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Using Vertical Electrical Sounding to Investigate Groundwater Resources in Ibillo, Akoko – Edo LGA, Edo State

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ABSTRACT

Electrical resistivity survey was carried out around Ibillo, Akoko – Edo LGA, Edo State in order to delineate geologic layers with a view of determining the thickness of the geologic layers and groundwater potential in the study area. The Petrozenith PZ – 02 Terrameter was used for data acquisition. The survey was carried out at two different locations (VES 1 and VES 11). A maximum of $300m$ and $140m$ current electrode spread was adopted for VES 1 and VES 11 respectively. The IPI2Win computer software was used to analyze the field data obtained which gave an automatic interpretation of the apparent resistivity values. The VES result showed the presence of six (6) layers for VES 1 and five (5) layers for VES 11. The average resistivity values and thicknesses of the first four layers delineated were $355.5\Omega m$ and $0.5m$ for the first layer, $277\Omega m$ and $1.004m$ for the second layer, $232.4\Omega m$ and $3.035m$ for the third layer, $182592.25\Omega m$ and $14.18m$ for the fourth layer respectively. However, due to differences in current electrode spread, the fifth layer for VES 1 has a resistivity of $365123\Omega m$ and a thickness $33.1m$ while the sixth layer has a resistivity of $14989\Omega m$ and undetermined thickness. Whereas, in VES 11 which has a lower current electrode spread, the fifth layer has a resistivity of $35800\Omega m$0m and undetermined thickness. The average depth to the interfaces are $0.5m$, $1.505m$, $4.54m$ and $18.7m$ respectively for the first, second, third and fourth interface. Also, the fifth layer in VES 1 has a depth of $35.2m$ to the interface while the fifth layer in VES 11 has undefined depth as the sixth layer in VES 1. The lithologic interpretations for the first five layers were sandy clayey topsoil, clay formation (clayey layer), claystone, highly weathered basement and fractured basement respectively. The depths to the aquifer are $35.2m$ and $25.2m$ for VES 1 and VES 11 respectively.

Keywords: Electrical resistivity, Electrical sounding, groundwater potential

INTRODUCTION

Electrical exploration methods maybe subdivided into two main groups. One group is concerned with the measurement of their capacitance. The galvanic, induction, magneto – telluric and telluric methods belong to the first group, and the induced polarization methods belong to the second group (Sabet M. A., 1975). The second group also includes gravity, magnetic, electrical and seismic methods.

All resistivity methods can be applied for studying variations of resistivity with depth (depth sounding methods) or for studying lateral changes in resistivity (horizontal profiling methods). The choice of a method depends on what is being searched for. The vertical electrical sounding (VES) method is a depth sounding galvanic method and has proved very useful in groundwater studies due to the simplicity and reliability of the method (Joshua E. O., Odeyemi O. O. and Fawehinmi O. O., 2011).

The electrical resistivity of rock is a property which depends on lithology and fluid contents. The solid earth is stratified into layers owing to the inhomogeneous nature of the earth's interior. It is however possible to delineate the subsurface through the application of geophysical methods. The major progress in this method depends on ability to capture changes in the electrical path caused by these resistors and, ultimately, be able to determine their locations, depths and thicknesses. If the earth is homogeneous, the resistivity measured is called true resistivity, otherwise, the term apparent resistivity is applied and this of course is the weighted average of the resistivities of the various formations (Osemeikhian, & Asokhia, 1994).

Electric conduction in some rocks can be electrolytic. Although some native metals and graphite conduct electricity, most rock forming materials are electrical insulators. Earth resistivity measurements are controlled by the movement of ions in pore fluids and also interstitial water in pores and fissures. One important thing to note is that the larger the pores and fissures, the smaller the resistivity (high conductivity) of a rock in the presence of water. Sometimes, the presence of clay in these pores and fissures results in the release of many ions by ion exchange processes. Thus, rocks containing clay minerals exhibit abnormally high conductivity.

Generally speaking, hard rocks are poor conductors. However, some natural processes like weathering, fracturing; hydrothermal alterations and shearing can increase the porosity and permeability of a rock, and in turn its increase in conductivity. Calcium carbonates reduces permeability of rock and as such increases its resistivity. Hence, porosity and fluid saturation tend to dominate electrical resistivity measurements. On the other hand, salt concentration, moisture content, compaction of pores or fissures within crystalline rock can result in low resistivities. Frozen and dry soils are good insulators (high resistivity) and are ineffective with electrodes (Reeve, 2008). Resistivity is therefore an extremely variable property, not only from formation to formation but also within formations.

To infer the lithologic units of Ibillo, the electrical resistivity method has been chosen and the vertical electrical sounding (VES) approach employed. Electrical methods are commonly used for mineral exploration. They are also used in shallow investigation of the nature of the subsurface.

The object of the survey was to determine the underground water potentials of the area with the intension of drilling a borehole to serve the water needs of inhabitants of the area.

Theoretical Background

It is well known that resistance, R in Ohms (Ω), of a wire is directly proportional to its length L and is inversely proportional to its cross-sectional area A.

That is

$$R \propto L/A \qquad (1)$$

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

Where ρ = the constant of proportionality, is the electrical resistivity which is a characteristics of the material and is independent of its shape or size. From Ohm's law, the resistance is given by:

$$R = \Delta V/I \qquad (3)$$

Where ΔV *is* the potential difference across the resistance, R, and I is the electric current through the resistance. Putting equation (2) into equation (3) and rearranging it gives:

$$\rho = A/L \cdot \Delta V/I \qquad (4)$$

Equation (4) may be used to determine the resistivity ρ of homogeneous and isotropic materials in the form of regular geometric shapes, such as rectangles and cylinders. In a semi-infinite material, the resistivity at every point must be defined. If the cross-sectional area and length of an element within the semi-infinite material are shrunk to infinitesimal size then the resistivity ρ may be defined as

$$\rho = \frac{\lim_{L\to 0}(\Delta V/L)}{\lim_{A\to 0}(I/A)} \qquad (5)$$

$$\rho = E_L/J \qquad (6)$$

where E_L *is* the electric field and J is the current density. In terms of electromagnetic field quantities, consider an electric field E (volts/m) with current density J (amps/m^2) and resistivity, ρ (Ωm). The vector form of Ohm's law can be written as:

$$\rho = E/J \quad (7)$$

$$J = \frac{-1}{\rho}\nabla V \quad (8)$$

where

V = electric potential in volts and σ = conductivity measured in $(\Omega m)^{-1}$.

We are interested in voltage at a distance 'r' from a point source of current in a half-space and not a whole space bearing in mind the air over the half-space. Again, we do not measure potential, but determine the potential difference between two electrodes. For a whole space, the total current I, flow away from one electrode to another across the sphere with area $4\pi r^2$. Ohm's law for one electrode then becomes

$$j = \frac{I}{4\pi r^2} = \frac{-1}{\rho}.\frac{dv}{dr} \quad (9)$$

$$\frac{I}{4\pi r^2}\int dr = \frac{-1}{\rho}\int dv \quad (10)$$

$$\frac{I}{4\pi}\int r^{-2}\, dr = \frac{-1}{\rho}\int dv \quad (11)$$

$$\frac{-I}{4\pi r^1} = \frac{-1}{\rho}V_{(r)} \quad (12)$$

$$V_{(r)} = \frac{\rho I}{4\pi r} \quad (13)$$

But for a half-space (Figure 1), the total current (I), flows across the sphere with area $\frac{1}{2}4\pi r^2$. So, $V_{(r)}$ becomes

$$V_{(r)} = \frac{\rho I}{2\pi r} \quad (14)$$

I = total current flowing from one current electrode to the other through the ground.

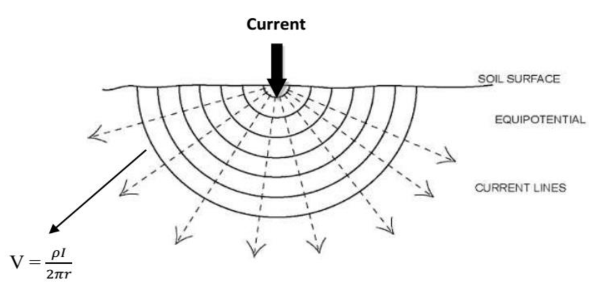

Figure 1: Distribution of current flow in a homogeneous soil (Samouelian, Cousin, Tabbagh, Bruand and Richard, 2007)

However, the potential and current electrodes are usually arranged in a collinear pattern as shown in Figure 3. The distance between a current and potential electrode is denoted by r_{ij} where the first subscript denotes the current electrode (C) and the second, potential electrode (P). The electric potentials measured at M and N in the general linear arrangement (Figure 3) is a superposition of equation (14) due to each source electrodes located at A and B. The distances between the electrodes are given by AM, BM, AN, and BN. V = 0 infinitely far from the current source, the potentials at M and N can thus be calculated using equation (14).

$$V_M = \frac{\rho I}{2\pi}\left[\frac{1}{r_{AM}} - \frac{1}{r_{BM}}\right] \quad (15)$$

Note the minus sign because of the current convention. We also have that

$$V_N = \frac{\rho I}{2\pi}\left[\frac{1}{r_{AN}} - \frac{1}{r_{BN}}\right] \quad (16)$$

The thrust of this research is measuring the voltage drop, ΔV between two electrodes, M and N.
The potential ΔV may be measured as

$$\Delta V = V_M - V_N \quad (17)$$

Putting equation (15) and (16) together gives (18)

$$\Delta V = \frac{\rho I}{2\pi}\left[\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \left(\frac{1}{r_{AN}} - \frac{1}{r_{BN}}\right)\right] \quad (18)$$

$$\Delta V = \frac{\rho I}{2\pi}\left[\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right] \quad (19)$$

$$\Delta V = \frac{\rho I}{2\pi}\left[\frac{1}{r_{AM}} + \frac{1}{r_{BN}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}}\right] \quad (20)$$

By solving equation (20) for ρ, we can determine the resistivity of the subsurface region. Equation (20) was derived by assuming a homogeneous and isotropic half-space. Because we are dealing with a heterogeneous earth, a measured voltage drop yields a resistivity value that is a weighted average along the current path way. Now, one can only consider apparent resistivity ρ_a of the subsurface.

$$\rho_a = 2\pi\frac{\Delta V}{I}\left[\frac{1}{r_{AM}} + \frac{1}{r_{BN}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}}\right]^{-1} \quad (21)$$

$$\rho_a = \frac{\Delta V}{I}K \quad (22)$$

$$\rho_a = R_{app} \cdot K \quad (23)$$

Where $K = 2\pi\left[\frac{1}{r_{AM}} + \frac{1}{r_{BN}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}}\right]^{-1}$ (24)

K is the “geometric factor” that will obtain a certain value for a given electrode configuration. For the wenner array, all of the separations are equal to a constant value “a” (Herman, 2001).
In the schlumberger array, the current electrodes, separated by AB are symmetrical about the potential electrodes, MN. The current electrodes are then expanded and the geometric factor assumes the form

$$K = \frac{\pi}{2}\cdot\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{\left(\frac{MN}{2}\right)} \quad (25)$$

Putting equation (25) into (22), the apparent resistivity for the Schlumberger array becomes

$$\rho_{SCHLUMBERGER} = \frac{\pi}{2}\cdot\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{\left(\frac{MN}{2}\right)}\cdot\frac{\Delta V}{I} \quad (26)$$

Resistivity can be found from measuring values of V, I and K.

General Geology and Vegetation

The subsurface of this area consists predominantly of undifferentiated basement consisting of undifferentiated schists including phyllites and Quartzites, massive and schistose also occurring as ridges. This area is chiefly a basement terrain characterised by undulating landscape within the Nigerian South-Western Basement Complex. The vegetation cover is thick comprising mainly of average height trees, shrubs and thick grasses.

MATERIALS AND METHODS

Materials

The materials used during the survey include Petrozenith PZ-02 Teramettter Electrical Resistivity Equipment, four steel electrodes, two plastic reels of current cables, two plastic reels of potential cables, crocodile clips, measuring tape and pegs.

Methods

A total of two VES sounding surveys were carried out in the study area as shown in Figure . The current and potential electrodes were planted according to the Schlumberger array, and the electrodes were connected directly to the terrameter. While the current electrodes were spaced out, the potential electrodes remained fairly constant. The values of the earth's resistance at each spread of electrodes were read off through the digital display by the terrameter. A geometric factor K was calculated for each spread. The resistance, R and geometric factor K were used to calculate the bulk apparent resistivity of the measured sequence for every spread.

To compliment surface geological mapping, Petrozenith PZ-02 Teramettter Electrical Resistivity Equipment was used to conduct a Vertical Electrical Sounding (VES). The Schlumberger configuration was used for total spreads (L) of 300m and 140m. VES stations were located within this property along Federal Government College Road in Ibillo Community. For VES I, 150m ($^L/_2$) was covered on the right running towards Ibillo Community, and another 150m ($^L/_2$) was run on the left towards Ibillo town. A total AB/2 spread of 70m ($^L/_2$) was covered on the right running towards Ibillo Community and 70m also covered on the left running towards Ibillo town for VES II as shown in Figures 2 and 3. Necessary precautions required in geo-electric measurement were duly considered and maintained. The survey lasted between 11.45hr to 14.45hr under favourable weather condition.

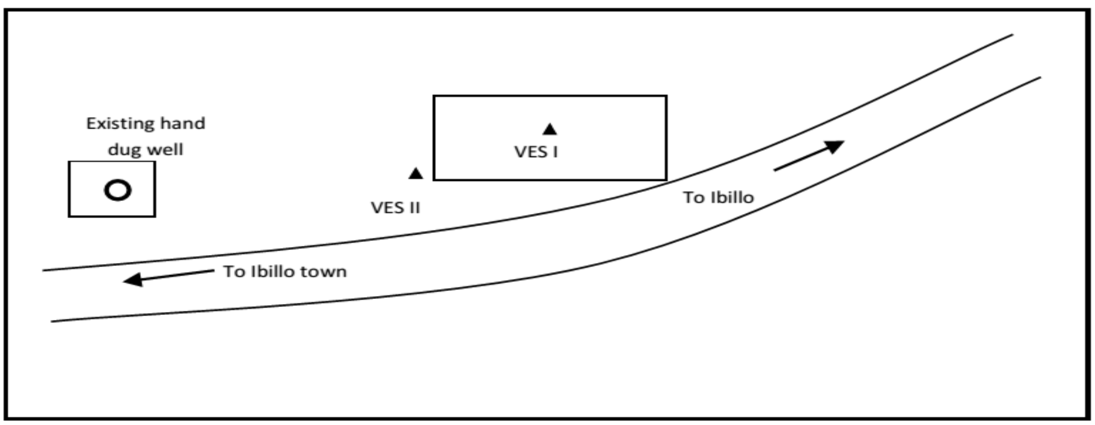

Fig 2. Site location map at Ibillo Town showing VES 1 & VES II

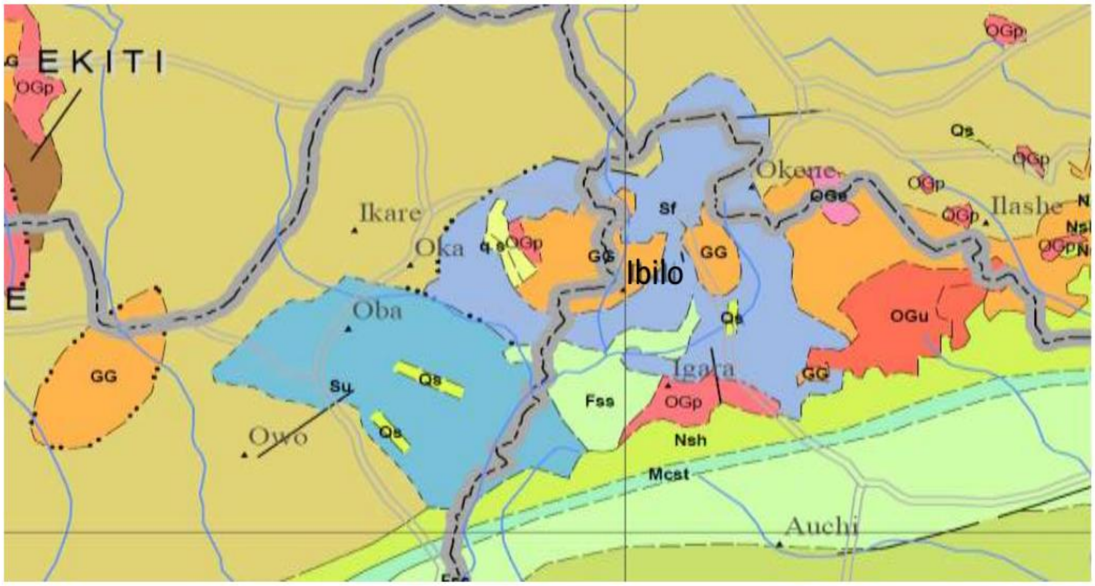

Fig 3. Map showing the Geology of Ibillo Community and its environs (Source: NGSA, 2002)
Qs = Quartzite, massive and schistose, also occurring as ridges
Su = Granite gneiss

RESULTS AND DISCUSSIONS

Table 1: Resistivity Data for Location 1

AB/2	MN/2	MN	R	K	R_a
1	0.5	1	92.42	2.3562	217.76
3	0.5	1	5.1	27.489	140.1939
5	0.5	1	0.94614	77.754	73.56617
10	0.5	1	0.54437	313.37	170.5892
14	0.5	1	0.47345	614.97	291.1575
17	0.5	1	0.23265	907.13	211.0438
21	0.5	1	0.65159	1385	902.4522
32	0.5	1	0.39724	3216	1277.524
47	0.5	1	0.22568	6939	1565.994
70	2	4	0.2186	3845	840.517
100	2	4	0.25695	7851	2017.314
150	2	4	0.18862	17668	3332.538

Table 2: Resistivity Data for Location II

AB/2	MN/2	MN	R	K	R_a
1	0.5	1	244.81	2.3562	576.8213
5	0.5	1	2.79	77.754	216.9337
10	0.5	1	1.38	313.37	432.4506
14	0.5	1	1.32	614.97	811.7604
17	0.5	1	0.45057	907.13	408.7256
21	0.5	1	0.00248	1385	3.4348
32	0.5	1	0.001	3216	3.216
47	0.5	1	0.9909	6939	6875.855
70	0.5	1	0.52338	15393	8056.388

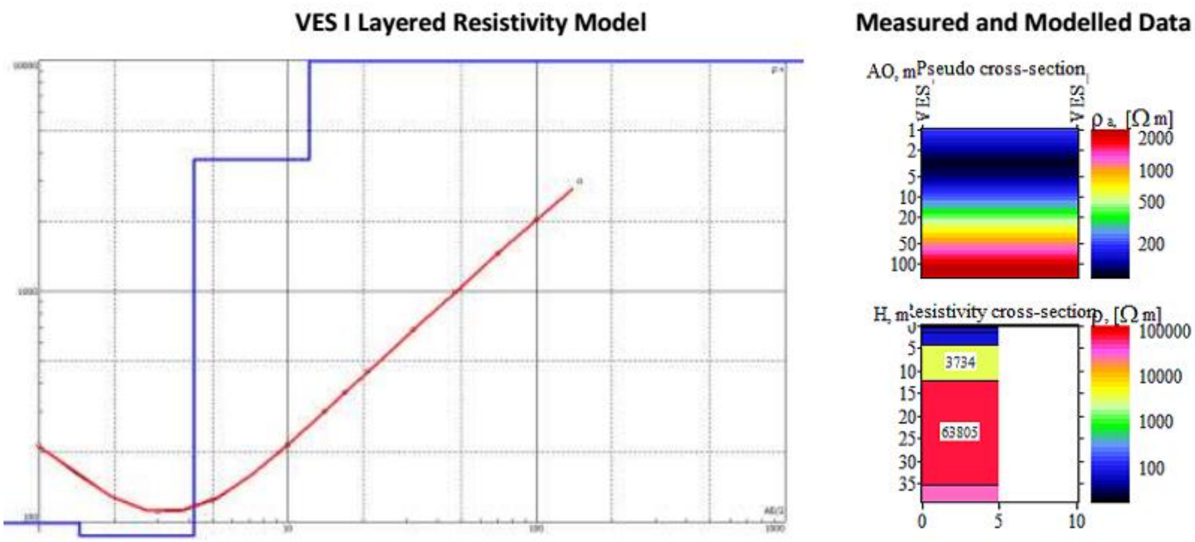

Figure 4. VES curve for location 1

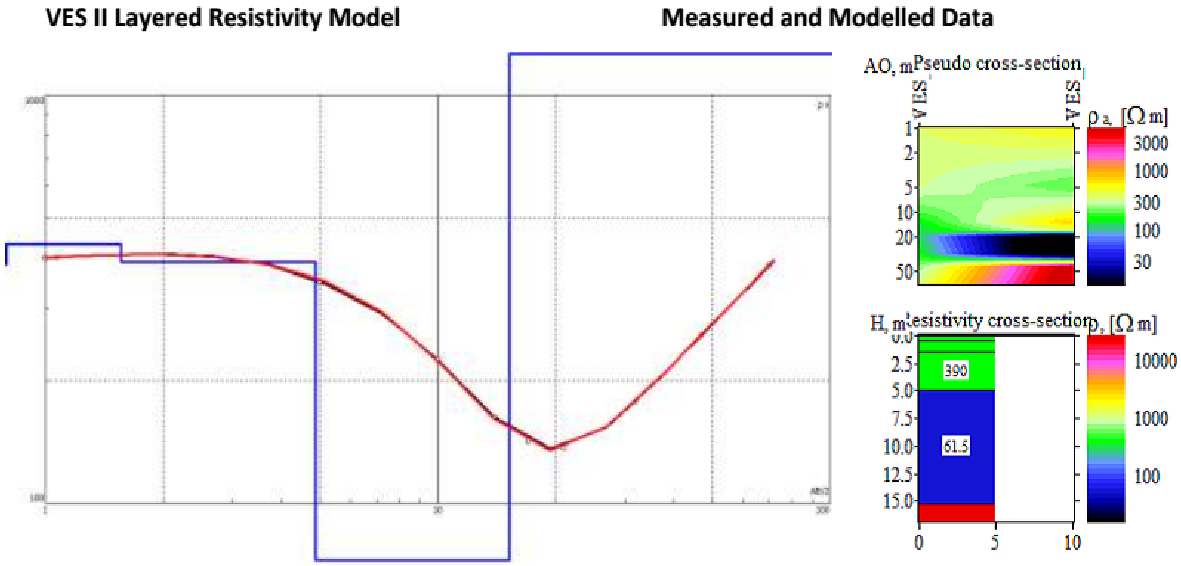

Figure 5. VES curve for location 11

All field data have been subjected to manual computation and finally to computer processing techniques, applying the ipi2win Resistivity Sounding Interpretation software. Result of data processing by the software package is integrated in order to arrive at the realistic composition and layering of the subsurface.

The vertical electrical sounding data was interpreted using the IPI2Win software program. Interpretation was done to obtain the true resistivity of subsurface layers and sounding curves show geoelectrical layers of various resistivities, thicknesses and depths as presented in Figures 4 – 5 and Tables 3 – 4.

The interpretation of the log – log curves and subsequent deductions made gave rise to the stratigraphic units along with their resistivities and thicknesses as shown in Tables 3 – 4 below.

Analytical result for VES I presented by the ipi2win software reveals six sub layers as follows:

Table 3. Interpretation of results from VES 1

LAYER	THICKNESS	DEPTH	RESISTIVITY	LITHOLOGY
1	0.5	0.5	325	Sandy clay topsoil
2	0.948	1.45	123	Clay formation
3	2.75	4.2	74.8	Claystone
4	7.96	12.2	7532	Highly weathered basement
5	33.1	35.2	365123	Fractured basement (Prospective)
6	Undefined	Undefined	14959	Highly fractured basement (prospective)

Analytical result for VES II presented by the ipi2win software reveals five sub layers as follows:

Table 4. Interpretation of results from VES 11

LAYER	THICKNESS	DEPTH	RESISTIVITY	LITHOLOGY
1	0.5	0.5	386	Sandy clayey topsoil
2	1.06	1.56	431	Clayey layer
3	3.32	4.88	390	Claystone
4	20.4	25.2	61.5	Highly weathered basement
5	Undefined	Undefined	35800	Highly fractured basement (prospective)

DISCUSSIONS

The shape of a VES curve depends on the number of layers in the subsurface, the thickness of each layer and the ratios of the resistivities of the layers (Osemeikhian and Asokhia, 1994). In Figure 4, the VES curve presents a KHK ($\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$) type curve. Also, the curve in Figure 5 presents a KHK ($\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$) type curve.

From Figures 4 – 5, the curves reveal that the average resistivity values and thicknesses of subsurface layers of Ibillo are estimated to be $355.5\Omega m$ and $0.5m$ for the first layer, $277\Omega m$ and $1.004m$ for the second layer, $232.4\Omega m$ and $3.035m$ for the third layer and $182592.25\Omega m$ for the fourth layer. In VES 1, six layers were delineated simply because larger spread was covered and the fifth layer has a resistivity of $365123\Omega m$ and a thickness $33.1m$ as shown in Table 3. In VES 11, with a lower spread and a total of five layers delineated, the fifth layer has a resistivity of $35800\Omega m$ while the thickness is undetermined as shown in Table 4. The sixth layer in VES 1 has a resistivity of $14959\Omega m$9m and undetermined thickness. The average depth to the interfaces are $0.5m$, $1.505m$, $4.54m$ and $18.7m$ respectively for the first, second, third and fourth interface. While the fifth layer in VES 1 has a depth of $35.2m$ to the interface. As indicated in Figures 4 and 5, the first four geo – electrical layers are probably sandy clayey topsoil, clay formation, clay stone and highly weathered basement respectively while the fifth layer for VES 1 may be fractured basement (prospective).

CONCLUSION

From the results of this research, the lithologies of Ibillo from the top down to the subsurface are hereby inferred to contain sandy clayey soil, clay formation and highly weathered basement. It is therefore recommended that for underground water development to achieve the best result:

a. Drilling should be done to a depth not less than 55.2 m (101.1 ft.) to allow for the fairly good reservoirs within the aquifer and to be able to tap all water from the aquiferous zone.
b. There should be adequate borehole logging of the samples, which should be done by an experienced and registered hydro – geologist.
c. There should be proper borehole completion exercise of gravel packing to enable the screened section to be protected from the overlying clayey bed.
d. The borehole drilling should be done with a competent drilling rig that is fitted with a drilling bit and then later a hammer bit specifically built for a basement terrain such as this and capable of achieving the recommended Total Drill Depth (TDD).
e. There should be adequate borehole yield test to determine the aquifer potentials prior to the pump installation.
f. VES I is preferred and therefore recommended for drilling a productive borehole at the location.

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