

SUBSURFACE INVESTIGATION FOR GROUNDWATER POTENTIAL OF BIU PLATEAU BASALT NORTH EASTERN NIGERIA, USING VERTICAL ELECTRICAL SOUNDING

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ABSTRACT

Groundwater is a very important component of water resources in nature. Since the demand of groundwater increases with population growth, it is necessary to explore groundwater more intensively. The importance of groundwater cannot be overemphasized. For this reason, the exploration for water is therefore a vital aspect of Geophysics. The resistivity method of surveying was carried out for the study of Groundwater potential in Biu town, Borno State, Nigeria. Data were acquired using the ABEM Terrameter 300C using the Schlumberger array. The data obtained were subjected to interpretation by partial curve matching and then by computer iteration and the results correlated with records from existing wells. A total of four geologic layers namely; top soil, weathered basalt, fractured basalt and fresh basement was delineated in this study. Results showed that the aquifer is located within the second and third layers comprising mainly of weathered and fracture materials. The first aquifer is the weathered basalt with resistivity ranging from 11.5 to 106.8 Ωm and thickness ranges from 2.73 to 31.32 m. while the second aquifer is the fractured basalt with resistivity ranging from 16.5 to 372.2 Ωm with thickness from 2.9 to 11.17 m. Appropriate depths to which potable water can be obtained from the various locations varies from 21.89 m to 38.33 m are recommended in this study. While depths in VES 6 and VES 7 are 10.45 m and 14.97 m are not good for groundwater exploration.

Keywords: Groundwater, Geoelectric, Aquifer, Plateau Basalt, Data, Electrical.

INTRODUCTION

Biu plateau basalt fall within the basement complex area of north eastern Nigeria. The area relies 100 % on groundwater source as surface water is absent in most part of the year. The area is experiencing massive infrastructural developments and couple insecurity affecting neighboring communities and thus, a resultant population growth. Portable water supply has been grossly inadequate to meet the ever increasing population and the demand for this essential resource by inhabitants of the area (Bello, 2014). Hence, this has led to the dependence on groundwater from hand-dug wells or boreholes by individuals as their main source of potable supply since public water supply from government has proven over the years to be grossly inadequate and for the most part, non-existent. The major effect of the situation is that some inhabitants who cannot afford alternative arrangements for potable water supply through hand-dug wells and boreholes resort to get water of unknown quality from water hawkers and also from surface water sources which include streams, rivers and lakes that are not particularly safe for direct consumption as a result of their exposure

to pollutants and pathogenic organisms that make these surface water sources not as clean as the groundwater.

Groundwater is the water that occurs beneath the ground surface, filling the pore spaces between grains in sediments and sedimentary rocks, and filling cracks and crevices in other types of rock known as aquifers. Groundwater is quite pure and largely confined from surface pollutants as a result of their depth of storage and natural filtration through different subsurface layers. Thus, there is a need to undertake an all-inclusive investigation of groundwater potential in the area to identify suitable locations for groundwater exploitation to alleviate the challenges of potable water supply in the area. Groundwater is described as the water found beneath the surface of the earth in underground streams and aquifers (Anomohanran, 2011). The reason why groundwater has become more popular as a source of potable water is due to its availability and quality when compared to other water sources. It is known to be free most times from pollutants and hence requires little or no decontamination before use. Various researchers have employed different methods in exploring this very essential life sustaining resource.

The advantages of vertical electrical sounding (VES) techniques of electrical resistivity method over other geophysical methods cannot be over emphasized as reported by other previous researchers. The ability of the electrical resistivity method to give detailed information about subsurface geology usually not obtained by other methods in prospecting for groundwater and because of its advantage which include simplicity in field technique and data handling procedure was presented in (Ibrahim *et al.* 2012 and Anomohanran, 2013). Surface geophysical survey as an instrument in Groundwater exploration has the basic advantage of saving cost in borehole construction by locating aquifer before embarking upon drilling. This method was able to delineate the formation layers and the aquifer characteristics of the location under study. Other researchers such as Oseji *et al.*, 2006; Nejad, 2009; Egbai, 2011; Anudu *et al.*, 2011; and Anomohanran, 2013 have all used the electrical resistivity method to investigate for groundwater in different locations. Bello (2014) conducted Vertical electrical sounding (VES) in part of Biu town to determine the location and depth to groundwater potential zone. Akande *et al.* (2016), Alhassan *et al.* (2017) carried out Vertical electrical sounding (VES) in northern part of Paiko, North Central Nigeria to determine the subsurface layer parameters (resistivities, depths and thickness) employed in delineating the groundwater potential of the area and established three to four discrete geoelectric layers, namely, the top layer, the weathered layer, the fractured/fresh layer, and the fresh basement layer. Fifteen VES stations were delineated as ground water potentials of the area, with third and fourth layer resistivities ranging from 191 to 398 Ωm . Depths range

from 13.60 to 36.60 m and thickness varies from 9.23 to 30.51 m

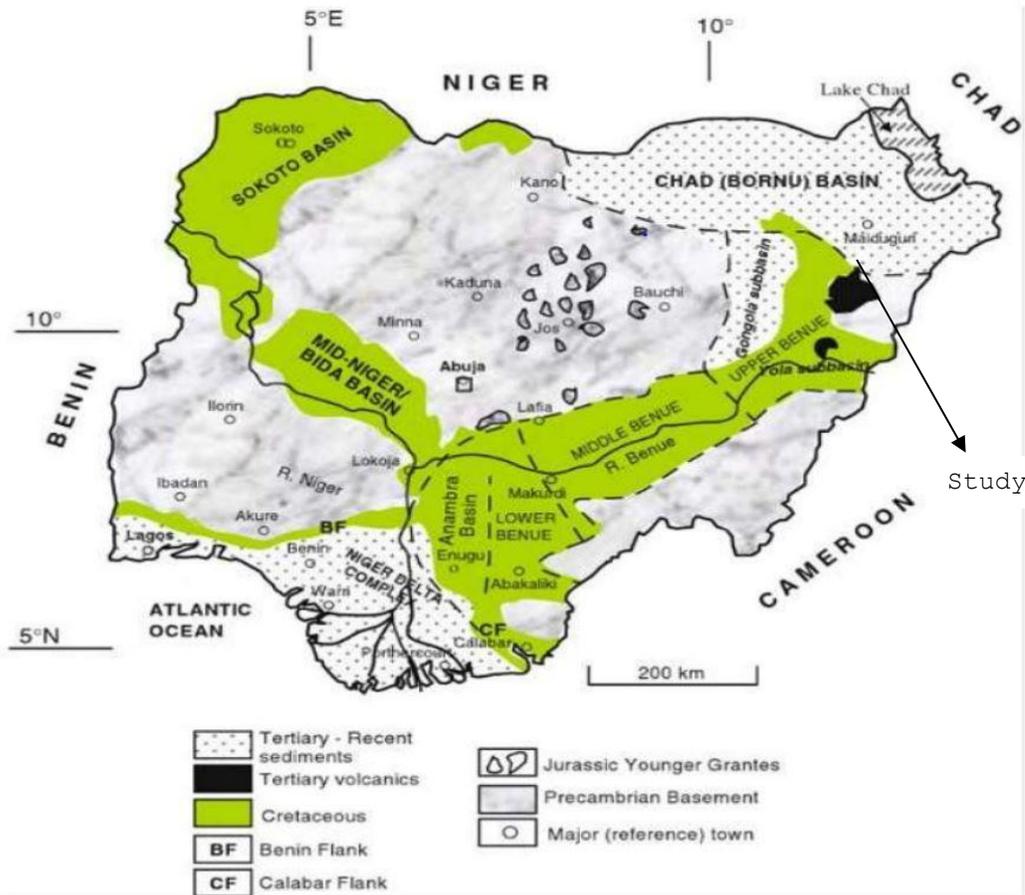


Figure 2.1: Geological sketch map of Nigeria showing the major geological components (Obaje, 2009)

LOCATION AND GEOLOGY OF THE AREA

Biu is the administrative headquarter of Biu local government area of Borno State. It lies between latitude $10^{\circ}34'10''$ N and $10^{\circ}44'22''$ N and longitude $12^{\circ}00'00''$ E and $12^{\circ}03'15''$ E in the North – East of Nigeria (Figure 1), it is 187 km from Maiduguri the State capital. The area is an agricultural district where the people are predominantly farmers. However, most of the hand – dug wells usually go dry during the dry season and the water is also polluted due to the infiltration of domestic waste. Infiltration rate is obviously higher when the soil is dry and can absorb much moisture than after it has been wetted, i.e (dry season) (Trojan and Linden, 1994; Nachabe *et al.*, 1999). During rainy season, infiltration rate is lower with high degree of pollution, because the groundwater level would rise

The Biu Plateau is a small part of Tertiary to recent volcanic province of Nigeria and Cameroon, which in turn, belongs to the continent- wide alkaline olivine basalt trachyte phonolite volcanic of Africa (Turner, 1978).

Falconer (1911), was the first to discuss and described the geology and geography of this area. He found out that in the South east of Borno toward Biu, the volcanic cones become high and more conspicuous, while the surface plateau according to native information then, became dissected and broken up to plains and

rocky valleys. He also pointed out that the lava flow had covered already existing basement rocks and the basalt themselves had suffered extensive weathering and erosion.

Carter *et al* (1963), pointed out that this part of the country has a greater volume and diversity of volcanic products than the Jos plateau from which a region free of Cenozoic volcanism separates it totally.

Biu plateau is the largest area of volcanic rock occurrence in Nigeria, the Plateau cover over 500 km². The areas is characterized by the occurrence of alkaline olivine basalts with thickness varying from 30 to 250 metres and occur in the form of tephra rings, cinder cones and composed of basaltic agglomerates, lavas, volcanic bombs, ashes and tuffs. About 50 volcanoes have been distinguished in the area (Carter *et al* 1963). It is also characterized by conical hills, or caldera forms and they are so well preserved that a late Tertiary or even Quaternary age is indicated. No accurate age can be given for the plateau basalt.

The Plateau of Biu is located on the structural and topographic divide between the Benue and Chad Sedimentary basin. The structural divide is a broad-fast west ridge or swell of basement whose surface expression terminates at about the western edge of the Biu Plateau. To the west, continuous outcrops of Cretaceous rocks link the two basins, although a subsurface rise, the Zambuk

Ridge persists, and is reflected in a thinning of cretaceous succession (Carter *et al* 1963).

The plateau lies within the Sahel Savannah and falls within the Central part of Biu plateau which is a low temperature region. The region under study is on an altitude ranging from 600 to a little above 800 metre above sea level. The area has two distinct types of climatic season; the dry season which lasts for about seven months from October to April followed by the rainy season which lasts for five months from May to September.

The basalts are usually strongly jointed and fissured. The earlier flows, usually consist of dense compact basalt, while the early flows are irregular jointed. The joints serve as loci of weathering and as channels for the circulation and storage of groundwater (Du Preez, 1965). The compact basalts are incapable of storing water, the groundwater held in the joints gives rise to numerous small springs on the higher parts of the Plateau. The basalts form the most important aquifer in Biu Plateau. The amount of water obtained in them depends on the degree of decomposition, jointing and the nature of the rock. The basalts show a superficial weathered zone consisting of black-grey and brown clay with residual boulders of partially decomposed rock. Moderate amounts of water may be present in the basalt alluvium but in general the quantity of water available is small and the water table is subject to considerable variation. Many villagers get their water partly or wholly from ground water source during the dry season.

Theory of the Electrical Resistivity Method

The theoretical basis of the direct current (dc) electrical resistivity method is provided by an elementary consideration of the nature of current and potential distribution in a homogenous, isotropic medium and further projection of the analysis to the model that fits the actual description of the earth, or nearly so (Hago, 2000).

For most materials, the physical principle that explains the method of conduction of direct current is summarized in Ohm's law. This is expressed in terms of the electrical resistance R as follows:

$$R = \frac{V}{I} \quad 1$$

Where I is the current and V is the potential difference across the material.

The concept of electrical resistance means that it can be applied to current fields in voluminous media, such as the earth, an alternative expression of Ohm's law, called the differential form of Ohm's law is required. The equation gives a relationship between the current

density \vec{j} and the electric field \vec{E} as follows:

$$\vec{j} = \sigma \vec{E} = \frac{\vec{E}}{\rho} \quad 2$$

Where σ is the conductivity and its reciprocal (ρ), is the resistivity.

The divergence condition can also be used to arrive at an equation for potential V about a single point source in a homogenous earth. The equation for the potential, V is given by:

$$\nabla \cdot \vec{j} = 0 \quad 3$$

The equation provides that all the current entering one side of a portion of the homogenous earth must leave the other side, unless there is a current source or sink within the said portion. That is, the

divergence of the current density does not occur at any other place except at the current source.

The relationship between current I and the current density \vec{j} through an area A is given by:

$$I = \int \vec{j} \cdot \vec{A} \quad 4$$

But $\vec{E} = \nabla V$ 5

Hence, from equations 2, 4 and 5,

$$I = \left(\frac{A}{\rho} \right) \nabla V \quad 6$$

From equations 1, 2 and 3, one can write that

$$\nabla I = \frac{1}{\rho} \nabla \cdot \vec{E} = \frac{1}{\rho} \nabla^2 V = 0 \quad 7$$

Where ρ is the constant of resistivity of the material. This implies that

$$\nabla^2 V = 0 \quad 8$$

Equation 8 is Laplace's equation which can be written in spherical polar coordinates as:

$$\frac{\partial}{\partial r} \left[r^2 \frac{\partial v}{\partial r} \right] + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left[\sin \theta \frac{\partial v}{\partial \theta} \right] + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 v}{\partial \phi^2} = 0 \quad 9$$

For a single current source, the potential can be assumed to be constant with respect to θ and ϕ directions; so that the derivatives of these parameters are zero and the potential variation will be due to the distance r from the source (Emenike, 2001). From this condition, equation 9 reduces to

$$\frac{\partial}{\partial r} \left[r^2 \frac{\partial v}{\partial r} \right] = 0 \quad 10$$

Integration, equation 10 becomes

$$V = \frac{B}{r} + C \quad 11$$

At a great distance from the source, $V = 0$ and the constant C will be zero. The constant B can be evaluated in terms of the total current flowing across a hemispherical surface of area, $A = \pi r^2$. From equation 6,

$$I = - \frac{2\pi r^2}{\rho} \nabla V = - \frac{2\pi r^2}{\rho} \frac{\partial v}{\partial r} \quad 12$$

Differentiating equation 11 one gets

$$\frac{\partial v}{\partial r} = \frac{B}{r^2} \quad 13$$

$$\therefore I = - \frac{2\pi r^2}{\rho} \frac{B}{r^2} = - \frac{2\pi B}{\rho} \quad 14$$

$$\text{Or } B = -\frac{I\rho}{2\pi} \quad 15$$

Putting equation 15 into equation 11 (with C = 0) gives the potential as

$$V = -\frac{I\rho}{2\pi r} \quad 16$$

Equation 16 is a solution of the Laplace's equation.

Since Laplace's equation is linear, the sum of two solutions is equally a solution (Grant and West, 1965). Thus for two current electrodes, where one is the source and the other a sink, the potential at a given point at a distance r_1 from the source, r_2 from the sink will be the algebraic sum of the potentials due to the source and sink respectively. This implies that:

$$V = -\frac{I\rho}{2\pi} \left[\frac{1}{r_1} - \frac{1}{r_2} \right] \quad 17$$

Many geologic situations, such as portrayed by the earth, involve conductivity distribution in a layered medium. The determination of the potential due to a point source in a layered medium involves more rigorous mathematical approaches some of which include the use of geometrical optics (based on the assumption that the behavior of electric current is similar to light rays) and solving Laplace's equation with appropriate boundary conditions (Bandani, 2011). The reason for these approaches is that the horizontal layers, which are regarded as having different but homogenous and isotropic electrical properties, introduce some heterogeneity into the ground causing a potential $V(r)$ at a distance r from a point source on the surface of an n -layered earth. By applying separation of variables to Laplace's equation in cylindrical co-ordinate, a general solution for the potential at the surface of an n -layered earth having, arbitrary resistivities and thicknesses is given by:

$$V(r) = \frac{I\rho_1}{2\pi} \left[\frac{1}{r} + 2 \int_0^\infty K(\lambda) J_0(\lambda r) \delta r \right] \quad 18$$

Where $V(r)$ is the potential at the surface of the earth at a distance, r from the current source, ρ_1 is the resistivity of the first layer, $J_0(\lambda r)$ is the zero-order Bessel function of the first kind, λ is a real integration variable ranging from -0.050 to ∞ ; and $K(\lambda)$ is the kernel function which is a function of the thickness and reflection coefficients for an assumed earth model. The earth is far from being homogenous. Practical experience shows that the earth is generally anisotropic, which implies that the equi-potential surfaces are no longer normal to the direction of current flow. Grant and West (1965) derived the potential for this condition and the condition of sloping interfaces. However, quantitative interpretation

processes in dc electrical methods rely to a great extent on the horizontally layered, isotropic, and homogenous model (Hopkins and Sullivan, 1978). This is mainly because on a large scale, individual rock formations can be considered to be homogenous.

MATERIALS AND METHODS

Electrical prospecting makes use of a variety of principles, each based on some electrical properties or characteristics of the materials within the earth. In this study, the electrical resistivity method employed the Schlumberger array configuration. In this method, measurements were made with increasing separation between the electrodes about the midpoint.

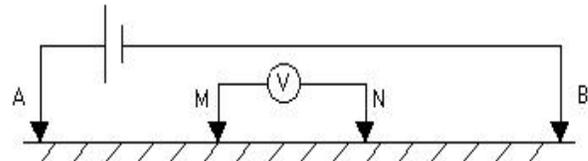


Figure 2. Four-electrode arrays used in resistivity surveying. A and B are current electrodes and M and N are potential electrodes. The configuration is called the Schlumberger array.

The principal instrument used for this survey is the ABEM (Signal Averaging System, (SAS 300C) Terrameter which displays apparent resistivity values digitally as computed from ohm's law. It is powered by 12V DC power source; other accessories to the Terrameter include booster, four metal electrodes, and cables for current and potential electrodes, three hammers, calculator, as well as measuring tapes. The electrodes M and N were also driven into the soil and connected to the voltage receiver. At each position of A and B, the current was sent, and the potential difference between A and B was measured. Also, the distances AB and MN were measured. From the field data, the apparent resistivity was determined and plotted against half electrode separation ($AB/2$).

DATA ACQUISITION AND ANALYSIS

The apparent resistivity values obtained from the geoelectric survey were plotted on a log – log graph against corresponding current electrode separation. The quantitative interpretation of the Vertical Electrical Sounding curves involves the use of partial curve matching technique to obtain the true resistivity and thickness of the subsurface layer. The results of the curve matching were used for computer iteration techniques using IX1D inversion software. The results of the Vertical Electrical Sounding were presented as geoelectric section as shown in table 1.

Table 1: Summary of the formation Parameter

Locat. VES	Lat. 10°	Log. 12°	1 st Layer		2 nd Layer		3 rd Layer		4 th Layer		Esti. Depth (m)	R.M.S %
			ρ_1 (Ωm)	h_1 (m)	ρ_2 (Ωm)	h_2 (m)	ρ_3 (Ωm)	h_3 (m)	ρ_4 (Ωm)	h_4 (m)		
1	37'34"	27'12"	12.73	4.86	101.47	15.35	372.20	8.43	449.75	-	29.19	1.03
2	34'30"	13' 25"	37.73	2.43	11.47	11.49	73.20	8.33	149.75	-	22.25	1.34
3	34'48"	13' 19"	70.30	1.30	11.60	11.60	16.50	9.00	307.40	-	21.89	0.95
4	35'18"	12' 25"	7.53	2.35	15.34	15.29	86.38	7.99	220.15	-	25.63	1.46
5	35'51"	12' 51"	19.08	2.06	106.84	31.32	234.39	2.90	429.25	-	36.28	1.69
6	37'11"	11' 18"	9.05	2.37	65.92	2.73	253.19	5.34	409.22	-	10.45	2.50
7	37'23"	11' 09"	6.68	1.76	72.12	5.02	198.39	8.19	329.13	-	14.97	0.84
8	37'27"	11' 14"	5.88	1.66	68.98	19.60	234.39	10.88	428.25	-	32.14	1.42
9	37'07"	11' 23"	2.16	0.95	65.92	26.21	244.39	11.17	389.25	-	38.33	0.98
10	36'45"	12' 34"	12.15	2.92	62.87	22.70	234.41	10.17	329.11	-	35.79	0.98
11	38'09"	11' 24"	37.73	1.35	11.47	8.05	73.20	17.87	149.75	-	27.27	2.29
12	38'00"	11' 24"	149.0	0.71	47.66	13.81	41.27	13.30	57.69	-	27.82	1.70
13	37'55"	09' 57"	58.80	5.22	244.00	11.07	15.63	16.51	55.04	-	32.81	0.80
14	35'48"	09' 44"	52.16	4.95	108.19	21.08	173.74	7.30	226.74	-	33.33	2.40
15	36'52"	10' 31"	8.49	2.51	3.60	15.34	45.67	11.08	429.29	-	28.94	1.63

Table 2: Classification of resistivity sounding curves

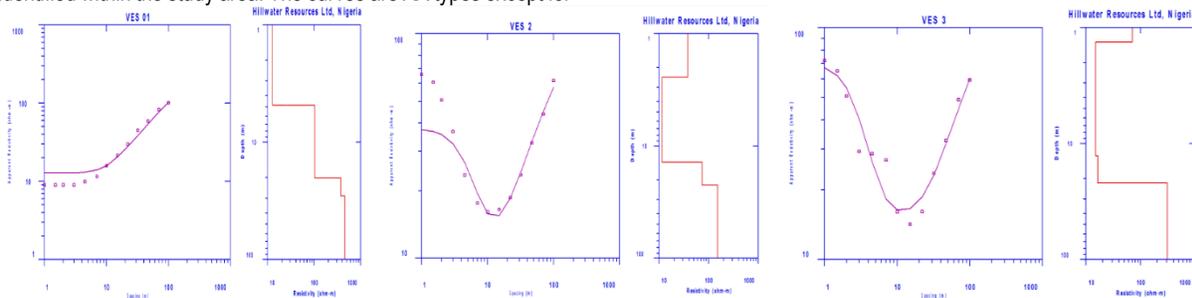
Curve type	Resistivity model	Model frequency	VES Locations
AA	$\rho_1 < \rho_2 < \rho_3 < \rho_4$	9	1,
HA	$\rho_1 < \rho_2 < \rho_3 < \rho_4$	4	4,5,6,7,8,9,10,
QH	$\rho_1 > \rho_2 < \rho_3 < \rho_4$	1	14
KQ	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	1	2,3,11,15
	$\rho_1 > \rho_2 > \rho_3 < \rho_4$		12
	$\rho_1 < \rho_2 > \rho_3 < \rho_4$		13
Total		15	

VES 2 and 3 which are HA types indicating the presence of four layers. The curves were interpreted using the partial curve matching technique using relevant master curve (Zohdy *et al*, 1974). The data was later refined by a computer iteration techniques using IX1D inversion software which gives a smooth model layers. Thickness was automatically generated from the spacing or frequency data and the model begins with the homogeneous earth (all layers set to the average resistivity found in the data.

The first layer has a resistivity value of (2.16 - 19.08) Ωm is made up of top soil with thickness ranging from (0.95 - 4.86) m. The second layer is weathered basalt zone with resistivity ranging from (11.5 - 106.8) Ωm and thickness ranges from (2.73 - 31.32) m. In the third layer, which is the fractured basalt has a resistivity ranges from (16.5 - 372.2) Ωm with thickness from (2.9 - 11.17) m. The fourth layer is the fresh basement also has a resistivity ranging from (149.8 - 449.8) Ωm , its thickness not penetrated. The aquifer in the study area is therefore defined by the highly weathered zone and the slightly weathered/fractured zones which are in agreement with Conred *et al* (1978). The variation in the resistivity the thickness of the aquiferous materials is due to the different rate at which different rock respond to weathering from one location to another.

RESULTS AND DISCUSSION

The field data were interpreted and processed qualitatively and quantitatively by using partial curve matching techniques and computer to obtain the resistivity values of the subsurface layers and their corresponding thickness (Table 1). From the interpretation of different VES curves, four subsurface layers were identified within the study area. The curves are AA types except for



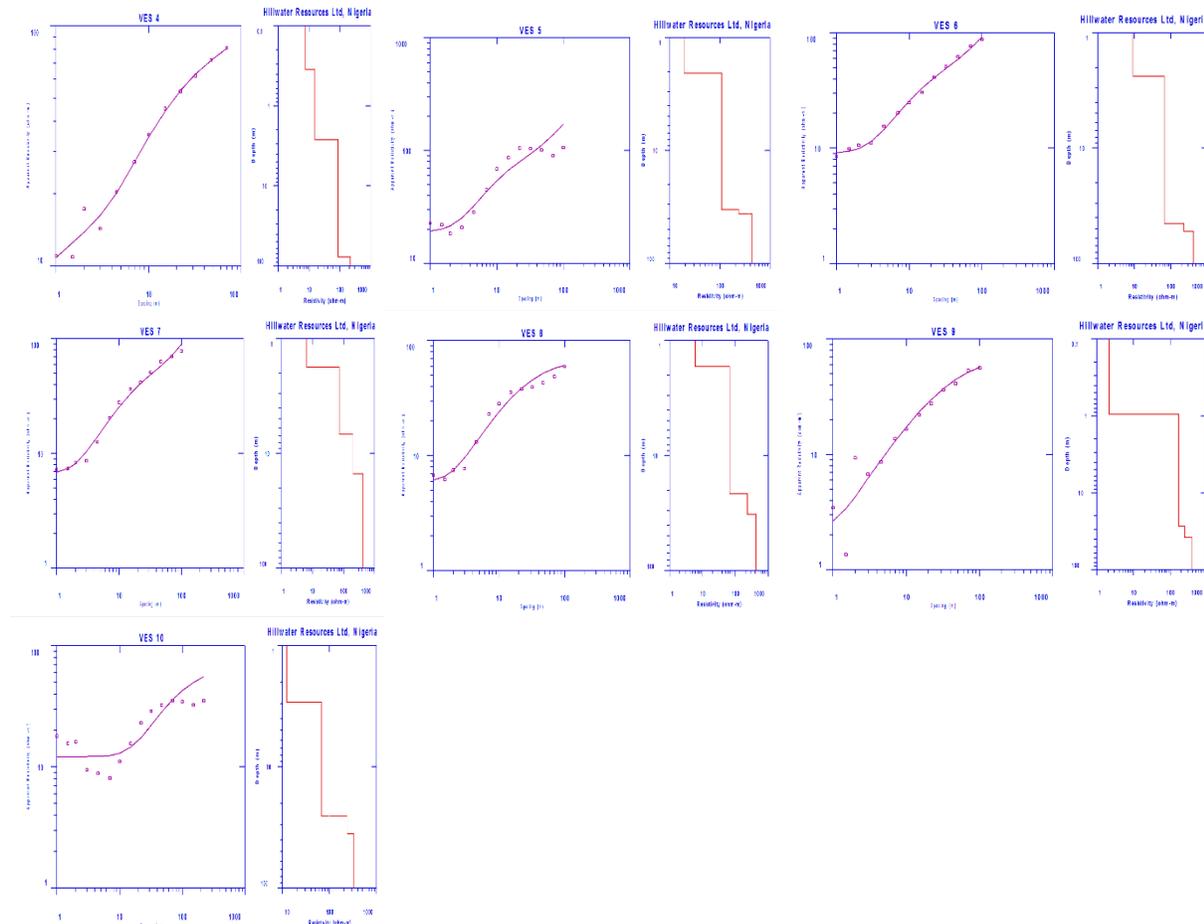


Figure 3: Interpretations of the VES.

CONCLUSION

Electrical resistivity method using Schlumberger electrode configuration was conducted in Biu town with the aim of studying locations of potential area for groundwater. The geoelectric investigations showed that there are four geoelectric layers and these layers correspond to top soil, weathered basalt, fractured basalt and fresh basements. The best layer which acts as the good aquifer are the second and third layers of the VES with the exception of VES 6 and 7, which consists of the weathered and fracture basalt formations. The bottom-most layer is compact fresh basement having mostly high resistivity. VES findings unearth promising groundwater-bearing zones of appreciably high thickness that was noticed at all locations except at VES 6 and VES 7 with their thickness of less than 8 and 13 metre respectively.

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