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Geophysical Investigation of Groundwater Potentials Using Vertical Electrical Sounding: Case Study of Boh Shongom Local Government Area Gombe State, Nigeria

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ABSTRACT

Thirteen (13) Vertical Electrical Sounding (VES) were carried out around Boh and its environs, employing Schlumberger array with a maximum electrode separation of AB/2 = 100 to determine locations favorable for sitting boreholes. The data obtained were processed and interpreted using Win Resist program. The results showed that ten (10) VES points displayed three layers, two (2) VES points displayed Five layers with only one (1) VES point with four layers. Geo-electric cross section revealed that the area is underlain by three geo-electric layers in some VES points and Five in others, top lateritic soil, weathered/fractured and fresh basement. The first layer has resistivity values of 13.7 to 118Ωm The second layer is a weathered/fractured basement with a resistivity of 29.3 to 1661.5Ωm and thickness of 5.7 to about 50m which constitute the aquiferous zones and the third/fourth and fifth layer is fractured/fresh basement with resistivity values of 353.5 to 3692.8Ωm. Base on the interpretation of curves of VES points and Geo-electric cross sections constructed; VES 2, 5, 6, 7, 9, 11 and 13 have good prospects for sitting and development of boreholes.

KEYWORDS

groundwater; resistivity data; resistivity curves; geo-electric section; Boh

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(1) INTRODUCTION

Water is one of the vital resources in life and therefore essential for human existence. It is a natural resource that is important for the survival of mankind and the natural environment. The availability of water has played a key role in the development of communities in the ancient times. Water scarcity prevented the development of settlements [1, 2]. Social welfare and economic development may also be hampered in the absence of reliable water supplies. This is particularly true of Sub-Sahara and Sahara countries, such as Nigeria, where water resources are extremely limited and highly valued as a social and economic good. [3] observed that more than two billion people worldwide depend on groundwater for their daily water supply, and a large proportion of the world's agricultural and industrial water requirements are supplied by groundwater. Groundwater development therefore constitutes a viable option or supplement to the expensive earth/concrete dam system of surface water supply where potential groundwater is good.

Geophysical methods have been a very useful tool in determining the geological characteristics of the underlying rocks by measurement of their physical properties. There are various techniques employed in groundwater exploration. However, electrical resistivity method is reliable in identifying zones of relatively low resistivity which might be indicative of saturated strata.

Vertical Electrical Sounding (VES) is an important geophysical tool for investigation of geological media. It is by far the most used method for geo-electric surveying because it is cost effective and produces moderate results. Moreover, the field measurement technique is adjustable for different topographic conditions. The results of VES measurements can be interpreted qualitatively and quantitatively. The principle of this method is to insert an electric current of known intensity through the ground with the help of two electrodes (Current electrodes – AB) and measuring the electric potential difference with another two electrodes (Potential electrodes – MN). The investigation depth is proportional to distance between the Current electrodes. The method is based on the estimation of the electrical conductivity or resistivity of the medium. The interpretation of the measurements can be performed based on the apparent resistivity values. To obtain the apparent resistivity as the function of depth, the measurements for each position are performed with several different distances between current electrodes [4, 5, 6].

Most resistivity techniques define a response function called apparent resistivity, which can be calculated from the surface measurements. The apparent resistivity is usually functioning of a variable that is related to the depth of current penetration. The apparent resistivity is equal to the true resistivity only when the subsurface is homogeneous. In practice, this condition is difficult to obtain. This is a convenient way of representing a response of the actual distribution of lateral resistivity in the subsurface measurements. If the electrodes are laid out along a profile and their separations are increased systematically, the change in the apparent resistivity will be a function of electrode spacing [7, 8, 9, 4, 5, 6] Haven said that the subsurface resistivity is measured by applying an electric current through two current electrodes and measuring the resulting voltage difference between potential electrodes. For the general four electrode spread, the potential difference ΔU between the potential electrodes is given below:

$U_1-U_2=\Delta U= I\rho/2\pi \{(1/r_1 -1/r_2)-(1/r_1 -1/r_2)\}$ ……………………………………………………………… (1)

$\Delta U=I\rho/2\pi (1/r_1 -1/r_2 -1/r_1 +1/r_2)$……………………………………………………………………………… (2)

$\rho=\Delta U/I \ 2\pi/((1/r_1 -1/r_2 -1/r_1 +1/r_2))$……………………………………………………………………(3)

Where ρ is the resistivity, I is the current and $r_{(1,)}$ $r_{(2\ ,)}$ r_3 and r_4 are the inter-electrode distances
$\rho_a= K_f (\Delta U/I)$…… (4)

Where K_f is the geometric factor and it depends on electrode configuration used in the field measurement. Resistivity measuring instruments normally give a resistance value, $R = \Delta U/(I\ \ )$ in practice the apparent resistivity value is calculated by

$\rho_a=K_f R$ ……… (5)

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value that is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement.

Over uniform earth or homogeneous isotropic medium this calculated resistivity is constant for different electrode separation and any current. However, if the ground is inhomogeneous, the calculated resistivity varies as the electrode spacing is varied or the array is moved about. This calculated resistivity is called "apparent resistivity", which is diagnostic of the true resistivity of the subsurface in the vicinity of the electrode array. The apparent resistivity may be smaller or larger than the true resistivity or in rare cases identical with one of the true resistivity values. The apparent resistivity is the same as the true resistivity in a homogeneous subsurface, but normally a combination of contributing strata of an inhomogeneous subsurface. The value of the apparent resistivity obtained with small electrode spacing is called the surface resistivity. In any electrode layout, the potential and current electrodes can be interchanged and from the principle of reciprocity, the apparent resistivity should be the same (unchanged) in either case [8, 10, 11, 12, 13, 14, 15, 16].

Therefore, this research employed the use of electrical resistivity method using vertical electrical sounding (VES) technique to explore the groundwater potential of the study area for human sustainability and development. The study provides information on depth to which groundwater can be exploited and reveal the geo-electrical layers one may encounter in the subsurface, which may coincide with geological layers.

1.1 Location, Extent and Accessibility

The study area is part of the Gongola arm of Upper Benue Trough. The area is located within Shongom Local Government area of Gombe State in the northeastern region of Nigeria. The area lies between Latitudes 9°46'00"N to 9°48'30"N and Longitudes 11°15'00"E to 11°17'00"E (Fig. 1). Boh town is the administrative headquarters of Shongom local government area and is inhabited by many people especially Tangale people. The area has an average elevation of 31 m to 590 m above sea level. Boh is underlain predominantly by basement rocks. The northeast and southwest structural trend controls the directional flow of the stream, rivers and valleys thus forming a dendritic drainage pattern. The climate consists basically of two Seasons, a rainy season and dry season. The onset of the rainy season is from April to June and ceases at the end of October, with an average rainfall of about 2.38 mm annually. The rainy period of the year last for 6 months, from April to October, with a sliding 31days rainfall of at least 2 mm. The month with the most rain in Boh is August, with an average rainfall of 5 mm. The rainless period of the year lasts for 5 months, from October to April. The month with the least rain in Boh is November [17]. During the raining season, temperature of the area ranges between 20 to 25 0C while in the dry season, the temperature ranges between 32 to 39 0C. This season is also characterized by humidity and temperature of about 25 0C while in the dry season, the temperature of about 32 0C is usually recorded. [17].

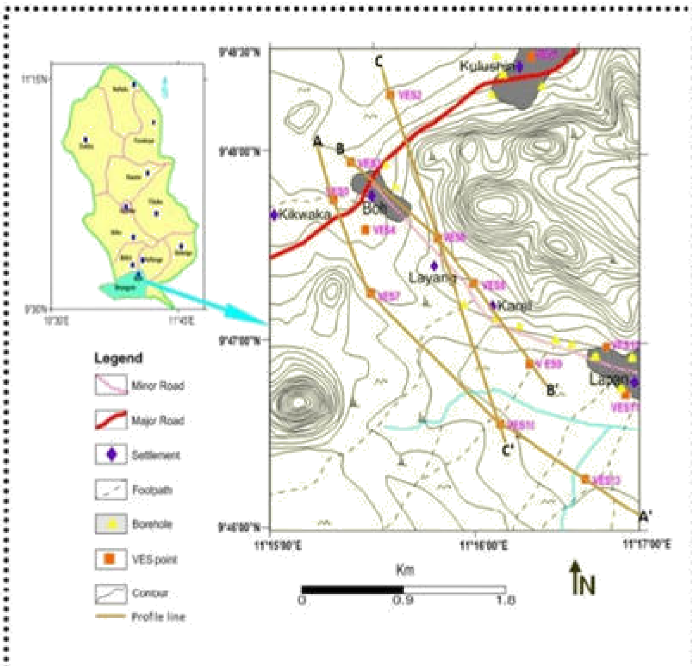

FIGURE 1: Topographic map of the Study area, After [18].

1.2 Geology and Tectonic Setting of the Area

The origin of the Benue Graben has been diversely attributed to tensional stress associated with South America-African separation tectonics in the Jurassic [19]. The Benue Trough was subjected to several folding episodes notably in the Cenomanian, Sentonian, Post Maastrichian and perhaps Paleocene. Numerous faults have been observed with the trough and the sediments-basement contacts show evidence of faulting. Of all the episodes of folding the Sentonian folds are the most prominent. This episode of folding gave the Benue Trough a unique character, the folds are parallel to the axial trend of the trough. The evolution of the Benue Graben is intimately connected to that of the South Atlantic Ocean (Figure 2).

A reconstruction of the relationship of the South America and African plates shortly after the South Atlantic began to open [20] suggest that the Gulf of Guinea, the Benue Trough and the South Atlantic developed between two RRR triple junctions one located beneath the present Niger Delta Miogeocline and the other North of Takatu Rift in South America.

It is now generally accepted that an RRR (rift-rift-rift) triple junction existed at the site of the present Niger Delta in early Cretaceous with arm as Gulf of Guinea (R), the South Atlantic (R) and the Benue Trough arm (R). The initial formation of the RRR triple junction at the location of modern-day Niger Delta was a consequence of a cycle of events which led to the separation of Africa from South America, opening of the South Atlantic and tectonic evolution of the Benue Graben. The study area is part of the Gongola arm of the Upper Benue Trough, northeast Nigeria. The Benue Trough was understood to be a trough that was formed due to rifting [21, 22].

The Benue Trough (Figure 2.) is an elongated rift basin in central West Africa filled with Cretaceous-Tertiary sediment. The Trough is one of the most important of all the Cretaceous sedimentary basins in Nigeria [23]. It stretches in the NE-SW direction for about 1000 km from a Precambrian Basement Complex. The southern limit is the northern boundary of Niger Delta, while the northern limit is the southern boundary of the Chad Basin. The Trough is bordered on each side by Crystalline Basement Complex, [21, 24, 25]. The Basement Complex is highly fractured and weathered. The study area falls within the Upper Benue Trough.

The Upper Benue Trough is divided into two branches trending N-S and E-W and named Gongola and Yola Arm respectively. [21] produced the foundation work of the geology of the Upper Benue Trough. The two arms are separated by NE-SW trending ridge called the Zambuk Ridge. The Cretaceous sedimentary deposits of the two sub-basins are characterized by the deposition of a continental deposit and overlain by marine deposits. Overlying the basement are syn-rift platform sediments ranging from early Cretaceous which in Northern Benue Trough is the Bima Sandstone, [21]. It consists of fanglomerates flanking fault-scarps, cross-bedded and of fluvial origin. Bima formation dated Late Aptian-Cenomanian. The name Yolde Formation was proposed for the transition beds recognized earlier between the Bima Group and the Pindiga Formation [21, 26]. A type section was designated in the Yolde stream in the western part of the Yola Arm. Adegoke suggested a Late Albian to Late Cenomanian age for the Yolde Formation on the basis of its palynofossils [27, 28]. The name Pindiga Formation was proposed for the calcareous beds and clay shales previously described [21, 29]. The Pindiga Formation developed in the Gongola Basin is equivalent to Dukul Formation, Jessu Formation, Sekuliye Formation, Numanha Shale and Lamja Sandstone of the Yola Basin.

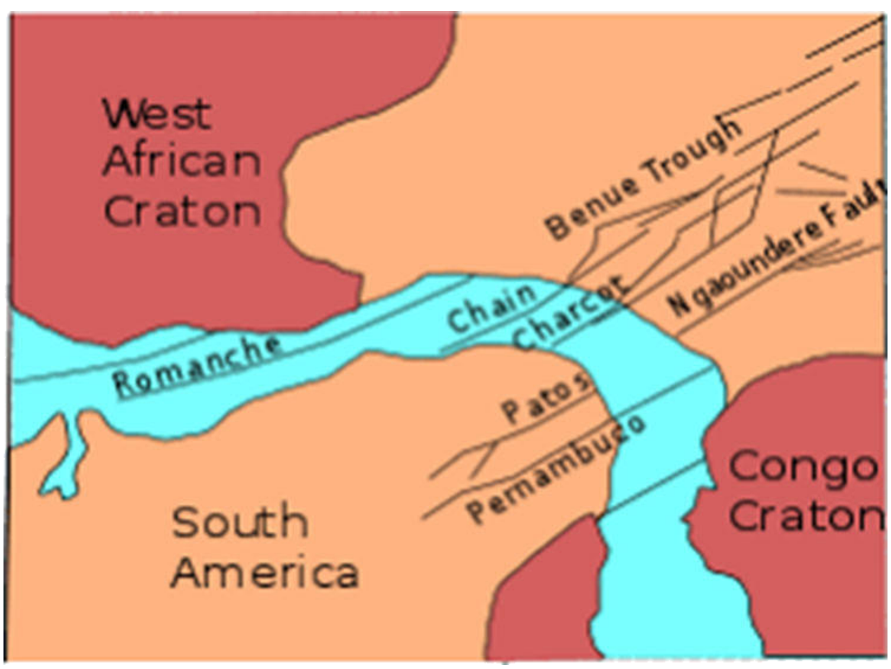

FIGURE 2: Map showing the Separation of Africa and South-America, After, [30].

In the Gongola-Gombe sub basin, the Gongila Formation and Fika Shale are the lateral equivalents of the Pindiga Formation. Lithologically, the Pindiga Formation is made up of dark/black carbonaceous shales and limestones intercalated with pale coloured limestone, shale and minor sandstone. The Gombe Formation overlies the Pindiga Formation and represents the youngest Cretaceous sediments in the Gongola arm of the Upper Benue Trough, The Gombe Formation is a sequence of estuarine and deltaic sandstones, shales, siltstones and ironstones which overlie the Pindiga, Gongila and Fika shale Formations in the Gongola arm of the Upper Benue Trough. Falconer named Gombe Formation near Gombe town as Gombe grits and clays and assigned an Eocene age to it. [26, 31] described the Gombe Sandstone at Kware stream as consisting of well bedded fine to medium grained sandstone, sandy and silty micaceous shale and occasional mudstones.

Kerri-kerri formation represents the record of early Tertiary sedimentation in North-eastern Nigeria and overlies the Cretaceous Gombe Sandstone unconformably in the Gongola Basin of the Upper Benue Trough. The Formation is essentially flat laying to gentle dipping of about 50 m [21]. The maximum thickness of the Kerri-Kerri Formation is about 300 m, although it varies from 300 m to over 320 m [32]. The type section of this Formation is exposed at Kadi about 100 km north of Kaforati. The Formation is considered to be Palaeocene in age. Figure 3 shows the stratigraphic successions of the Upper Benue Trough.

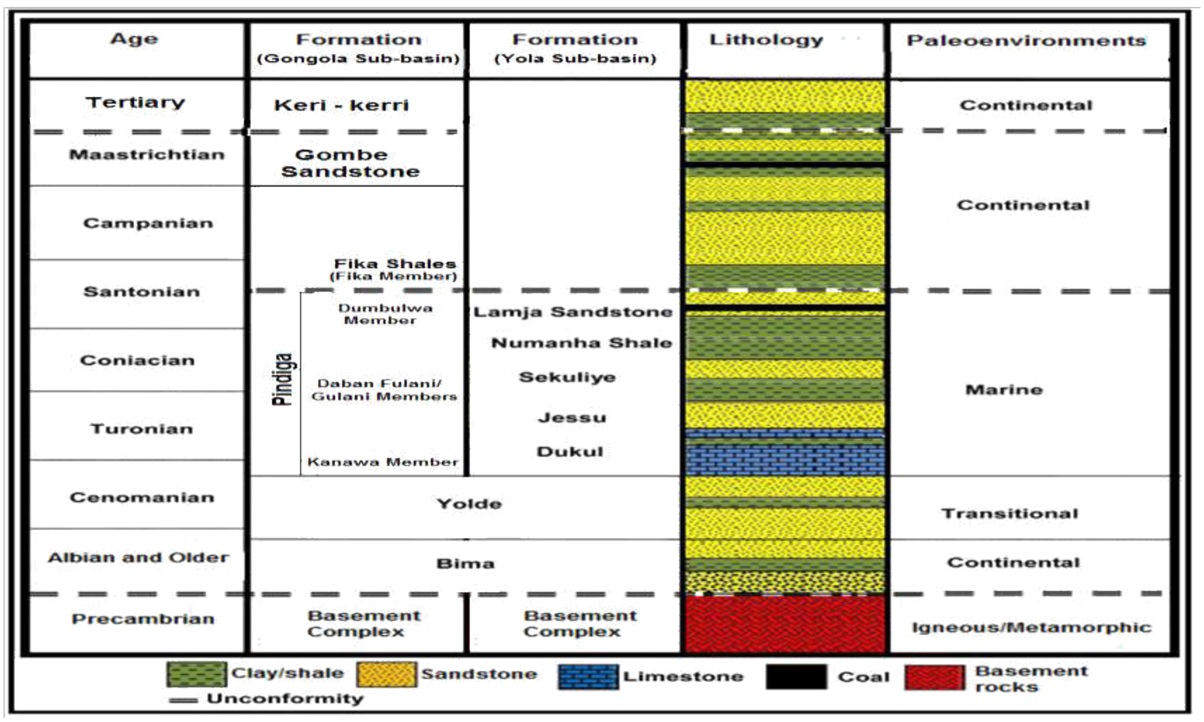

FIGURE 3: The Stratigraphic Succession of the Upper Benue Trough, After, [33].

1.3 Geology of the Area

The geologic map of the study area (Figure 4) revealed that, Boh is generally underlain by four different rock types: Bima Formation, Basalt, Granite and Porphyritic granite [34]. According to [35] the lithology of the study area comprises of two major rock units; The crystalline complex which is represented by older granite comprising of coarse porphyritic granites and biotite granites constitute about 85% of the rock types in the area, the basaltic plugs outcrop in the south eastern part of the study area occupying about 5% of the area. They occur within the sedimentary rocks that characterized the southern parts of the study area, their contact with the Bima sandstone is well defined, and the sedimentary rock identified in the area is Aptian-Albian-Bima sandstone which occurs in the southern parts of the area, covering about 10% of the study area. It outcrops mostly in the southern parts as plains with some prominent hills. The sandstone is cream to Gray in color and varies from medium grained to very coarse-grained in texture. The Bima sandstone is characterized with Joints, Beddings and Faults.

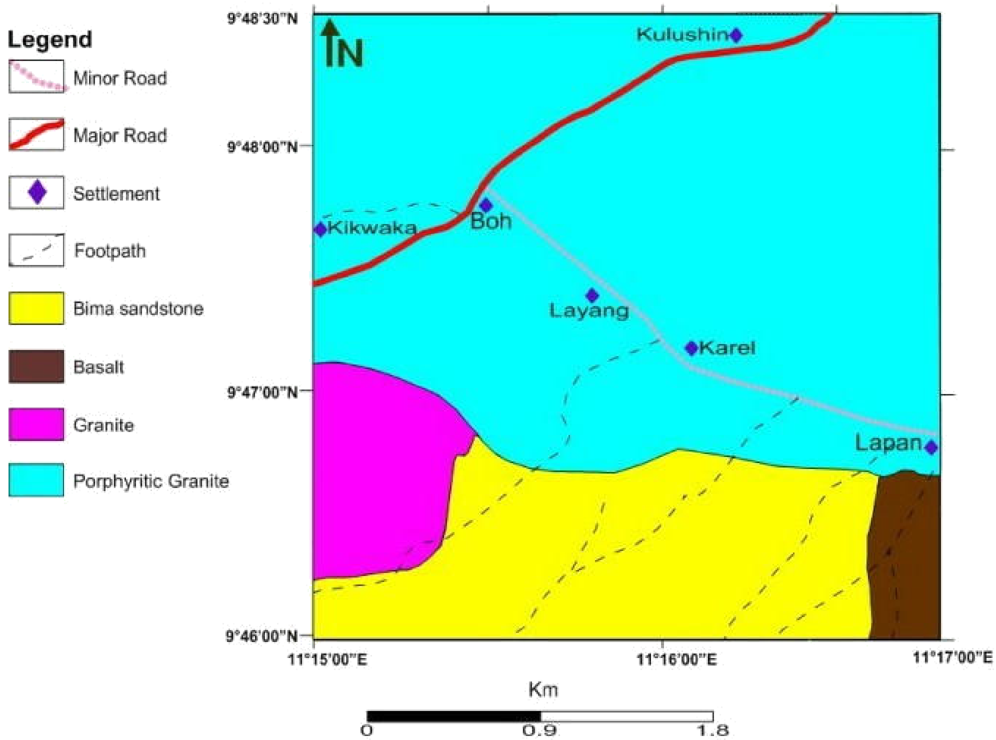

FIGURE 4: Geologic Map of the Study Area. After, [36].

(2) MATERIALS AND METHODS

2.1 Vertical Electrical Sounding Survey

The data was collected using standard electrode configuration of Schlumberger configuration using the principle that the current electrodes vary along a straight line in both directions. However, the potential electrodes are remaining constant and moved when better results of subsurface strata is needed in case of weak signals. Various types of electrode configurations like Wenner array, Dipole-dipole, Pole-pole and Pole-dipole are available but Schlumberger electrode configuration was adopted due to its flexibility and accuracy in results for data collection (Fig. 5) for any linear, symmetric array AMNB of electrodes, equation 1 can be written in the form:

ρ_a= ((AB/2)^2- (AB/2)^2)/MN- ΔV/I…………………………………………………………………… (6)

The resistivity meter used in this research was Direct Resistivity Meter (DDR-3) water stone, In view of its high resolution and depth probe, the Schlumberger configuration (Fig. 5) was used for this survey. The resistivity meter was placed at the exploration site which is suitable for lateral spreading of the cable wires in either direction. The non-polarizing electrodes (inner electrodes) needed for measuring the potential differences are placed at predetermined distances on either side of chosen center near to the measuring equipment and current electrodes (outer electrodes) were also placed on either side. Covered cable were connected to the potential electrodes as also the current electrodes are connected to the proper terminals on the equipment. The power supply pack is also connected to the instrument. The current electrodes are driven into the ground at least 10 to 15 cm deep each on either side of the center with use of hammer. The working of the instrument begins and is operated as per the principles used in the instrument.

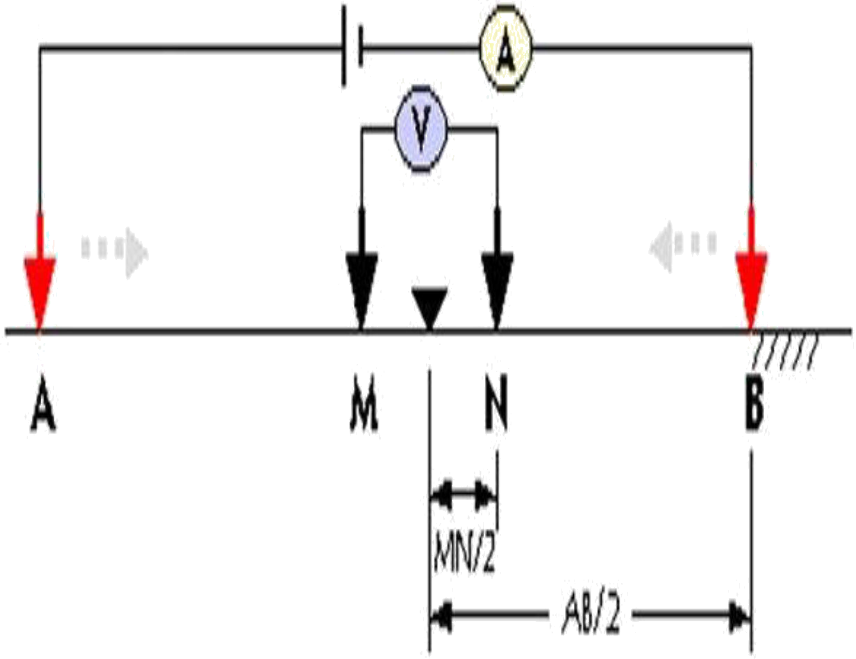

FIGURE 5: Schlumberger array.

Current was passed through the two extreme electrodes (current electrodes); the potential difference was received by potentiometer of DDR-3 meter between the two inner electrodes spaced at = 0.5 m, 2 m, 10m. While AB = 200m due to the fact that the overburden in the area is not as thick as to require a large current electrodes spacing for deeper penetration and current electrodes were moved equally on the either side (as the distance between electrodes increases, the depth of penetration also increases) of the station point according to designed acquisition parameters in the study, the design was 1.5, 2, 3, 4.5, 7, 10, 10, 14, 17, 20, 25, 30, 45, 45, 60, 70, 80 and 100m. A total of thirteen (13) VES point were marked out for the survey and the data of each VES point were recorded on data sheet, the locations (co-ordinates and elevation) of each VES point was also recorded with the aid of GPS (Global Positioning System).

2.2 Data Processing

The apparent resistivity (ρ_a) was calculated for each VES point using 〖ρ〗_a = RK_f. Where K_fthe Geometric factor and R is the Resistance. The resistivity data were processed using WINRESIST software.

(3) RESULTS

3.1 Interpreted Curves and Models of VES

The interpreted curves and models of the study area revealed Q, H, KHK and QK curve types with model layers of three, four and five. The layers thickness ranges from 0.5 to 58.6m (Figure 6 and Table 1).

3.2 Geo-Electric Cross Section Along Profile A-A'

The geo-electric cross-section (Fig. 7) is characterized by four layers of top soil with resistivity varying from 13.7 to 118.0 ohm-m, weathered basement with resistivity ranging from 29.3 to 896/7 ohm-m, fractured basement (240.0 to 258.2 ohm-m) and fresh basement (230.5 to 2359.1 ohm-m).

3.3 Geo-Electric Cross Section Along Profile B-B'

The geo-electric cross-section (Fig. 8) is made up of four layers: top soil, weathered basement, fractured basement and fresh basement with resistivity of top soil ranging from 13.7 to 35.9 ohm-m, weathered basement from 132.8 to 1661.5 ohm-m, fractured basement with 33.0 ohm-m and fresh basement from 353.5 to 1388.7 ohm-m.

3.4 Geo-Electric Cross Section Along Profile C-C'

The geo-electric cross-section (Fig. 9) consist of three layers of top soil, weathered basement and fresh basement. The resistivity of the top soil varies from 14,1 to 43.2 ohm-m, weathered basement from 896.7 to 1661.5 ohm-m and fresh basement from 525.3 to 3692.8 ohm-m.

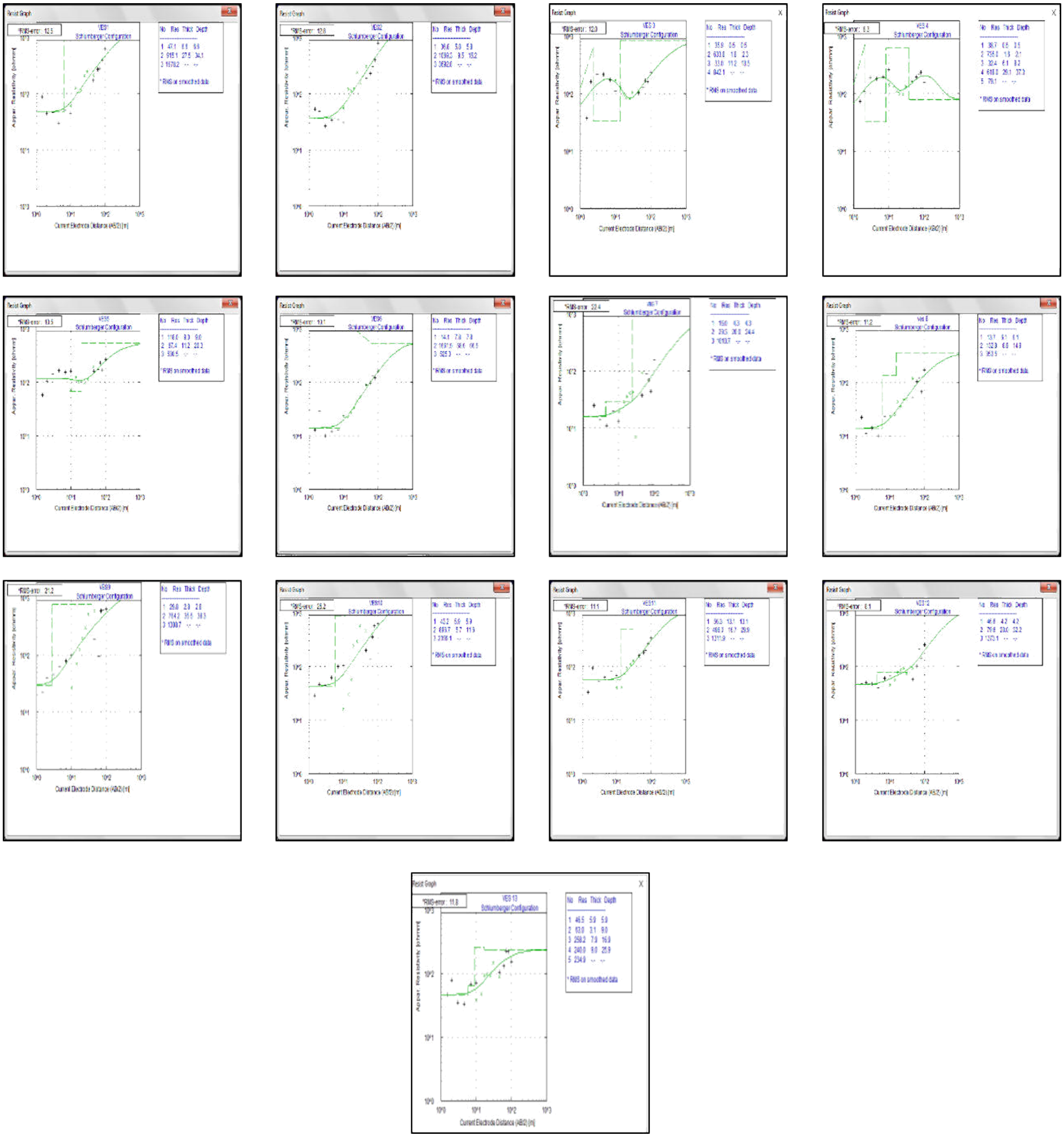

FIGURE 6: Interpreted Curves and Models of VES 1 to 13.

TABLE 1: Geo-electric Parameters and Lithologic Delineation at Boh and Environs (Model Parameters).

VES No.	Location	Layers	Resistivity (Ωm)	Layer Thickness (m)	Depth (m)	Lithology	Curve Type
1	N9°48'26" E11°16'25"	1	47.1	6.6	6.6	Top soil	Q
		2	915.1	27.5	34.1	Weathered/fractured Basement	
		3	1678.2	-	-	Fresh Basement	
2	N9°48' 12" E11°15'40"	1	36.8	5.8	5.8	Top soil	Q
		2	1069.3	9.5	15.2	Weathered/fresh Basement	
		3	3692.8	-	-	Fresh Basement	
3	N9°47' 55" E11°15'28"	1	35.9	0.5	0.5	Top Soil	KQ
		2	633.8	1.8	2.3	Weathered Basement	
		3	33.0	11.2	13.5	Fractured Basement	
		4	842.1	-	-	Fresh Basement	
4	N9°47'33" E11°15'23"	1	38.7	0.5	0.5	Top Soil	KHK
		2	735.0	1.6	2.1	Weathered Basement	
		3	32.4	6.1	8.2	Highly/fractured Basement	
		4	618.0	29.1	37.3	Fractured Basement	
		5	79.1	-	-	Fresh Basement	
5	N9°47'33" E11°15'32"	1	118.0	9.0	9.0	Top Soil	H
		2	62.9	11.2	70.3	Weathered/fractured Basement	
		3	485.6	-	-	Fresh Basement	
6	N9°47'29" E11°15'54"	1	14.1	7.8	7.8	Top Soil	Q
		2	1661.5	58.6	66.5	Weathered/fractured Basement	
		3	525.3	-	-	Fresh Basement	
7	N9°47'15" E11°15'33"	1	16	4.3	4.3	Top Soil	Q
		2	29.3	20.0	24.4	Weathered/fractured Basement	
		3	1010.7	-	-	Fresh Basement	
8	N9°47'18" E11°16'8"	1	13.7	6.1	6.1	Top Soil	Q
		2	132.8	8.9	14.9	Weathered/fractured Basement	
		3	353.5	-	-	Fresh Basement	
9	N9°46'52" E11°16'26"	1	29.8	2.8	2.8	Top/lateritic Soil	Q
		2	764.2	35.5	38.3	Weathered/Saturated Sandstone	
		3	1388.7	-	-	Fresh Basement	
10	N9°46'34" E11°16'16"	1	43.2	5.9	5.9	Top/lateritic Soil	Q
		2	896.7	5.7	11.6	Weathered/Saturated Sandstone	
		3	2359.1	-	-	Fresh Basement	
11	N9°47'28" E11°15'53.9"	1	36.3	13.1	13.1	Top/lateritic Soil	Q
		2	496.0	16.7	29.9	Weathered/Saturated Sandstone	
		3	1311.9	\-	-	Fresh Basement	
12	N9°47'14.5" E11°15'33"	1	46.6	4.2	4.2	Top/lateritic Soil	Q
		2	79.6	28.0	32.2	Weathered/Saturated Sandstone	
		3	1373.1	-	-	Fresh Basement	
13	N9°47'17.5" E11°16'79"	1	46.5	5.9	5.9	Top/lateritic Soil	Q
		2	63.0	3.1	9.0	Weathered/Saturated Sandstone	
		3	258.2	7.9	16.9	Highly/fractured Basement	
		4	240.0	9.0	25.9	Fractured Basement	
		5	234.9	-	-	Fresh Basement	

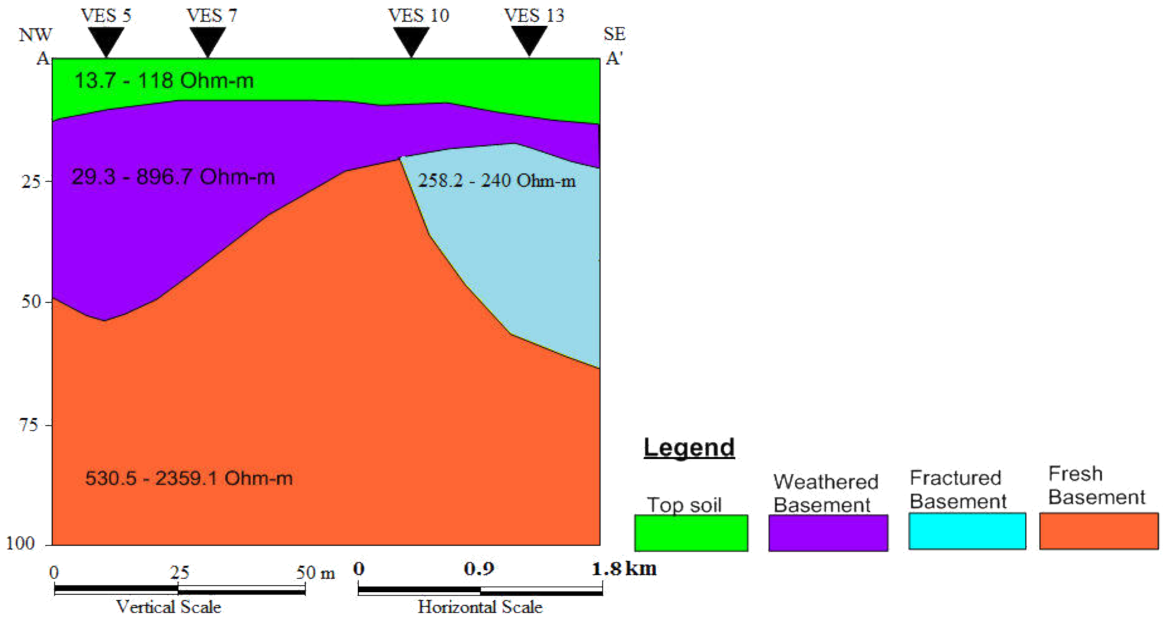

FIGURE 7: Geo-Electric Cross Section Along Profile A-A'

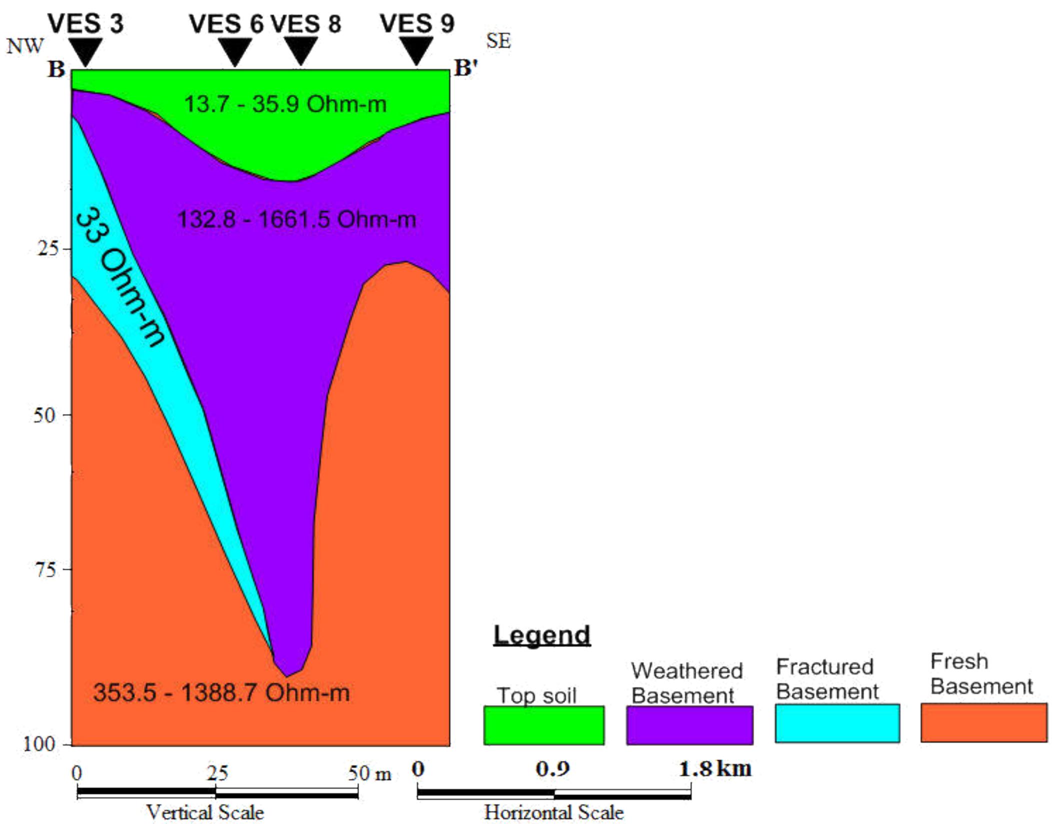

FIGURE 8: Geo-Electric Cross Section Along Profile B-B'

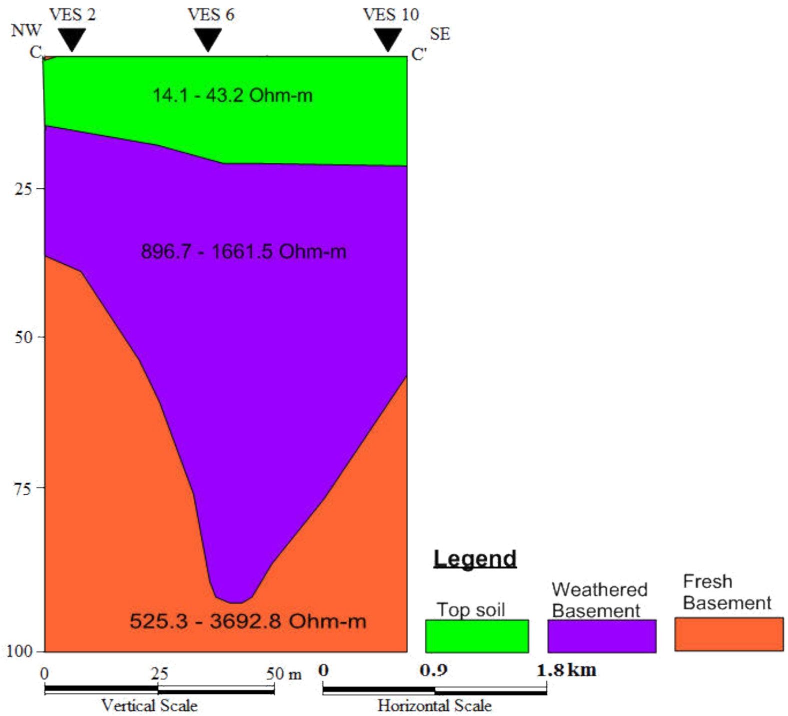

FIGURE 9: Geo-Electric Cross Section Along Profile C-C'.

(4) DISCUSSION

The acquired data from Geophysical survey was analyzed in accordance with the WINRESIST computer software. The basic working principal of which is the conventional curve matching the interpreted field curve (Fig. 6) for each VES point in the study area are presented in Table 1. The assumption during the interpretation is that the underlying formations are horizontal and parallel to earth surface

The final digital inversion results of VES interpretation (using WINRESIST software) were used for the construction of three geo-electrical cross-sections. The three geo-electric cross-sections were constructed along three profiles [Fig. 7 (A-A), Fig. 8 (B-B') and Fig. 9 (C-C')]

Thirteen Vertical Electrical Soundings (VES) were conducted using the Schlumberger configuration with a maximum current electrode of 100 m using DDR-3 meter, and the results revealed the thickness of layers, resistivity of layers, fitting error and curve-types of the 13 VES points in the study area. The area is underlain by three and or four and five geo-electric layers in some VES points. The first layer represents the top/lateritic soil. The second layer is a weathered basement, while the third, fourth and fifth represents fractured, and or fresh basements (at the VES points whose display four or five layers).

Curve types identified are simple H and Q, types and complex KHK, and KQ characterized by three layers, reflecting lithological variations in the area. The Q curve types were the most dominant curve types suggesting high increase in resistivity from first to third layer, the H curve type indicating the low resistive layer overlain and underlain by high resistive layers. The general signature of the curves suggests alternate sequence of conductive-reflective, resistive-conductive layers, reflecting topsoil, weathered/fractured zone, porous and permeable un-weathered crystalline rocks nature of the study area. It was responsible for the discrete resistivity layers obtained in the curves.

The area is characterized by Low, medium, fairly high and high resistivity layers. The units with low and medium resistivity values were interpreted as topsoil (clay/ laterite/sand) which consists of conductive materials varying in composition from clay, laterite and sand, derived from weathering of basement and highly compacted sedimentary rocks depending on the local variation of the mineralogy of the basement and sedimentary rock. Fairly high resistivity layer represents the slightly weathered and fractured zone, and the nearly porous and permeable rocks. High resistivity values characterize the un-weathered, fresh crystalline bedrock in the study area and are generally identified by higher values, while on the sedimentary portion; the high resistivity value is a characteristic of highly consolidated sandstone. The crystalline basement and highly compacted sedimentary rocks normally have low porosity and permeability, except where they are faulted, fractured or jointed. Thus, they are devoid of groundwater which influences the resistivity.

Geo-electrical cross sections were drawn along profile A-A', (Fig. 7) made up of four (4) vertical electrical sounding points which are VES 5, VES 7, VES 10 and VES 13. This section revealed the presences of three geo-electric layers, the top soil, weathered/fractured basement and fresh basement. The top soil has resistivity ranging from 13.7 to 118 Ωm and with average thickness of about 7.5m. The second layer is weathered /fractured basement has resistivity value ranging from 29.3 to 896.7 Ωm, the thickness is about 20 m at VES 7 at depth of 24 m suggesting good points for sitting borehole. The third layer is fresh basement has resistivity value ranging from 530.5 to 2359.1 Ωm and infinite thickness.

The Geo-electrical section along profile B-B', (Fig. 8) is made up of four vertical electrical sounding points which are VES 3, VES 6, VES 8 and VES 9. The first layer which is top soil has resistivity value ranging from 13.7 to 35.9 Ωm. The thickness this layer is limited. The second layer is a weathered/fractured basement and or fractured Basement at VES 3, has resistivity value ranging from 132.8 to 1661.5 Ωm and the thickness of this layer at VES 6 and VES 9 is about 50 and 30m at depth of almost 55 and 35 m respectively, hence are suitable for sitting of borehole which is typical of basement terrain (Mohammed et al., 2007). The third layer is fresh basement and has resistivity value ranging from 353.5 to 1388.7 Ωm and infinite thickness.

Geo-electrical cross section along profile C-C', (Fig. 9) revealed the presence of three geo-electric layers, top lateritic soil, weathered/fractured basement and fresh basement comprising of three VES points: VES 2, VES 6, and VES 10. The top soil has resistivity range from 14.1 to 43.2 Ωm, and thickness increases from VES 2 towards VES 6 to VES 10. The second layer is a weathered/fractured basement with resistivity value ranging from 896.7 to 1661.5 Ωm and the thickness of about 50 m at VES 6 suggesting suitable site for sitting borehole at VES 6. The third layer is a fresh basement, has resistivity value of 525.3 to 3692.8 Ωm and thickness of Infinite depth.

(5) CONCLUSION

The following conclusion can be drawn from the findings of this study:

1. The curve types obtained in the study area are simple Q and H, and complex KHK and KQ curve types.
2. Three to five distinctive geo-electric layers were identified. The first layer represents the top lateritic/top soil, the second layer is a weathered basement, the third and fourth layer is fractured basement and fifth layer is fresh basement.
3. The second layer is considered to be a weathered/fractured basement rocks in the study area which constitute the aquifer zones.
4. Geo-electric sections which were analyzed based on hydro-geological importance of the study area revealed that the area can be categorized into low groundwater potential.
5. The low yields of wells arising from aquifer and inadequate understanding of the hydrogeology of the crystalline basement in the aquifer system are perhaps due to lack of fractures in some part of the Study area.

(6) RECOMMENDATION

It is recommended that, Borehole should be drilled in VES points 5, 7, 10 and 13 because they are the potential zones for groundwater exploration which is indicative of their low resistivity, and therefore suggesting good points for sitting boreholes. It is also recommended that an integrated geophysical survey should be carried out in the study area in order to have accurate results.

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