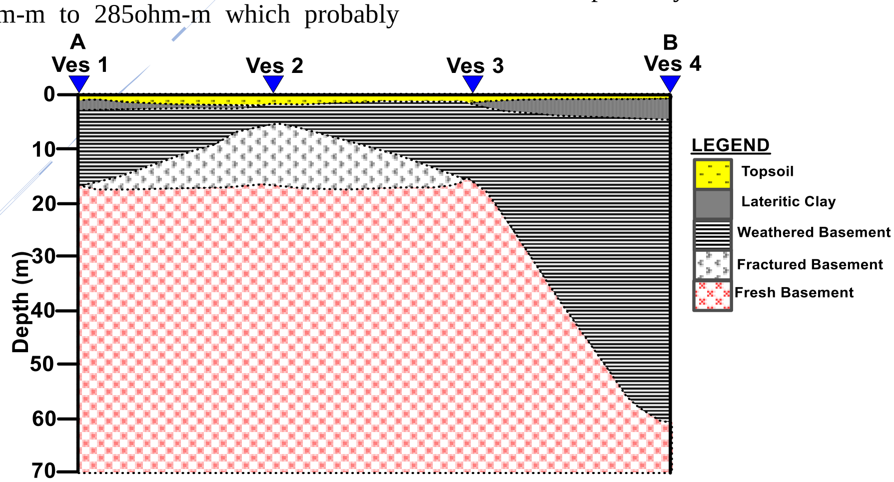

Figure 6: Geoelectric Section of Profile AB

The Geoelectric Section of Profile CD

The profile CD suggest a four subsurface layer, which is derived from geoelectric section shown in (Fig. 7) the first layer which is the superficial cover has resistivity values ranging from 22 ohm-m to 1328 ohm-m with an average thickness of 1.7m.This consist of sand, clay and silt soil. The underlying layer has resistivity values ranging from 69 ohm-m to 139 ohm-m which consists of sand, clay around VES 06 and 07 and a weathered basement around VES05 and 08. The third layer has resistivity value ranges between 92 ohm-m to 1034 ohm-m which is likely a weathered basement around VES 06, 07 and 08 and a fresh basement around VES 05 with an average thickness of 9m.

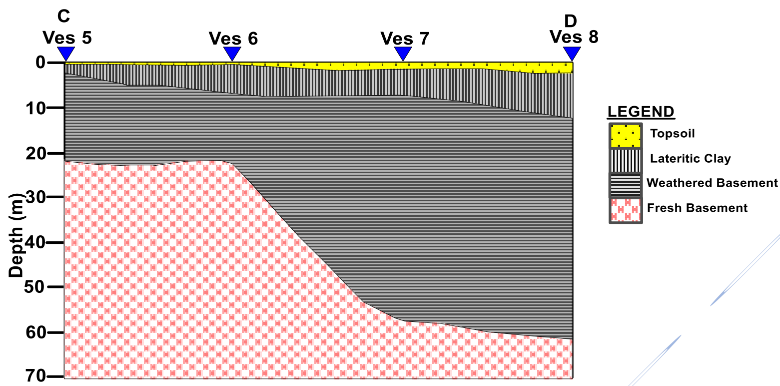

Figure 7: Geoelectric Section of Profile CD

The Geoelectric Section of Profile EF

Figure 8 shows geoelectric section along profile EF. This suggests four subsurface layers with the first layer having resistivity values between 14 ohm-m to 588 ohm-m, the average thickness of this superficial cover is 2m. The layer is made up of sandy, clay and silt. The underlying layer has resistivity values ranging from 34 ohm-m to 356 ohm-m, this layer is the weathered basement with an average thickness of 9m. The third layer has a resistivity value from 192 ohm-m to 2333 ohm-m which is a fractured basement with a thickness of 12m. The fourth layer has a resistivity values greater than 1000 ohm-m and is of infinite thickness. This layer is the fresh basement rock.

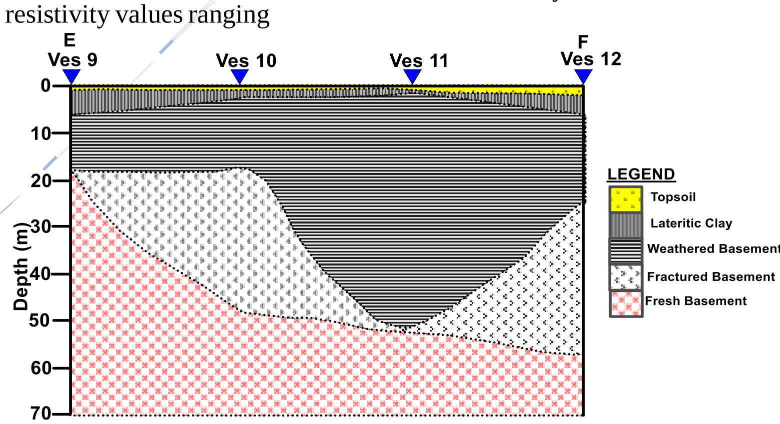

Figure 8: Geoelectric Section of Profile EF

The Geoelectric Section of Profile GH

This profile suggests that the region is underlined by four subsurface layers; the superficial cover (first layer) has resistivity values ranging from 171 ohm-m to 624 ohm-m. The thickness varies from 1.2m to 2m; this layer probably is made up of sandy, clay and silt (lateritic) soil. The second layer has resistivity values between 21 ohm-m to 138 ohm-m with an average thickness of 11.3m. This layer probably is the weathered layer, the third layer has a resistivity value ranges from 70 ohm-m to 727 ohm-m which is the fractured basement with an average thickness of 13m.This region is most likely favourable for groundwater exploitation based on the weathered layer and the presence of fractures. Evidence supporting this is the existing borehole near VES15.

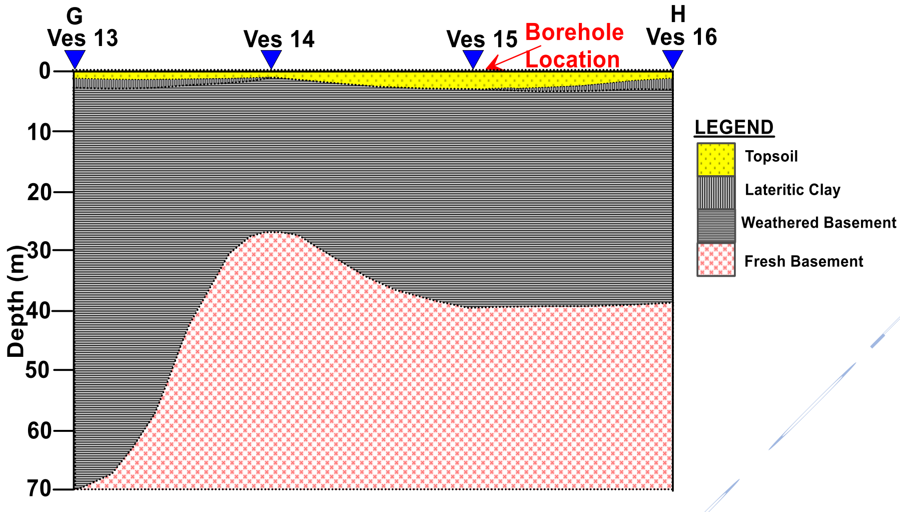

Figure 9: Geoelectric Section of Profile GH

The Geoelectric Section of Profile IJ

Figure 10 shows geoelectric section along profile IJ. This profile suggests three to four subsurface layers. The first layer is the superficial cover with an average resistivity value ranges from 145 ohm-m to 2734 ohm-m. The thickness of this layer is 1.5m. The underlying layer consists of sandy loam and a weathered basement with resistivity value ranging from 36 ohm-m to 388 ohm-m around VES 17, 18, 19 and 20. The third layer has a resistivity from 50 ohm-m to 797 ohm-m, which probably is the fractured basement with an average thickness of 11m. The fourth layer has a resistivity values range from 342 ohm-m to 17136 ohm-m with an infinite thickness this layer is the fresh basement.

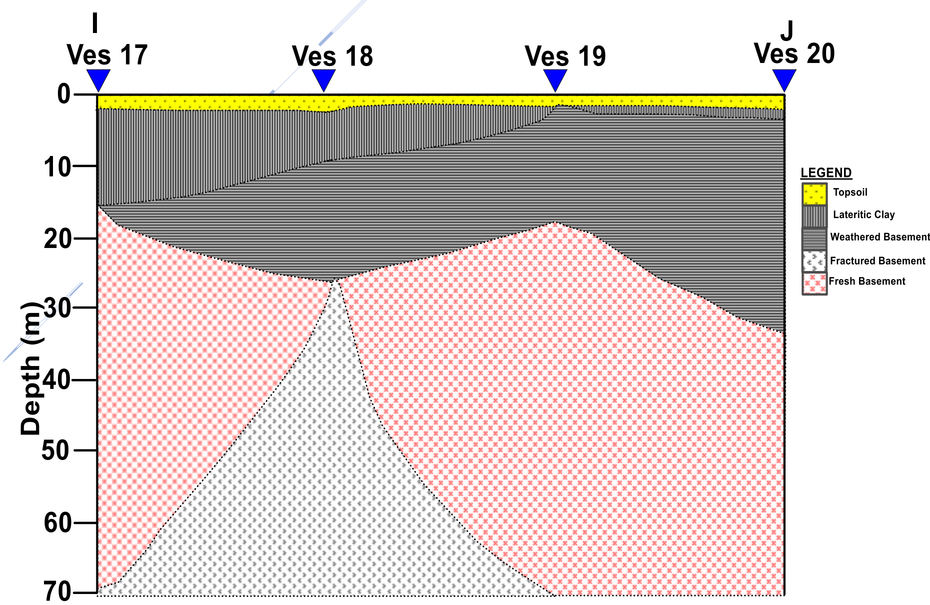

Figure 10: Geoelectric Section of Profile IJ

The Geoelectric Section of Profile KL

Figure 11 this profile suggests three to four layers; the first layer has an average resistivity value of 100 ohm-m with an average thickness of 3m. This layer contains a sandy, loam and clay. Beneath this layer is the second layer with resistivity value ranging from 15 ohm-m to 204 ohm-m which most likely is the weathered basement intruded the layer. The third layer has a resistivity value of 2719ohm-m and the thickness about 13m. The fourth layer is the fresh basement with the thickness running to infinity and resistivity value ranging from 660 ohm-m to 10744 ohm-m.

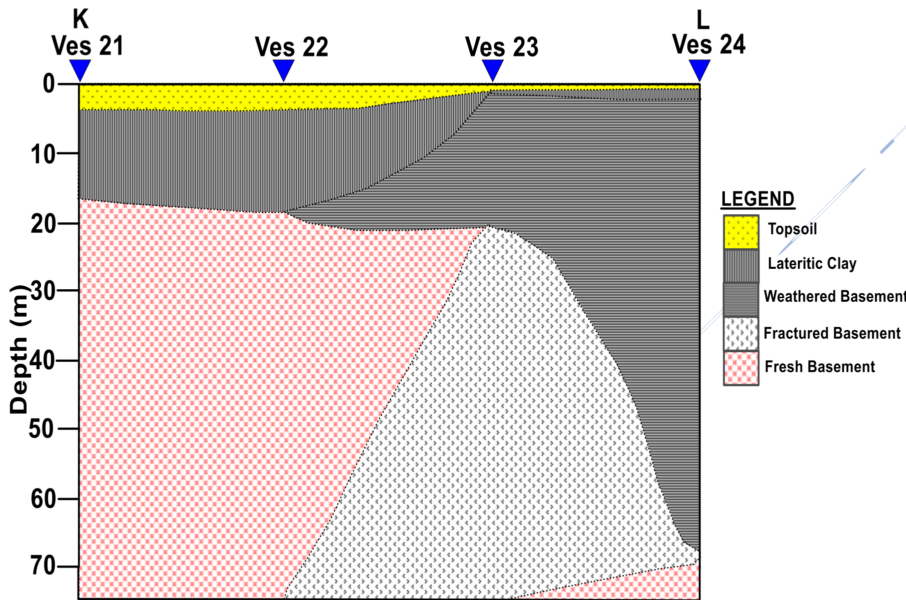

Figure 11: Geoelectric Section of Profile KL

Maps Produced from Interpreted Data

In order to look at some subsurface structural trends in the study area and to reveal the lithological sequence of the formation, specialized maps were produced from the interpreted resistivity data obtained for the whole VES stations with the aid of computer software (Sufer V 11.0). The essence of these maps is to show the lateral variation of resistivity over a horizontal plane at certain depth. In other words these maps indicate distribution of resistivity in the area.

Iso - Resistivity Map of the surface layer (top soil)

The map was produced by contouring the resistivity values of the top soil at the twenty four (24) VES points along all the locations of the six (6) profiles within the study area. A contour interval of 200 ohm-m was used for the map. The resistivity values of the top soil vary between 100 to 3000 ohm-m. The higher resistivity values are noticed around VES02, VES06, VES10 and VES18. The topsoil resistivity map is shown in the Fig. 12.

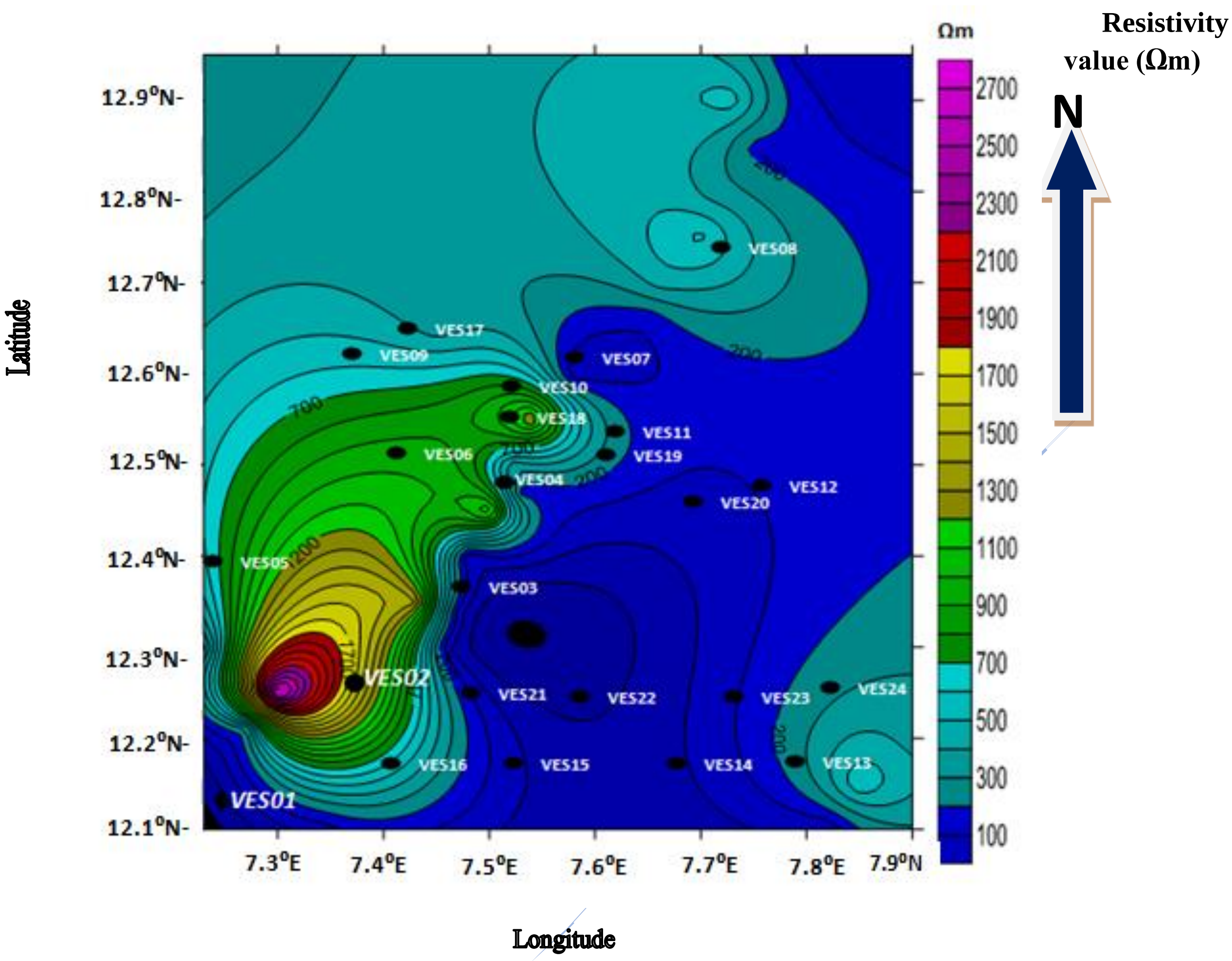

Figure 12: Iso-Resistivity map of Surface Layer

Aquifer Thickness Map

In the basement complex the main aquifer is the weathered and the fractured rocks. However, other formations such as gravel layer may serve as underground water bearing layer. The aquifer thickness map fig. 13 was produced from the interpreted data of the weathered/fractured layer thicknesses at twenty four (24) VES points along all the locations of the six (6) profiles within the study area at a contour interval of 2m. The map shows the variation of aquifer thickness from one place to another. The aquifer thickness varies from 1 to 50m with an average of 28m as shown in Fig.13 below.

Thickness (m)

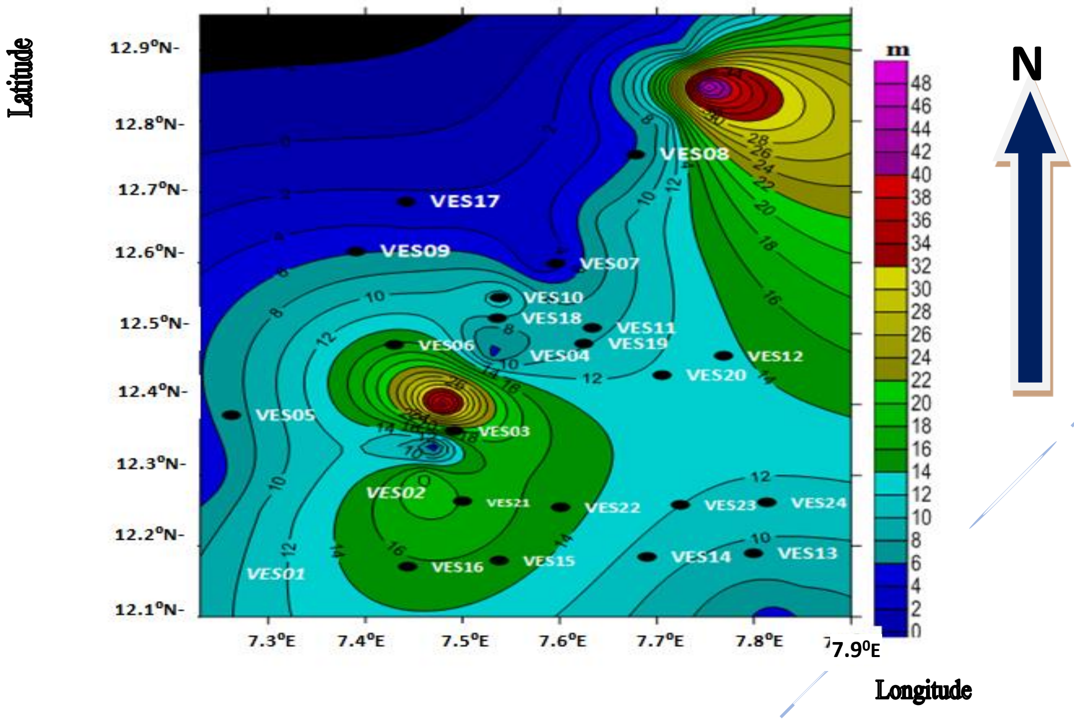

Figure 13: Aquifer thickness Map

Depth to the Basement Map (overburden thickness map)

The overburden thickness map was produced from the interpreted depth to the basement at each sounding point. Fig. 14 was prepared to view the geometry or topography of the basement under the study area in order to enable a general overview of the variation in the overburden thickness. The map shows that the basement topography is rugged or undulating being deeper at some points and shallower at other points. The depth to basement ranges from 4m to 60m as in the Fig.14.

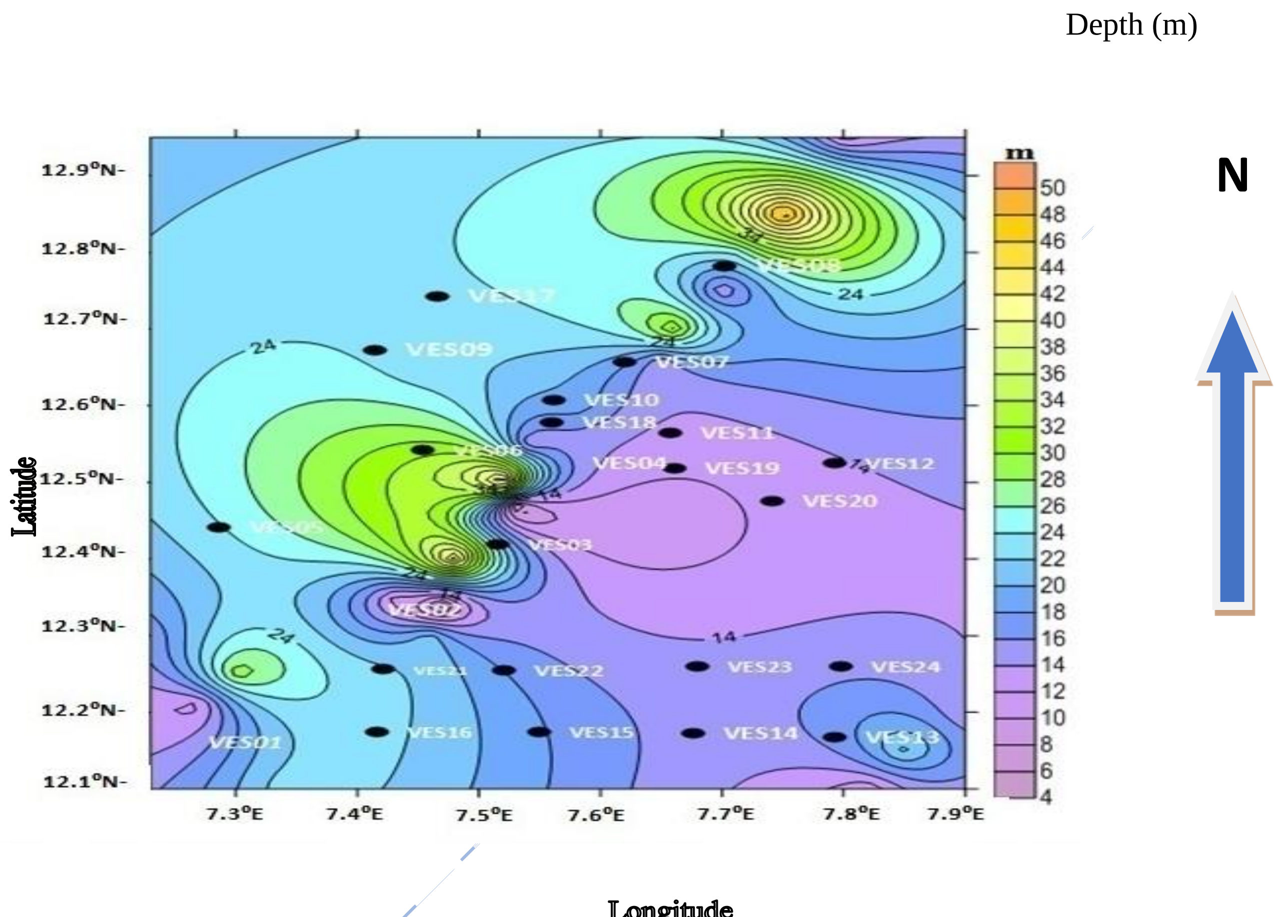

Figure 14: Depth to the basement map (overburden thickness map)

Conclusion

The geoelectric sections for the profiles suggest that the study area is underlain by the three to four layers of different lithological composition, namely the superficial cover consisting of sandy, clay, silt, weathered laterite/ fresh laterite/weathered basement, fractured basement and fresh basement rock. The laterite in the first layer shown in some locations is of great importance as it reduces surface run-off and aids infiltration into the underlying aquifer.

The thickness of the weathered basement in the northern and central part of the study area is large enough to harbour substantial quality and quantity of water; the area is suitable for hand dug wells or preferably boreholes. The fractured basement that is underlying the weathered basement around VES 06, 08, 016and 017 are potential areas for groundwater exploitation because of good source of recharge by rain water.

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