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Fracture Delineation for Groundwater Target in a Precambrian Hydrogeological Setting in Part of Ado Ekiti, Southwestern Nigeria

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Abstract

This paper focused on the delineation of fracture zones in relatively Precambrian aquifer rocks for groundwater targeting in New Iyin road of Ado Ekiti, Southwestern Nigeria from Geophysical imprints. A total of two (2) Electromagnetic (EM) profiles and six (6) Vertical electrical sounding (VES) were acquired. The traverse was conducted along the Eastern to western flank. Four prominent geologic layers were delineated to diagnose the prolific aquifer units in the study area, which includes the fractured aquifer and the weathered layer. The entire traverse shows the signature for Water bearing zone, which are considered homogeneous of the aquifer. Four signature of aquiferous zone along the traverse 1, comprises both weathered, fracture and partly fresh basement along the traverses is 6m, 7m, 12m and 16m. However, the hydrogeological significance of the traverse is prolific mostly in VES 6, which is a diagnostic feature of the aquifer owing to the appreciable thickness being the targeted point for groundwater development in the Precambrian rock of New Iyin, Ado Ekiti. The hydrogeological pattern in the area gives an overview of the nature of aquifer layers and this will invariably help the drillers as well as water resources policy makers in their drilling operations.

Keywords

Fracture, Delineation, Precambrian aquifer, VES, EM, Homogeneity, Hydrogeological significance

Introduction

Groundwater is a very important source of drinking water in both rural and urban part globally. Owing to the influx of people to the community and over-dependent on groundwater by the dwellers of New Iyin, this has thus necessitate the prompt action to further conduct an hydrogeological and geophysical survey to further understand the groundwater condition in the community. New Iyin is situated in Ado Ekiti of Ekiti State in Nigeria. Groundwater exploration has been carried out in this area using Electromagnetic and Vertical Electrical sounding to delineate subsurface fracture zones for groundwater targeting. Delineation of fracture zone in a Precambrian rocks involved an extensive and highly scientific

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technology and this has proved to be regarded as a basis for targeting water bearing layers. The groundwater in a typical Basement Complex environment is usually contained in the weathered and /or fractured basement rocks or alluvial deposits within flood plain [1]. In typical hard rock, area of basement rock overlain by variable unconsolidated materials referred to as overburden. Integrated geophysical such as resistivity and electromagnetic methods, are commonly used in groundwater exploration, mainly due to the close relationship between electrical conductivity and some hydrological parameters.

The use of geophysical techniques for groundwater exploration and water quality evaluations has increased over the last few years due to the rapid advances in computer software and associated numerical modeling solutions [2]. The Vertical Electrical Sounding (VES) has proved very popular with groundwater prospecting due to simplicity of the techniques. The electrical geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth. Fractured basement will be more porous and permeable than weathered layers that consist of clay. Geophysical methods have solved numerous exploration problems because it is rapid, can cover expanse of land in limited time, and can penetrate subsurface to a greater depth. It has been a very useful tool in mapping subsurface, estimating reserves in mineral resources exploration and monitoring pollution. Geologically, the area is underlain by part of crystalline Precambrian Basement complex rocks of Southwestern, Nigeria.

Oyegoke SO, et al., carried out a research on the effectiveness of Geophysical Assessment of Boreholes Drilled in Basement Complex Terrain at Afe Babalola University, Nigeria Using Electromagnetic (E.M.) Method of groundwater investigation using a PQWT S500 groundwater detector equipment. The method of electromagnet used in their findings is similar to that which was used for this study. Their findings pointed out that the subsurface map indicates that the geologic formation has two potential locations at 13m and 17m along the horizontal axis that penetrated to a depth of 130m that could have been better points for the location of boreholes for groundwater exploitation.

The occurrence of groundwater in recoverable quantity as well as its circulation in the Precambrian Basement Complex is controlled by geological factors [3,4]. Ariyo and Adeyemi [5] upheld that most often, the occurrence of groundwater in the Basement Complex terrain is localized and confined to weathered/fractured zones.

Groundwater yield is enhanced by the presence of fractures within the basement rock, which could probably be because of the relatively high permeability. Based on Olayinka, et al., Oyedele, and Olayinka [6,7] classification of aquifer potential as a function of the basement rock, the basement rock can be classified as high fractured permeability because of weathering. In tropical basement rock, weathering process creates superficial layers, with varying degrees of porosity and permeability. This unconsolidated superficial layers, if significantly thick, porous and permeable, makes good aquifer units.

A detailed geoeletric survey and Electromagnetic survey covering New Iyin road of Ado-Ekiti, southwestern Nigeria was carried out to determine the geoelectric parameters (resistivities and thicknesses) of subsurface layers ,fracture zones and their hydrogeologic properties. Borehole drilling companies, water professionals, which operate within the study area to aid their drilling activities, can use this study and Knowledge of the location of the aquifers, their thickness can help eliminate the problem of abortive boreholes within Ney Iyin areas. In lieu of the statement above, the objective of this paper is to decipher the fracture zone for groundwater resources management in New Iyin and its environs using the Magnetotelluric method of passive electromagnetic techniques which image the subsurface condition up to 150m using the PQWT-TC150 groundwater detector equipment and the direct current electrical resistivity method employing the vertical electrical sounding techniques using Campus Omega earth resistivity meter.

Fundamental Principle of Magnetotelluric Surveying Techniques

The **Magnetotelluric technique** is a passive **electromagnetic (EM**) Method involving measuring fluctuations in the natural electric (E), and magnetic, (B), fields of geomagnetic disturbances originating principally in the ionosphere in orthogonal directions at the surface of the Earth as a means of determining the conductivity structure of the Earth at depths ranging from a few tens of meters to several hundreds of kilometers. The fundamental theory of exploration MT was first propounded by Tikhonov [8] and, in more detail, by Cagniard [9]. The Instrument called as (Natural Electric Field Frequency Selection System) geophysical instrument, shortly known as frequency system worked on the principle of electrical difference of natural earth magnetic field (frequency 0-30 kHz), the several different frequencies of electromagnetic field changes is the law to study the underground field/material changes to solve the Geological problems. It is a one of the method for an alternating current exploration method. PQWT-TC150 (Figure 1) Series of Geophysical prospecting instrument uses the natural electric field source as a working farm, with resistivity contrasts underground rocks and minerals or groundwater, based on measuring the natural electric field on the surface of the N different frequency electric field component, according to their different variation to study Abnormal changes in geological bodies produce, reaching solve geological problems one electrical prospecting methods. According to this theory, the design and production of the equipment is based on the so-called potential frequency of detecting instrument, referred to natural selected frequency electric field instrument or instruments for geological exploration work. The instrument is the use of natural earth field source without going through artificial field that is omitted clumsy power supply system in order to achieve the simple, lightweight instrument.

After data collection by the unique built-in computing functions, the instrument can automatically draw curve graph and profile map with one button, according to the profile map, understanding of the geological structure is accurately

Figure 1: PQWT-TC150 Geophysical groundwater detector Equipment.

cleared and determination of the location of rock frame, karst cave, aquifer etc. is quickly and scientifically done.

The M, N electrode probe (transducer) is attached via a cable earth's magnetic field to electrical signal input to high impedance input stage , after the anti-jamming exchange amplification, frequency selection, the desired operating frequency is selected and then by the A/D sampling, central processor (CPU) for data processing. Where in the entire measurement process, high-speed central processing unit (CPU) of the control, instrumentation automatic range conversion and automatic frequency selection. Finally the equipment display the measured data and curves graph, and then click "profile" the instrument will automatically draw profile map directly on the LCD of instrument, also can output measurement data, curve graph and profile map by USB cable to computer for analysis and making geological conclusion.

Fundamental principle of geoelectrical resisitivity method

For an ideal situation that is geometrically constrained with a current through a homogenous media in a well-defined uniform cross section between two potential electrodes, using the Ohm's law, the resistance R is given by

$$R = V/I \quad (1)$$

Where R denote the resistance, V denote the voltage and I denote the current. The resistance is also proportional to the cross sectional area and the distance between the electrodes and the relationship is given by

$$R = \rho\ (L/A) \quad (2)$$

Combining equations 1 and 2 together gives

$$V/I = \rho\ (L/A) \quad (3)$$

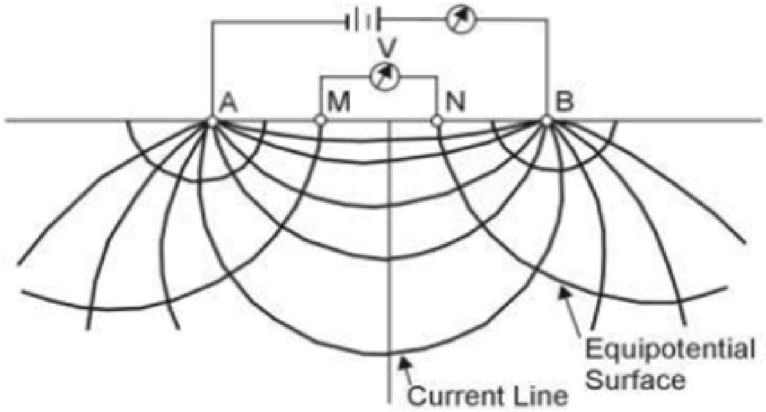

Figure 2: Equipotential and current lines for current A, B and potential electrodes M, N.

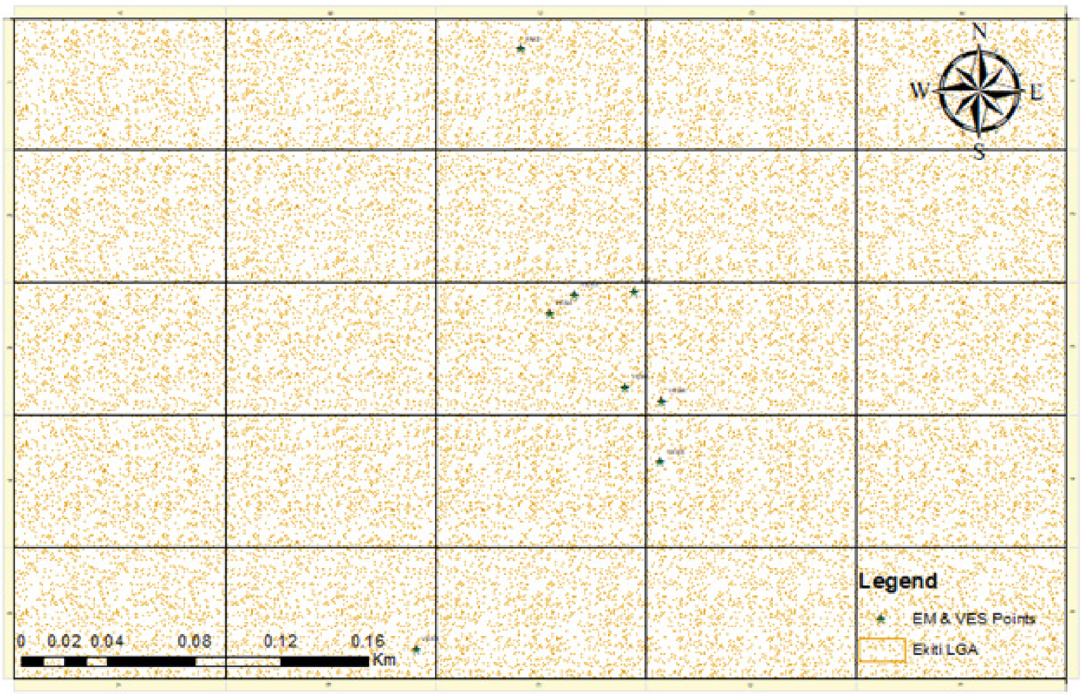

Figure 3: Spatial relationship Location Map of the study area showing the EM Traverses and VES points.

Where A is the cross sectional area, V is the voltage, I is the current and L is the distance between the electrodes.

The constant of proportionality ρ is the apparent resistivity and data from resistivity surveys are represented by apparent resistivity which takes into account arrangement and spacing of electrodes. From the relationship above the potential at any point is given by:

$$V = \rho I/(2\pi r) \quad (4)$$

V is the potential in volts, ρ is the resistivity of the medium and r is the distance from the electrodes. For the electrode pair with current I at electrode A, and -I at electrode B, the potential at a point is given by the algebraic sum of the individual contributions as seen in Figure 2 below.

Therefore; $V = V_A + V_B$ (5)

$$V = \rho I\left(\frac{1}{2\pi r_A} - \frac{1}{2\pi r_B}\right) = \frac{\rho I}{2\pi}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) \quad (6)$$

Where r_A and r_B are the distance from the point between current electrodes A and B. For the pair of voltage electrodes M and N, the potential V may be measured as:

$V = V_M - V_N$ (7)

Where, V_M and V_N are potentials at M and N.

Thus, total voltage effect can be represented as:

$$V = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}\right) \quad (8)$$

Where, AM is distance between electrode pair at A and M; AN is the distance between electrode pair A and N. The distances are the actual distances between the respective electrodes, whether or not they lie on a line.

$$Denoting\ \frac{1}{2\pi}\left(\frac{1}{AM}-\frac{1}{BM}+\frac{1}{BN}-\frac{1}{AN}\right) by\ 1/K,$$

Equation 8 above becomes

$$V = \rho L/K \qquad (9)$$

Equation 9 results to resistivity ρ = KV/I

K is the geometric factor and only a function of the geometry of the electrode arrangement. Resistivity can be found from measuring values of V, I and K [10].

Study Area, Geology and Hydrogeology of the Study Area

The study area is New Iyin in Ado Ekiti, southwestern Nigeria which lies geographically between Latitude 7° 38' 47.7'' N and 7° 38' 50.2'' N and Longitude North of 5° 11' 36.0'' E and 5° 11' 37.7''E as seen in Figure 1. The spatial location of the EM stations and VES stations are seen in Figure 3. The study area is accessible through road, and as at the time of survey, the surrounding consists of residential buildings. The Geology of the study area is predominantly a Precambrian basement complex. The major rock units distinguished are the undifferentiated migmatite-gnesis-quartzite complex, charnokitte, older granite and unmetamorphosed dolerite dykes believed to be the youngest. The Precambrian basement complex of southwestern Nigeria underlies the area with local geology essentially granite, gneiss and migmatite as seen in Figure 4 below.

Hydrogeologically, the study is highly weathered and fractured which signified a good groundwater potential layers from the survey carried out on the field. The hydrogeological atttributes of these rock types depend on the degree of weathering and fracturing of the underlying rock. The intense deformational structures of these rocks permit adequate aquifer properties needed to generate the well water. This could be responsible for the varying hydrogeological properties of the different rock types in the study area. The weathered zone possesses a lot of void spaces where underground water percolates and the fractures are higly prominent in the study area which is a good diagnostic feature of a groundwater potential area.

Methodology

The method employed for this study include field geophysical methods of Electromagnetic survey using PQTW-TC 150 groundwater detector equipment and the Geoelectric surveying using the Campus Omega earth resistivity equipment.

Electromagnetic survey

Data acquisition, data processing and presentation

The equipment used for the Electromagnetic (EM) Survey is PQTW, an automatic groundwater detector seen in Figure 1. The geophysical equipment scan the subsurface up to the depth of 150m. **Two (2) profiles** traverses were utilized and traverses was done along the Eastern to western flank in the study area (Figure 3). The accurate location of the EM profile station was acquired using the Garmin 72 Global Positioning system (GPS) and the coordinates recorded. The electromagnetic method measures the electrical component

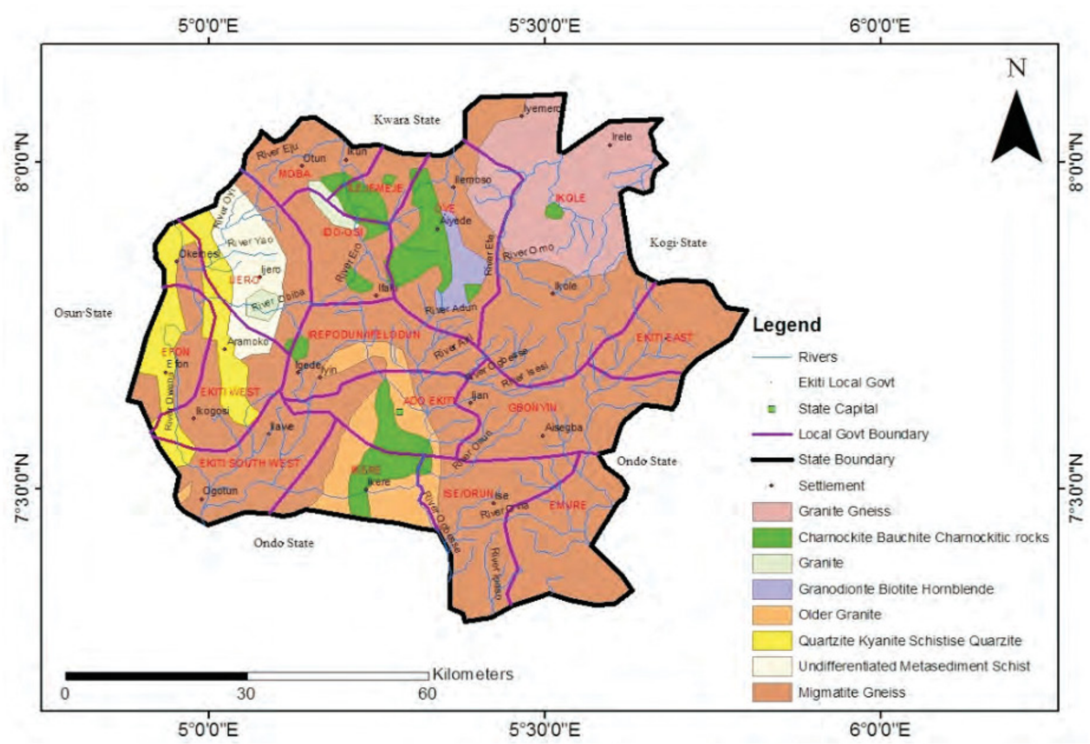

Figure 4: Geological Map of Ado Ekiti showing the Geology of the Area and its environs (Ademilua,1997).

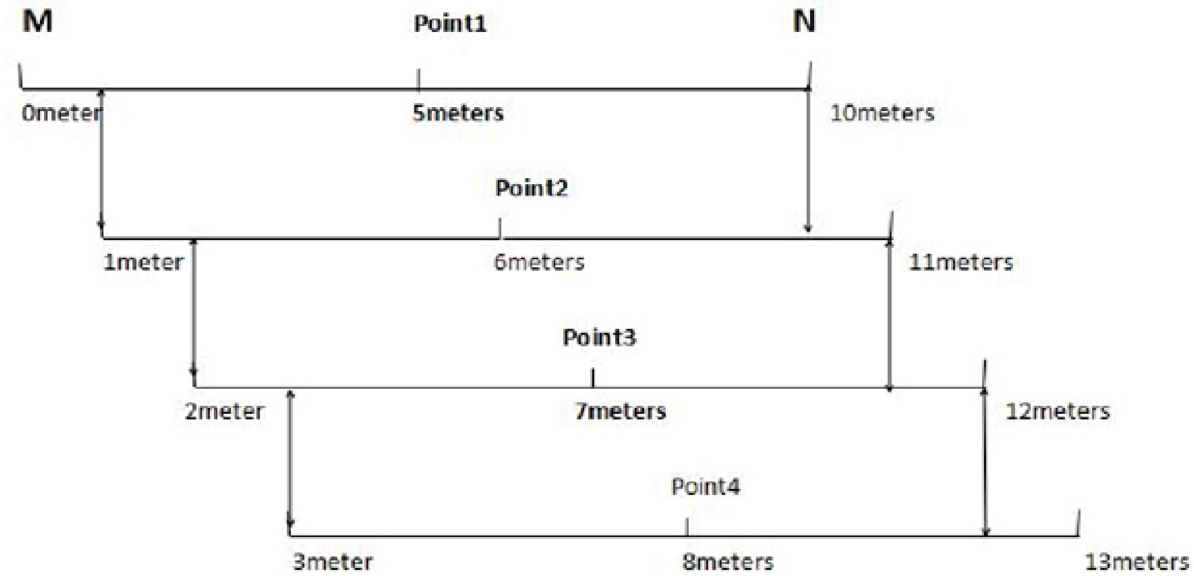

Figure 5: The Field set up and measurements.

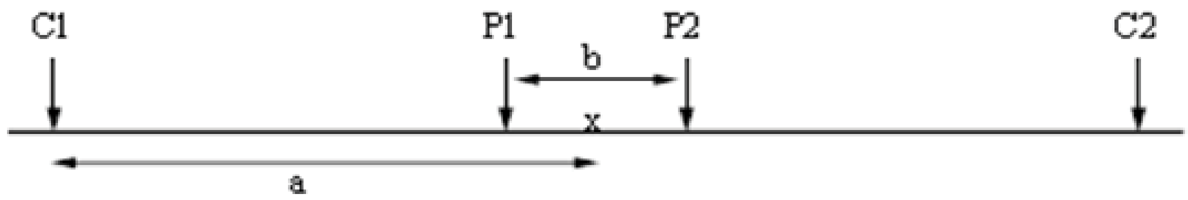

Figure 6: Schematic representation of the Schlumberger array.

of the electromagnetic field of the earth, so called natural electric field method; and the corresponding frequency is chosen as measured within - 50 meters, that the selected frequency, so called frequency selection method, it is always referred to as natural potential frequency method. According to this theory, the design and production of equipment called potential frequency of detecting instrument, referred to natural selected frequency electric field instrument or instruments for geological exploration work. The instrument is the use of natural earth field source without going through artificial field that is omitted clumsy power supply system in order to achieve the simple, lightweight instrument.

The field electromagnetic data acquisition involved marking 10 meters distance from the tape and marks the start place of 0 meters. The M N two electrode bar equidistance is 10 meters, both M N will move 1meter after finished measure the point 1 and M N Electrode equidistance wiring as seen in Figure 5 below: It is better to measure and tap at 10 Meters of M N equidistance, and both M N move 1 meter, because the water detector was designed at 10 meters of M N equidistance, and M N both move 1meters. Changing the MN equidistance has the effect on the depth of measurement. The equipment automatically scan the subsurface and after data collection by the unique built-in computing functions, the instrument can automatically draw curve graph and profile map with one button, according to the profile map, a clear understanding of the geological structure and quick determination of the location of ore body (seam), hollow (cave), water (aquifer) are scientifically delineated.

Vertical electrical sounding

Data acquisition, data processing and presentation

The vertical electrical sounding is an electrical resistivity method, which is very useful in delineating the sub-surface resistivity of earth materials. **Six (6) VES** points were sounded as shown in Figure 3 above. The electrode spacing (AB/2) was varied from 1m to 100m for all the VES points. The acquisition of the data was done with a campus omega earth resistivity meter. It consists of introducing current into the ground and measuring the resistance at each point. One pair, the current electrodes (C_1 & C_2), meant to introduce an electric current (I) into the ground and the other pair, potential electrodes (P_1 & P_2) to measure the potential difference (V) produced as a result of the current flow. The apparent resistivity value is then obtained using the equation 10 below:

$$\rho = \frac{K\Delta V}{l} \tag{10}$$

Where K denotes the geometric factor and relied heavily on the electrode configuration used during the field investigation. The Schlumberger electrode set-up was employed and its geometric factor is calculated as follows:

$$K = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{2MN} \right] \quad (11)$$

Where AB/2 denote half the current electrode spacing (**a in Figure 5)** and MN denote the potential electrode spacing **(b in Figure 6).**

The apparent resistivity is then calculated using equation 11 above to have the apparent resistivity of each layer using the equation 10 above respectively. The data is then interpreted qualitatively or quantitatively. The qualitative interpretation involves a visual inspection of profiles, maps, and pseudo-sections while the quantitative interpretation involves partial curve matching and computer iteration. The quantitative interpretation gives the approximate resistivity values of the earth material. The interpreted VES results are presented as the geo-electric model as seen in Figure 7 and Figure 8 respectively. Vertical Electrical Sounding (VES) results were obtained and the curves generated were matched with standard master curves and auxiliaries (partial curve matching technique). These curves are termed schlumberger depth sounding curve generated when inputting in the data processed with WINREST software to model the 1-D Dimensional overview of the study area as seen in Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14 and the Table 1 is the model summary of the results showing the interpreted data. The exact location of the VES points were acquired by Garmin 72 Global positioning system (GPS) and the coordinates recorded.

Results and Discussion

From the results of the surveyed carried out, there are four (4) lithostratigraphic units, which includes the top soil material, sandy clay, partly weathered basement and fractured with partly fresh basement delineated as an inferred Geology of the area.

Geo-electric sections

The Geo-electric models were traced in two (2) folds along

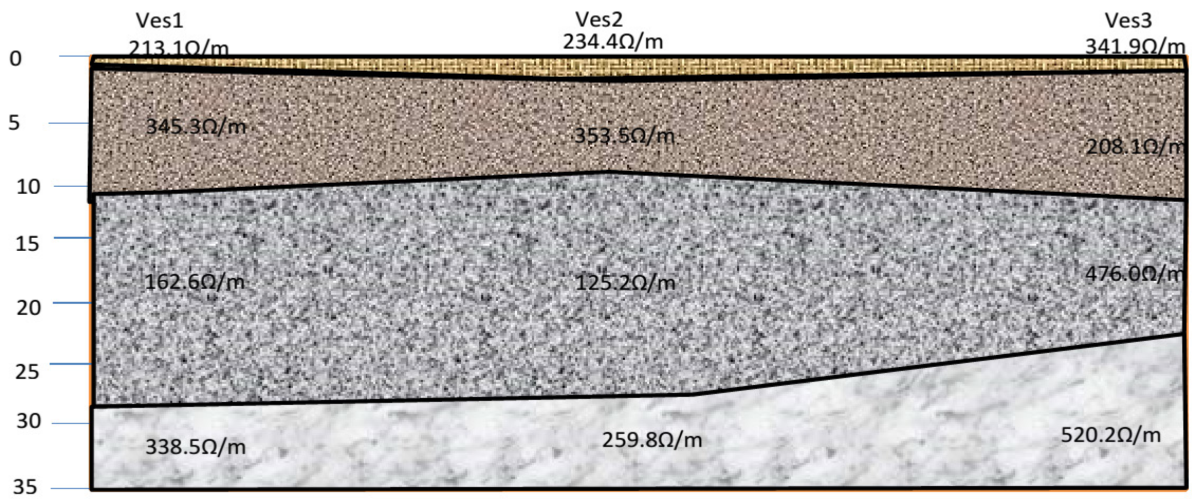

Figure 7: Geo-electric model along traverse 1.

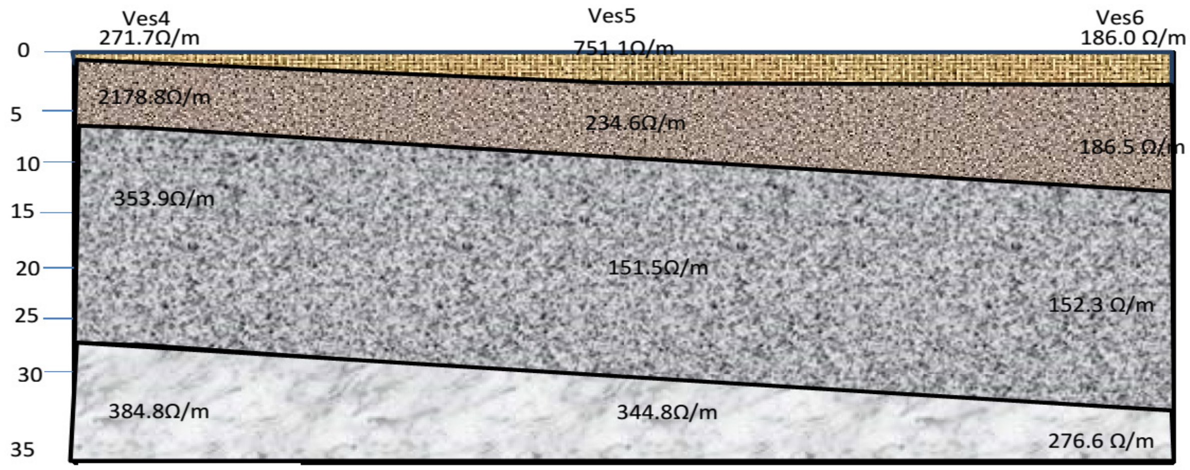

Figure 8: Geoelectric along along Traverse 2

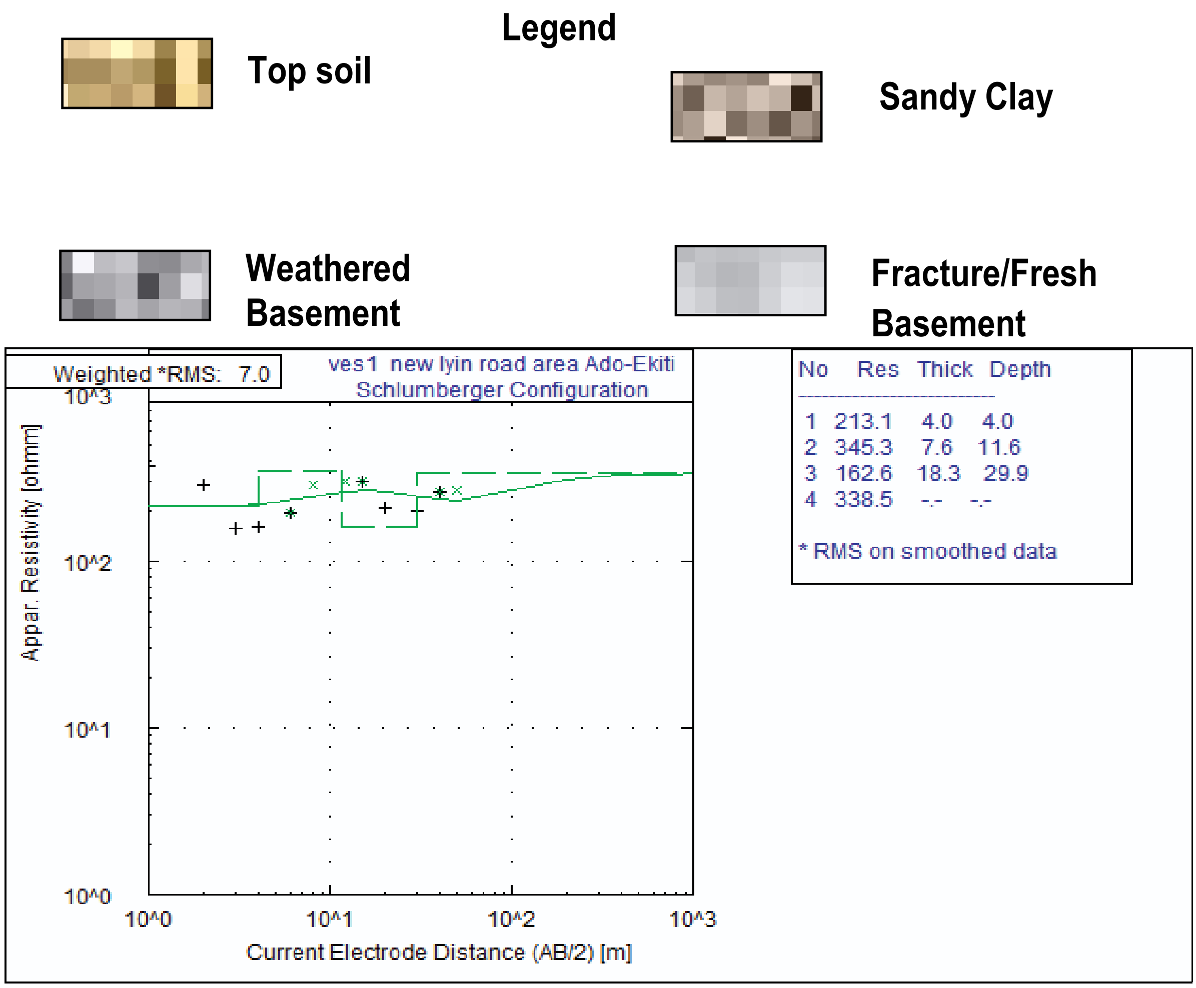

Figure 9: One Dimensional Depth sounding curve for Ves 1.

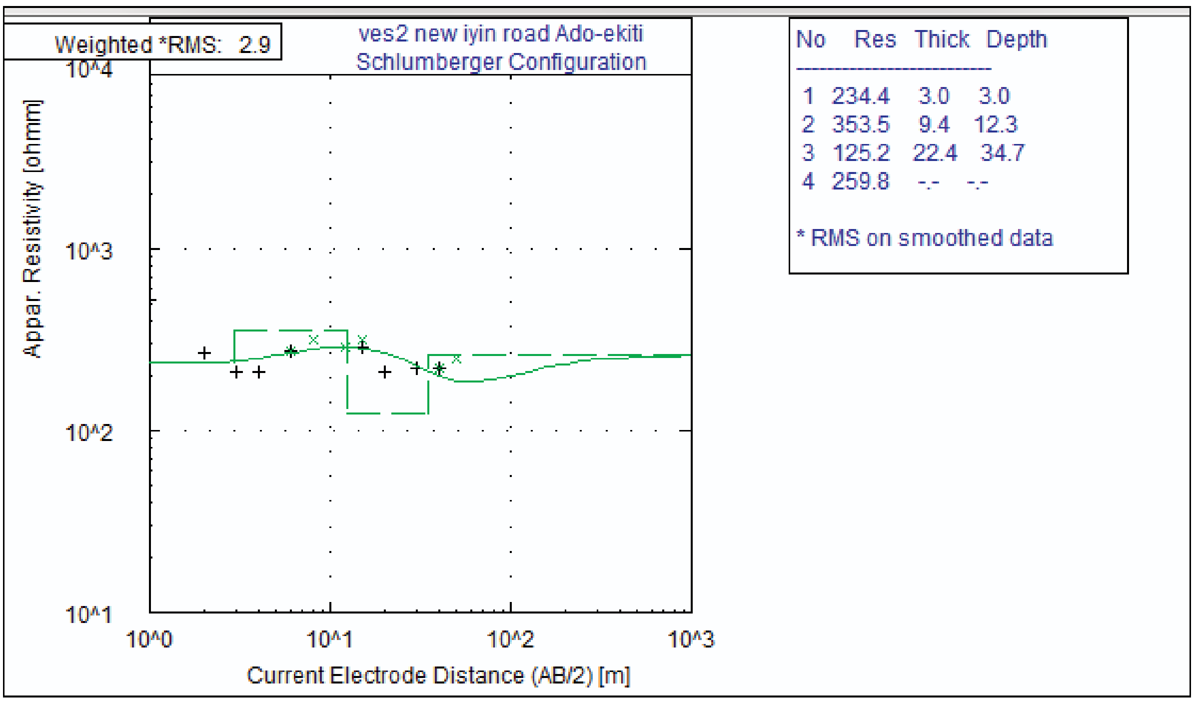

Figure 10: One Dimensional Depth sounding curve for Ves 2.

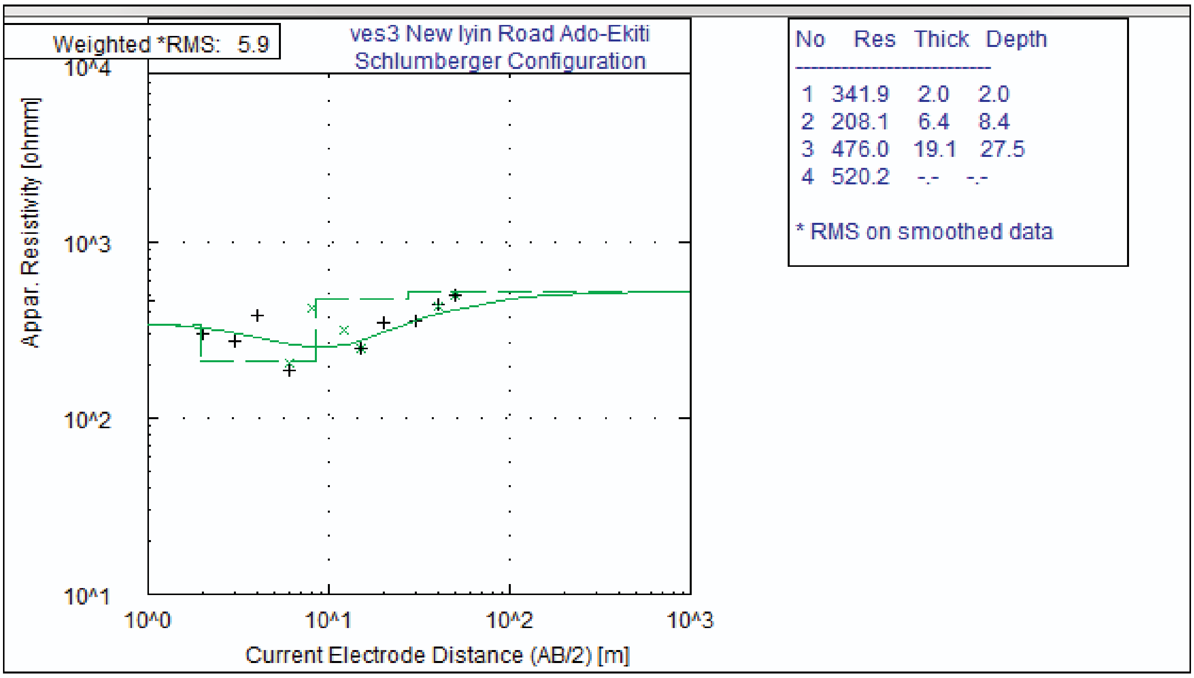

Figure 11: One Dimensional Depth sounding curve for Ves 3.

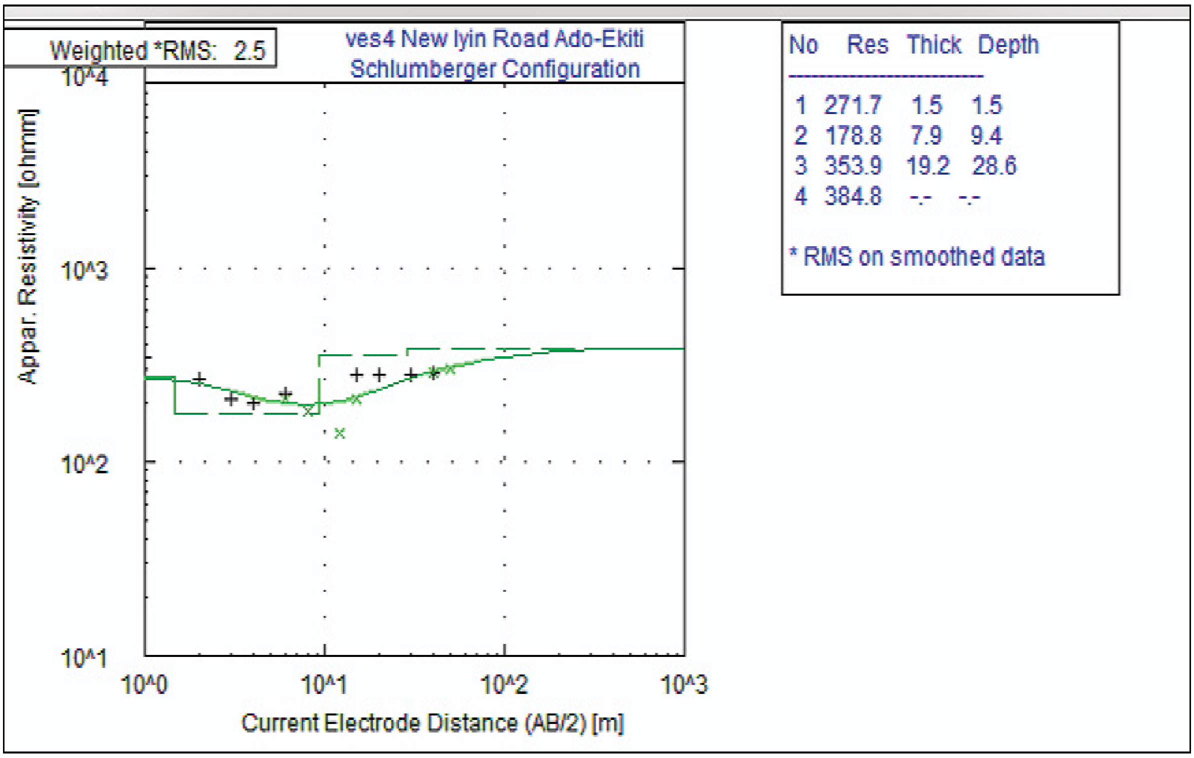

Figure 12: One Dimensional Depth sounding curve for Ves 4.

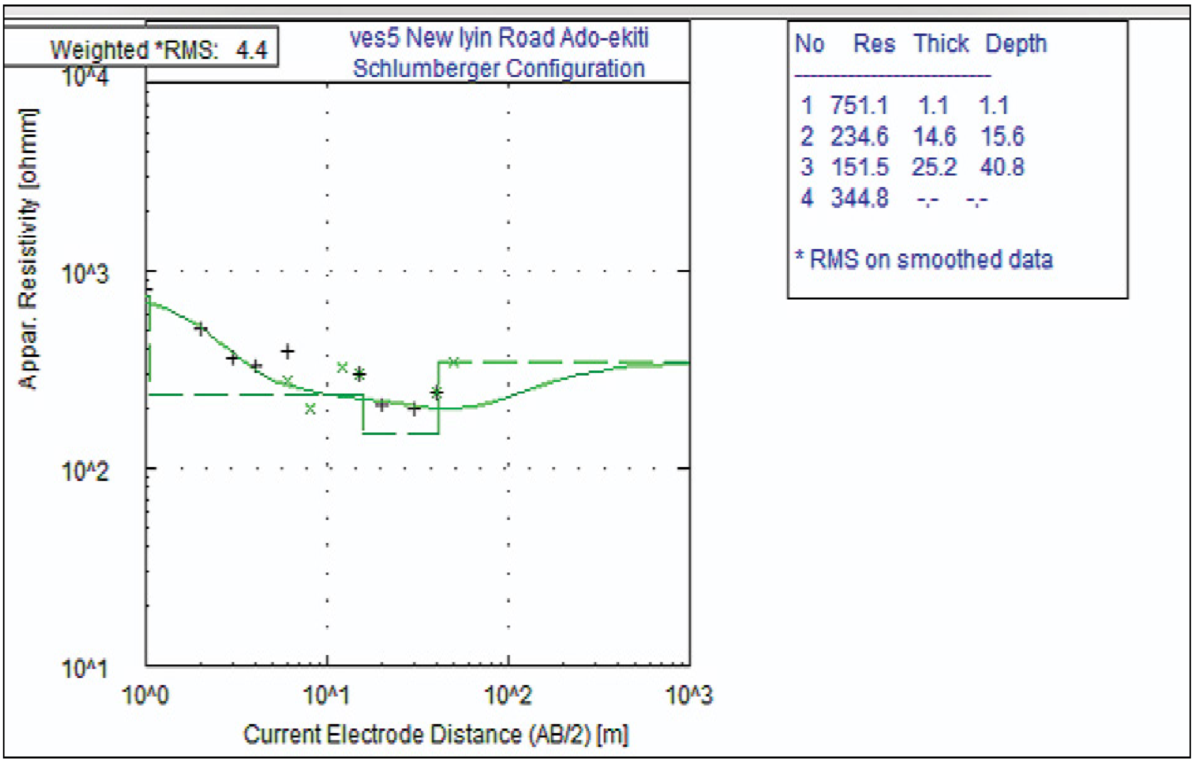

Figure 13: One Dimensional Depth sounding curve for Ves 5.

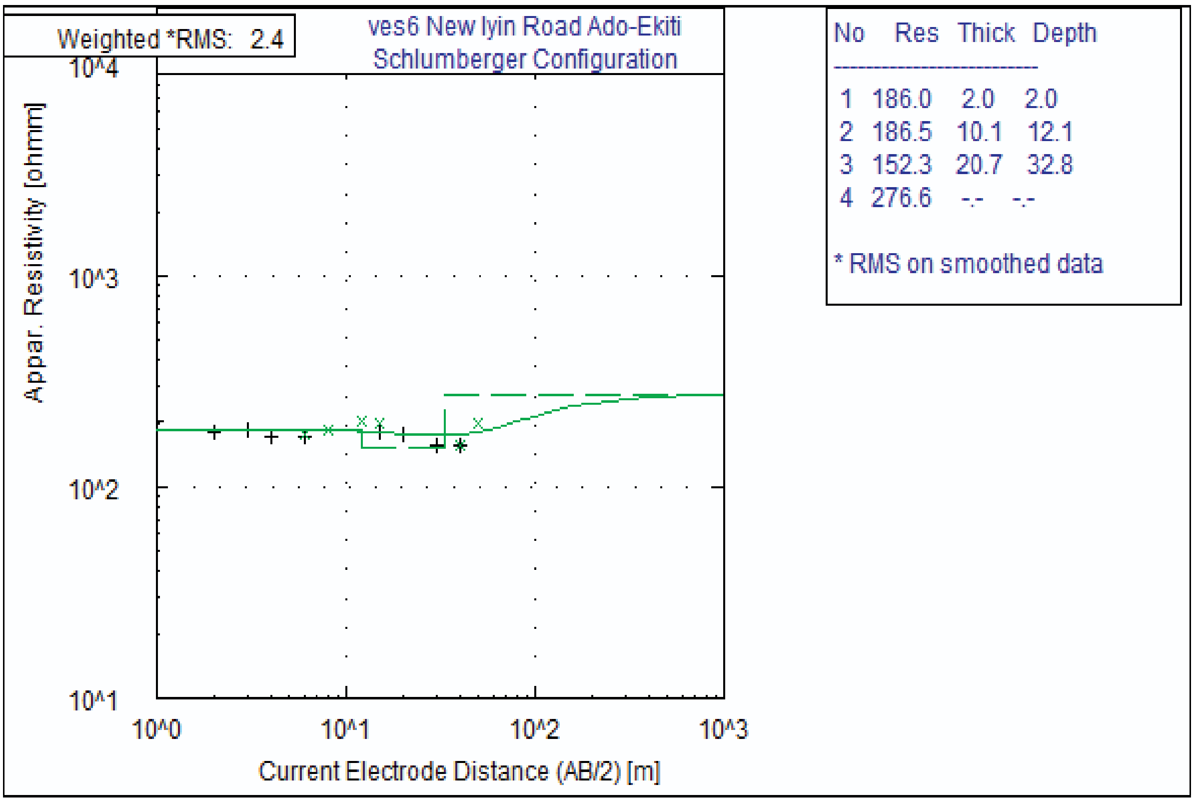

Figure 14: One Dimensional Depth sounding curve for Ves 6.

Table 1: Model synopsis of interpreted VES data.

Ves stations	Type of curve	No of layer	Resistivity (Ohm/m)	Depth (m)	Inferred Lithology
1	KH	4	213.1	28.9	Top soil
			345.2		Sandy clay
			162.9		weathered basement
			338.9		Partly fractures/Fresh Basement.
2	KH	4	234.4	34.7	Top soil
			353.5		Sandy clay
			125.2		weathered basement
			259.8		Partly fractured/fresh basement.
3	KH	4	341.9	27.5	Top lateritic soil
			208.1		Sandy clay
			467.0		Fractured basement
			520.2		Partly fresh basement.
4	HK	4	271.7	28.6	Top soil
			178.8		Clayey sand
			353.9		Partly fractured basement
			384.8		Fractured basement
5	HK	4	751.1	40.5	Top soil
			234.6		Clayey sand
			151.5		Partly fractured basement
			344.8		Fresh basement
6	KH	4	186.0	32.8	Top soil
			186.5		Clayey sand
			152.3		weathered basement
			276.6		Fractured basement.

the transverse 1 and transverse 2 as seen in Figure 7 and Figure 8 below. The geo-electric model cut across West East in transverse 1 while North South in transverse 2.

Geo-electric Sections along Traverse 1 (West-East): The geo-electric models were traced along the transverse comprising of VES 1, VES 2, VES 3. The top sand resistivity values ranging between 213.1 ohm-m to 341.9 ohm-m along VES 1, VES 2, and VES 3 with alternative thickness ranges 2.0m to 4.1 m. as seen in Figure 5, Figure 6 and Figure 7 respectively. In these cases (With the high ranking of resistivity and with thin depth, this tentatively may be an indicator of laterite. However, the second layer of the transverse show resistivity values ranging between 208.1 ohm-m to 353.5 ohm-m while the thickness depth ranges between 8.4m to 12.3m, therefore, the resistivity value show the composition values from Sandy Clay formation, thus inferred from the resistivity value obtained from the Sandy clay. The third layer is characterized to be a weathered Zone sandwiched with partly fracture zone. The resistivity of this layer ranging from 125.2 ohm-m to 476.0 ohm-m.

However, the last layer inferred to be a partly fracture and have the resistivity value to be 259.0 ohm-m-520.20 ohm-m. In this traverse, VES 2 value reveals the most prolific between the VES 1 and VES 3. The geo-electric section was draw along the traverse. The top sand has the resistivity between 186.0 ohm-m to 751.1 ohm-m with thickness of 1.1m to 2.0m. Aquifer depth of the study area is seen in Figure 15.

The second layer has resistivity between 176.6 ohm-m to 234.6 ohm-m with thickness depth of approximately 9.4m to 15.6m. The third layer has resistivity of 151.5 ohm-m to 358.9 ohm-m with thickness of 28.6m to 40.8m.

Electromagnetic survey results

Four-layer profile section were delineated from the Sub-surface profile of the electromagnetic survey as seen in Figure 16 and Figure 17 below. The traverse is along the Eastern to western flank. The entire traverse shows water bearing body signature, which are considered homogeneity of the aquifer. Figure 16 and Figure 17 are the Profile Survey for EM station 1 and 3 while Figure 18 and Figure 19 are the profile curve for EM station 1 and 2 respectively.

Moreover, there are distinctive four signature of Water bearing zone along the traverse, which comprises both weathered fracture and partly fresh basement and

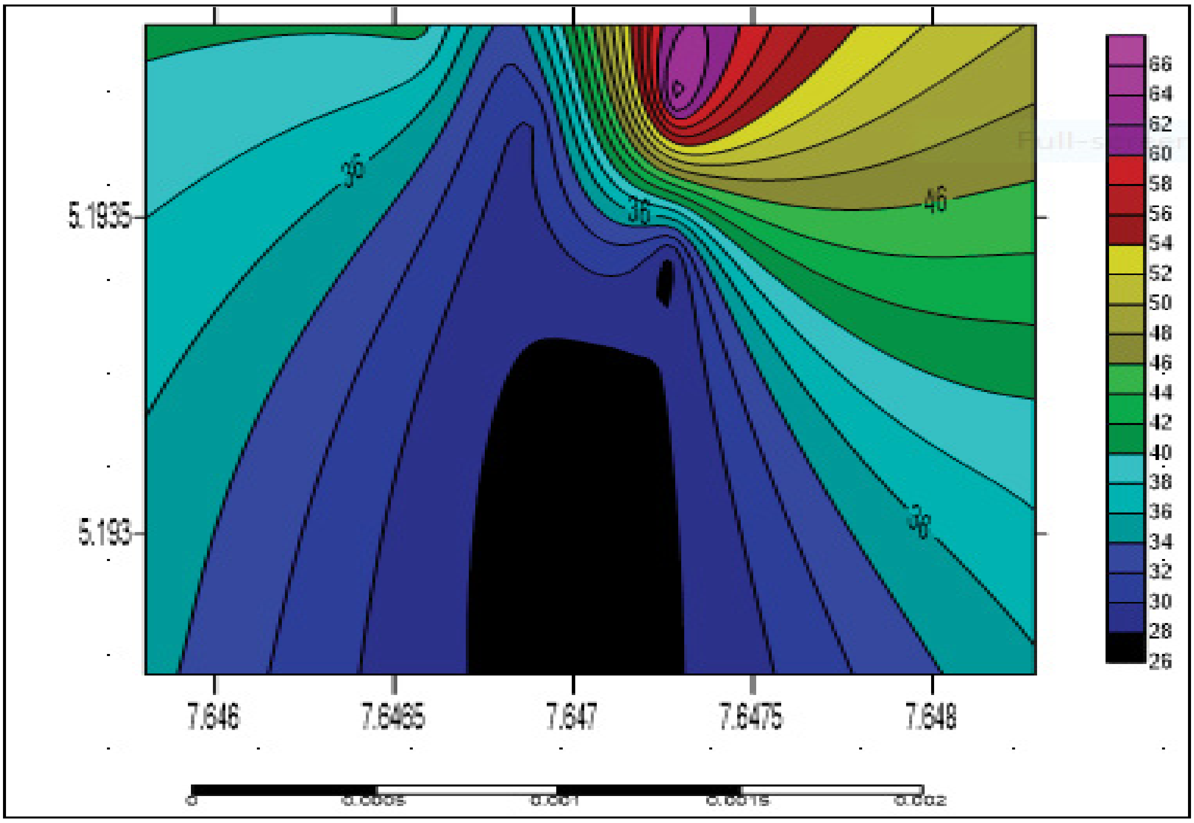

Figure 15: Aquifer depth contour Map of the study area.

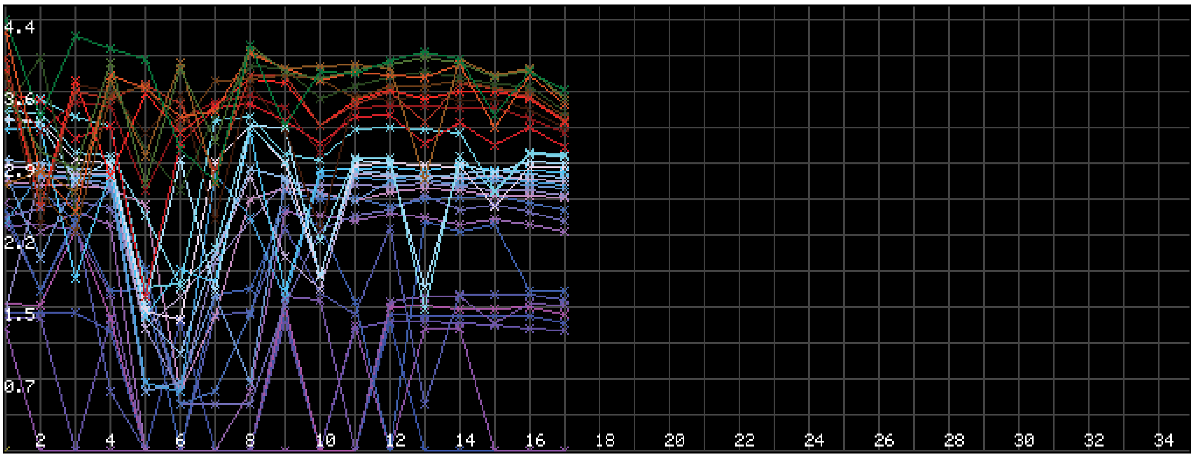

Figure 16: Profile Survey for EM station 1.

the traverses is 6m, 7m, 12m and 16m being the four (4) distinctive signature for zones of aquifer. The 6m traverse is the most highly prolific aquiferous zone in the study area respectively as seen in Figure 18 above. According to Olayinka AI, et al., [6] stated that for an area to be prolific zone in terms of groundwater potentials, the overburden thickness greater than 10 m. virtually the two (2) EM station have potential for groundwater water as the overburden thickness is greater than 10m (Figure 20).

The sub-surface profile in Figure 17 shows a four (4)-layer profile section. The traverse is from the Northern to Southern flank. This profile curve is a diagnostic features aquiferous zone, which is homogeneous in nature. However, there are also three (3) signature of aquifer zones along the traverse, which comprised of the fracture and partly fresh basement relatively of 7m, 10m, 12m. The 7m traverse is the most highly prolific aquiferous zone, because of the high fractured potential as seen in Figure 21 depicting a fracture delineation map of the study area.

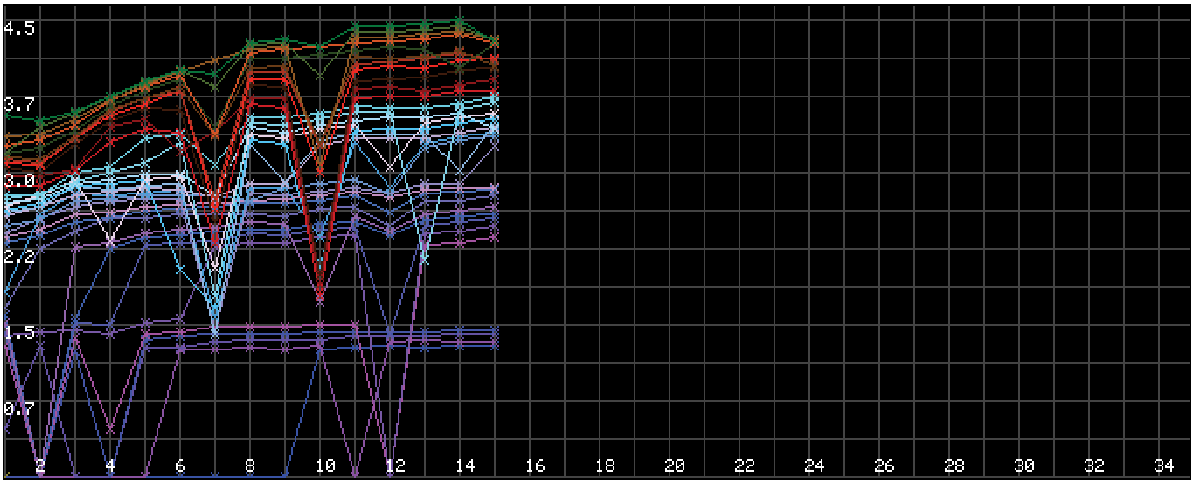

Figure 17: Profile Survey for EM station 2.

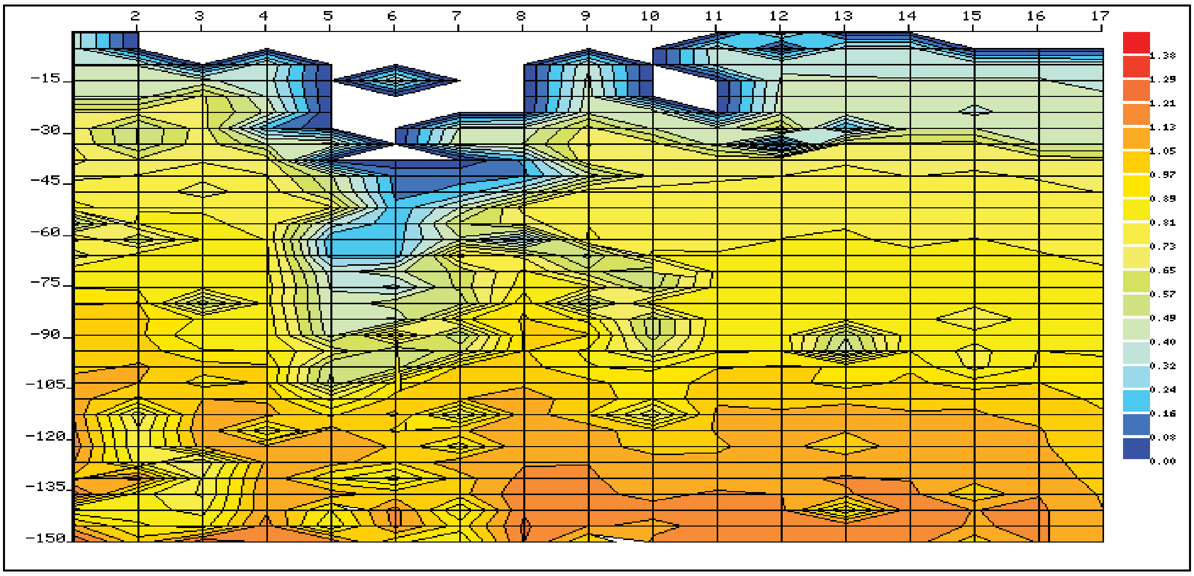

Figure 18: Profile Curve for EM station 1.

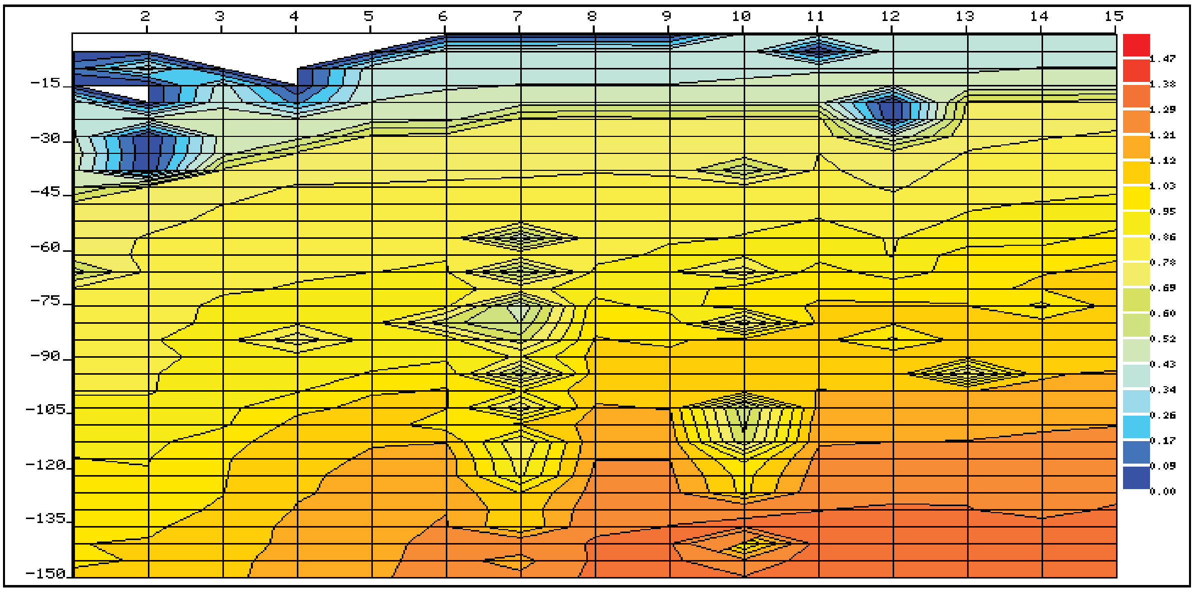

Figure 19: Profile Curve for EM station 2.

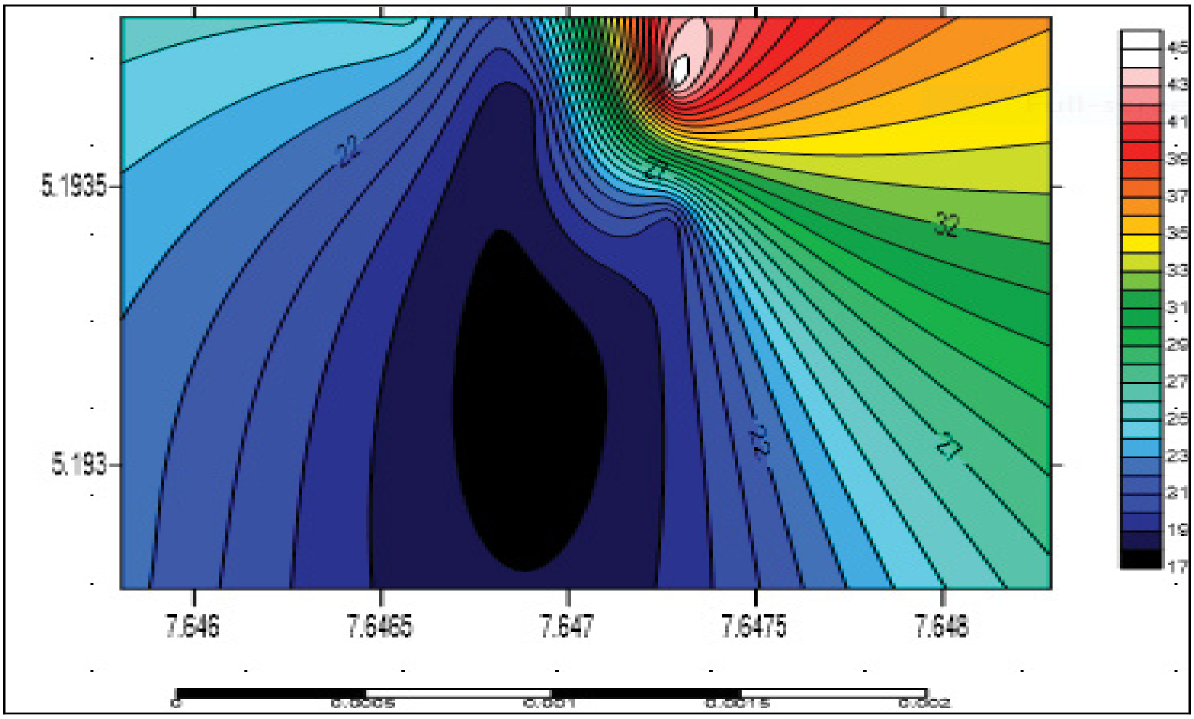

Figure 20: Aquifer potential Map of the study area.

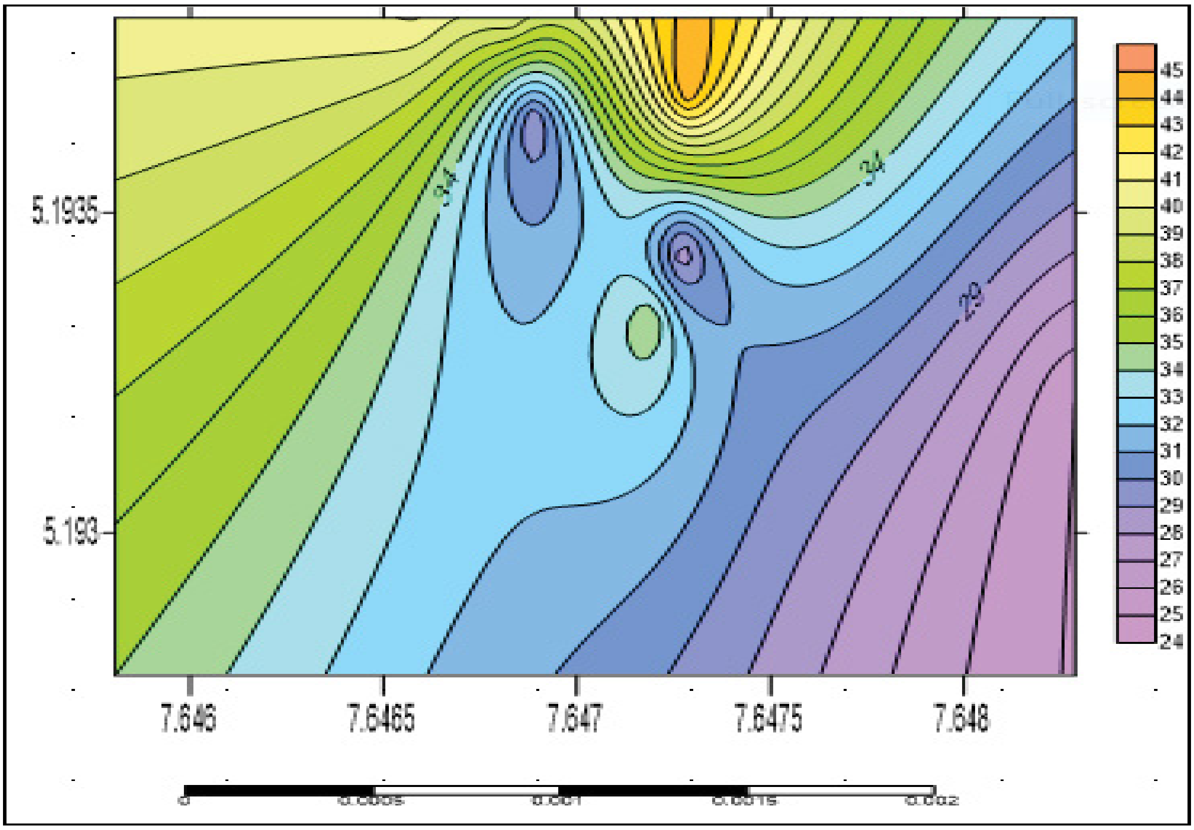

Figure 21: Fracture delineation depth Map of the study area.

Conclusion

A holistic measure for the assessment of groundwater potential of the area is very important. However, the use of Electromagnetic and Vertical electrical sounding methods has proved to be a veritable tool in fracture delineation to assess the hydrogeological settings and groundwater potential of the area. The result of the study shows a very prominent groundwater potentials and the study area is hydrogeological significant. Hydrogeologically, Groundwater development in the study area is mostly within the weathered overburden and the fractured bedrock basement. Also the result presented in this study has attempted to delineate the subsurface lithology and geo electric structure underlying the study area. The area is underlain by four layers of different lithological units. The geophysical methods used in this study have greatly assisted in evaluating groundwater potential. Weathered and fractured horizons have been identified in the study area underlying VES stations, and all of these constitute the aquifer zones. There are distinctive four signature of Water bearing zone along the EM traverse 1, which comprises both weathered fracture and partly fresh basement and the traverses is 6m, 7m, 12m and 16m being the four (4) distinctive signature for zones of aquifer while there are also three (3) signature of aquifer zones along the EM traverse 2, which comprised of the fracture and partly fresh basement relatively of 7m, 10m, 12m.

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