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Application of One-Dimensional resistivity inversion to map and characterize aquifers in ObigboPortharcourt

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Abstract:*Twenty (20) Vertical electric soundings (VES) were acquired in Obigbo main dumpsite Portharcourt to delineate the subsurface geology of the area for groundwater development, and thereafter the geoelectric data was converted into relevant hydrologic properties of aquifer (transverse resistance and longitudinal conductance) for aquifer characterization. Interpretation of the twenty (20) VES profiles showed three (3) lithologies which are topsoil, clay and sand, with sand acting as the main aquifer unit. 1D geologic sections computed from the resistivity interpretation showed that the aquifer system in the area consists of unconfined and confined aquifer units within the second, third, and fourth geoelectric layers. Unconfined aquifers were observed within the second geoelectric layer with thickness of 0.6-6.5m for VES 02, third geoelectric layer with thickness of 0.2-64.1m for VES 12, second layer with thickness of 0.1-68m for VES 05, second layer with thickness of 0.3-4.2m for VES 15 and second layer with thickness of 0.4-4.0m for VES 16; while confined aquifers were observed within the fourth geoelectric layers for VES 02, 15, and 16, with thickness of 64.1-68.3m, 64.1-68.2m, and 64.1-68.3m respectively and within the third geoelectric layer for VES 03 with thickness of 4.3-64.1m. Transverse resistance (Tr) computed for second geoelectric layer in VES2, VES3, VES12 and VES15, show high values of transmissivity (Tr>10,000ohm-m^2) indicating high yield of water, while longitudinal conductance values were very low between 0.1 to 0.19Mhos, hence the aquifer units within this layers are weakly protected and has a risk of contamination.In VES 15 and 16, two confined aquifers were observed within their second and fourth geoelectric layers. Within the second layer in VES15 the confined aquifer observed has a thickness of 0.3-4.2m and Tr of about 11,340ohm-m^2 and is overlain by a thin layer of clay and suggests that the sand aquifer within this layer is weakly protected and has a risk of contamination while the confined aquifer observed within the fourth layer for VES 15 has a thickness of 64.1-68.2m and is overlain by a thick layer of clay, suggesting that the sand unit is well protected and is favorable for groundwater development in the area. Also in VES 16 within its second layer is an unconfined aquifer with thickness of 0.4-4.0m, and Tr of about 4298ohm-m^2 which indicates high yield, but is vulnerable to contamination from surface runoffs but within the fourth geoelecric layer is a confined aquifer at about 65m below the subsurface, suggesting that the sand unit is favorable for groundwater development. 2D Resistivity map drawn to image the second and third geoelectric layers from VES 1 to 20 show variation in resistivity caused by changes in lithology (sediments), and pore fill, which affects flow characteristics of aquifer delineated within the third layers. In VES 12, within its third geoelectric layer was an unconfined aquifer with thickness of about 0.2-64.1m and transverse resistance (Tr) was about 290,891ohm-m^2 (very high) therefore, flow characteristics of water within the third geoelectric layers in the area is towards VES 12.*

Keywords*: Resistivity inversion, Groundwater, Vertical electrical sounding(VES), Aquifer characterization and Geo-electric section.*

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I. Introduction

In groundwater investigation/production practice, geophysical survey of the subsurface rock materials are usually carried out to determine the water bearing potentials of the proposed site, to assess the viability of the project in the given site by acquiring hydrogeological information necessary for siting a productive well. Some key information to be obtained from the survey includes, estimated drill depth, type of geological formations (subsurface geologic materials) to be encountered, saline-fresh water interface. Estimates of relevant aquifer characteristics such as transverse resistance, transmissivity and hydraulic conductivity are derived from the geophysical parameters obtained after interpretation of geophysical data acquired through geophysical surveys in the proposed site, thereby enhancing the chances for locating zones of high quality water saturated layers (aquifer), and their protectivity (Oladapo and Akintorinwa 2007).

Adequate knowledge of these hydrological properties is essential for proper design and construction of the water supply borehole, which depends on the quality of geophysical data obtained from a geophysical survey. Resistivity methods are frequently used in groundwater investigation, mapping of geological formations and in geotechnical and environmental problems (Meju, 2002). The popularity of the method is mainly due to the simplicity of field procedures (non-explosive), availability of interpretation tools and relevance of the results. There are a great variety of possible arrays (i:e Schlumberger soundings, Wenner profiling, pole–pole surveys, pole–dipole and dipole–dipole profiles and gradient maps).

The interpretation of resistivity data usually involves one-dimensional (1-D) or two dimensional (2-D) modelling. 1D electrical method using Vertical Electrical Sounding (VES) has been employed over the years to characterize aquifers in different geologic environments and to map fractures in basement areas (Koefoed, 1979; McDowell, 1979 and Ayolabi et al, 2003), however this result is limited to resistivity change in the vertical direction (Loke, 2001). 2D resistivity images/tomography are created by inverting about hundreds to thousands of individual (VES) resistivity measurements (Loke and Barker, 1996a, b) to produce an accurate model of the subsurface resistivity. Although such a sophisticated method is used when the area has been densely surveyed using a grid of VES technique, and the VES points very close to each other.

Several authors have noticed the effect of non-layered structures located in the vicinity of vertical electrical soundings (Queralt et al., 1991). Some authors have used such “lateral effects” and performed 2-D inversions of the data for a given geo-electric layer of interest (Beard and Morgan 1991; ElQuady et al., 1999).

Interpretation of 1-D resistivity sounding (vertical electric sounding) involves 1-D inversion and forward modelling to obtain layer parameters which includes resistivity, thickness and depth of the subsurface layers, from which geo-electric sections are computed to fit the resistivity model. After computing the geo-electric model, we can combine a number of 1-D resistivity model for a given geo-electric layer of interest to obtain a 2-D resistivity image of the subsurface materials using programmed resistivity inversion techniques (Loke, 2001; Beard and Morgan 1991). Therefore, there is a possibility to use the sensitivity of the Schlumberger array for 2-D inversion for groundwater investigation.

In this study, 1-D electrical survey using vertical electric sounding (VES) technique was used to map aquifers in ObigboPortharcourtfollowed by 2-D resistivity inversions to image specific layers to determine flow direction of water and characterization of the delineated aquifer by determining aquifer type (confined or unconfined), aquifer thickness, and flow properties i:e transverse resistance, longitudinal conductance and transmissivity.

II. Climate and Geology of the Study Area

` The study area, Obigbo (main dump site) is located in Oyigbo local government area of Rivers State, part of the Niger Delta between latitude 4°30′41″N and longitude 7°32′24″E.Lapidus (1990) defined topography as the general configuration of the land surface, including size, relief and elevation. According to Illoeje (1972), the relief describes the height and depth of the area above and below a given datum. The undulations in the area are expressed in terms of the depressions in its topography. The study area (Obigbo main dump site) is characterized by low flat topography with no undulations. The elevation is variable between 4 to 8m above sea level.

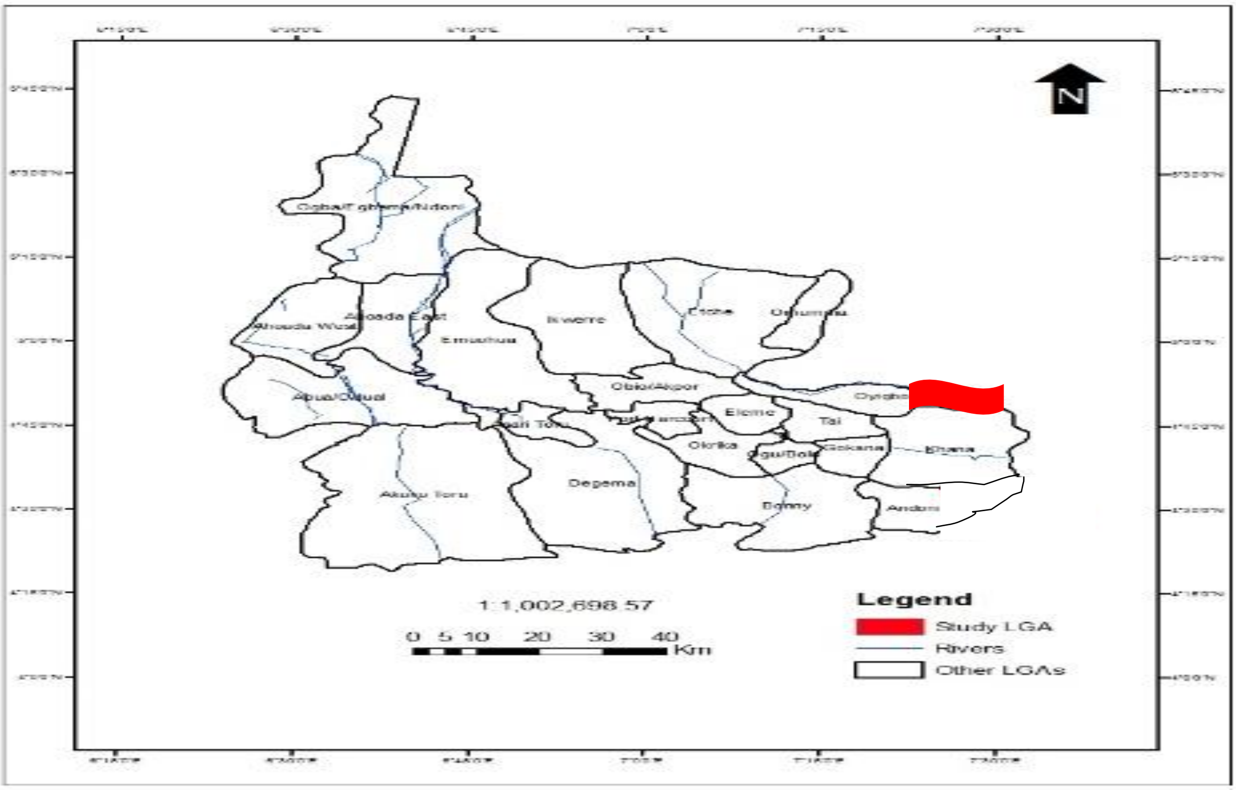


Figure 1: Map of Rivers State showing the study location (in red).

The area is part of the Niger Delta and has a network of streams that are typical in a deltaic setting. The amount of water drained in and out from the region is a function of the total rainfall, evaporation and losses due to absorption. The topography is dissected by severalrivers which cut and shape out the path along which they flow to form fluvial channels. Geologically, Obigbois part of the Niger Delta basin and consists of three litho-stratigraphic units, namely: The Akata Formation (Paleocene in age), which is overlain by the Agbada Formation (Eocene in age), and is overlain by the Benin Formation (Mioceneto recent). These stratigraphic units are based on the works of Reyment (1965), Short and Stauble(1967);Murat1970) and Merki (1975). The study area (Obigbo) lies on the coastal plain of the Niger Delta sedimentary basin and it is located in the Tertiary to Quaternary coastal plain sands (otherwise called the Benin Formation).

III. Materials And Methods

The electrical resistivity method was used for this study. Twenty (20) vertical electrical soundings (VES) were occupied in the area using the Schlumberger technique and labelled as VES1 to VES20 within their respective geographic co-ordinates. The VES profiles VES2, VES6, VES8, VES10, VES14 VES16, VES 18, VES12 and VES20 are located at the precincts of the study area, while others are within neighbouring locations in the area to enhance a vivid coverage of the area.

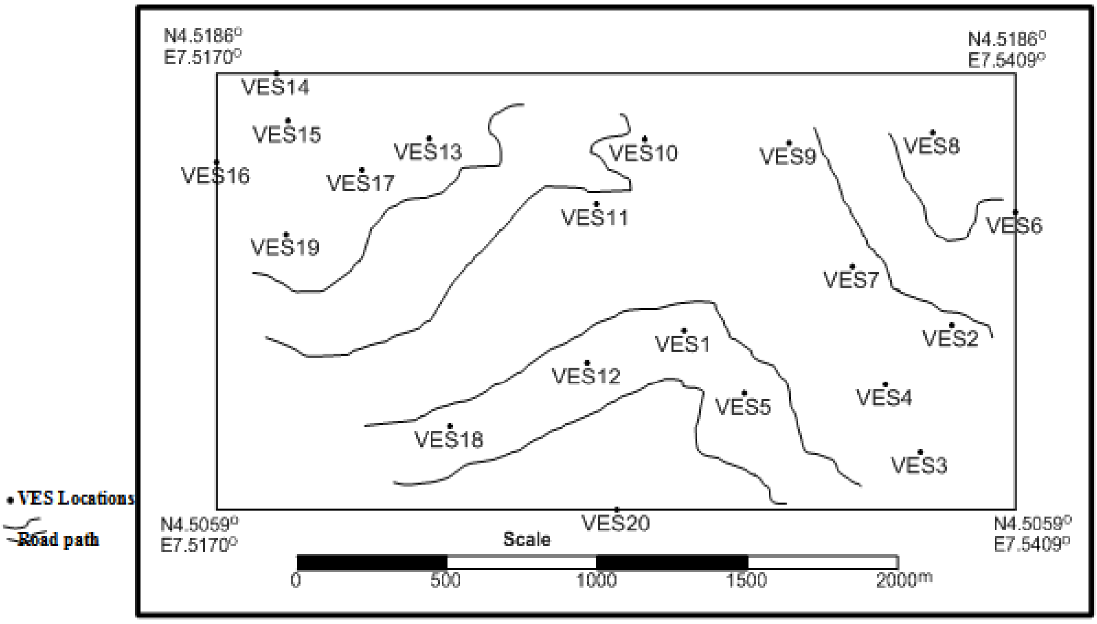


Figure2: Base map of data acquisition showing the sampled locations occupied in the study area

The VES data was acquired with a maximum electrode spacing (AB/2) of 225m. In each case ground resistivity data acquisition were made using DZD-6A Resistivity Meter of high data resolution and the co-ordinates of each sampled location was taken using a GPS (global positioning satellite). 1D resistivity data was inverted using the Res1dinv program to generate the resistivity model and curve type from which a cross-section of the subsurface (geo-electric sections) for the resistivity surveys were produced using Strata-4 software application. The four standard curves used in 1-D resistivity interpretation and their resistivity models includes A-curve ($\rho1<\rho2<\rho3$), Q-curve ($\rho1>\rho2>\rho3$), K-curve ($\rho1<\rho2>\rho3$), and Q-curve ($\rho1>\rho2<\rho3$).

3.1 Determination of hydrologic properties of aquifer from resistivity inversion result.

Hydrologic properties of the sand aquifer were computed from the layer parameters (resistivity, thickness and depth) obtained from 1-D resistivity inversion. Aquifer characterization involves the determination of aquifer flow properties, and the aquifer type (confined or unconfined). An aquifer can be characterized by its transmissivity, its quantitative expression of the productivity of an aquifer and coefficient of storage, which determines its storage capacity (Offodile, 2013). The combination of thickness and resistivity (obtained from resistivity interpretation) into single variables otherwise known as "Dar Zarrouk" parameters can be used as a basis for the evaluation of aquifer properties (Niwas and Singhal, 1981).

The DarZarrouk parameters computed for this study includes Transverse Resistance (RT), and Longitudinal Conductance (Lc) which were used to infer on aquifer transmissivity and its protectivity (for a confined aquifer case).

For a horizontal, homogeneous, and isotropic layer, the Transverse Resistance RT (Ωm^2) is defined mathematically as;

$RT= \rho h$ (1)

the Longitudinal Conductance Lc(mho) is defined as:

$LC = h/\rho$ (2)

Whereh is the thickness of the layer (in metres) and ρ is the electrical resistivity of the layer in ohm-metres. On a purely empirical basis, it can be admitted that the transmissivity of an aquifer is directly proportional to its transverse resistance i.e. the highest (RT) values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones and vice versa (Oladopo and Akintorinwa, 2007). The total longitudinal unit conductance value was used in evaluating overburden protectivity of the aquifer. This is because the earth medium acts as a natural filter to percolating fluid and its ability to retard and filterpercolating ground surface polluting fluid is a measure of its protective capacity. The aquifer protective capacity characterization is based on the values of the longitudinal unit conductance of the overburden rock units in the area (Oladopo and Akintorinwa, 2007). The research workflow is shown in figure 3 below.

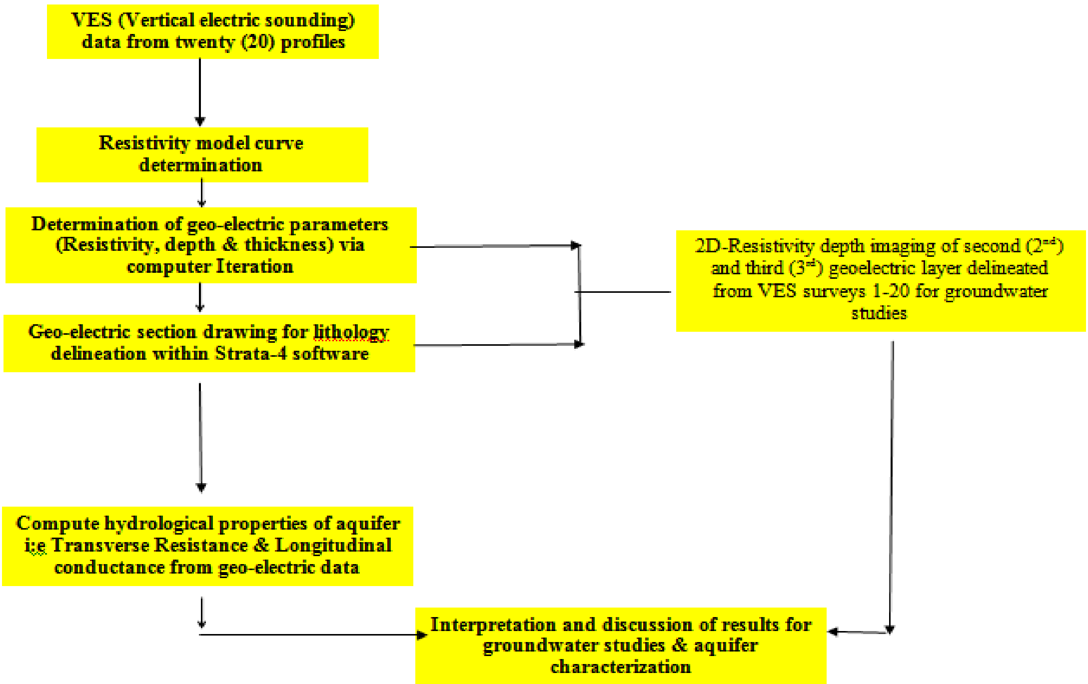


Figure 3: Showing the Workflow of the procedure and research design used.

IV. Results, Interpretation And Discussion

4.1VES Geo-electric model and Iteration results after interpretation

The geoelectric models and iteration results for VES profiles 1-20 is shown in figures 4.1 A- T below. The RMS error obtained is less than 1%, which is within the standard limits of error, hence the reliability of the inversion results. The results showed 3-4 geoelectric layers which are top soil, clay and sand with sand acting as the aquifer unit.

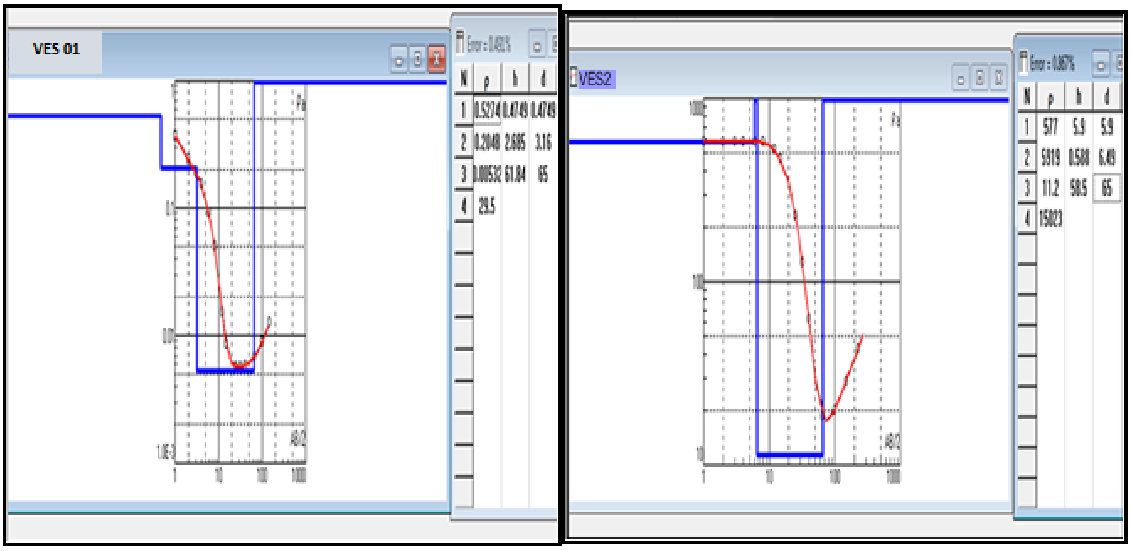


Figure 4 (B): Geo-electric model &layer parameters for VES 2 (KH curve type).**Figure 4 (A):** Geo-electric model & layer parameters for VES 1 (QH curve type).

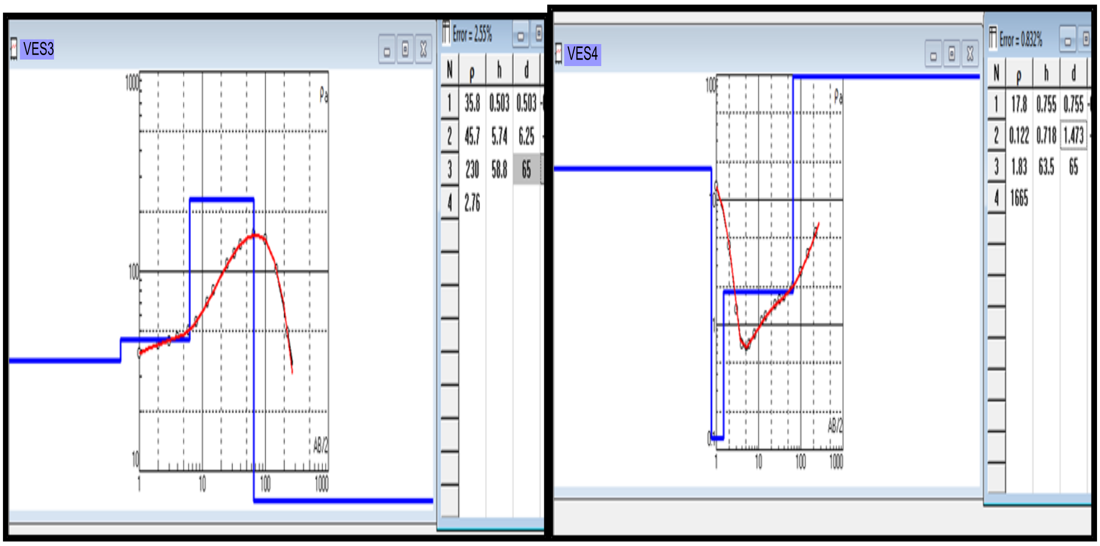


Figure 4 (D): Geo-electric model &layer parameters for VES 4(HK curve type).**Figure 4(c):** Geo-electric model &layer parameters for VES 3 (KA curve type).

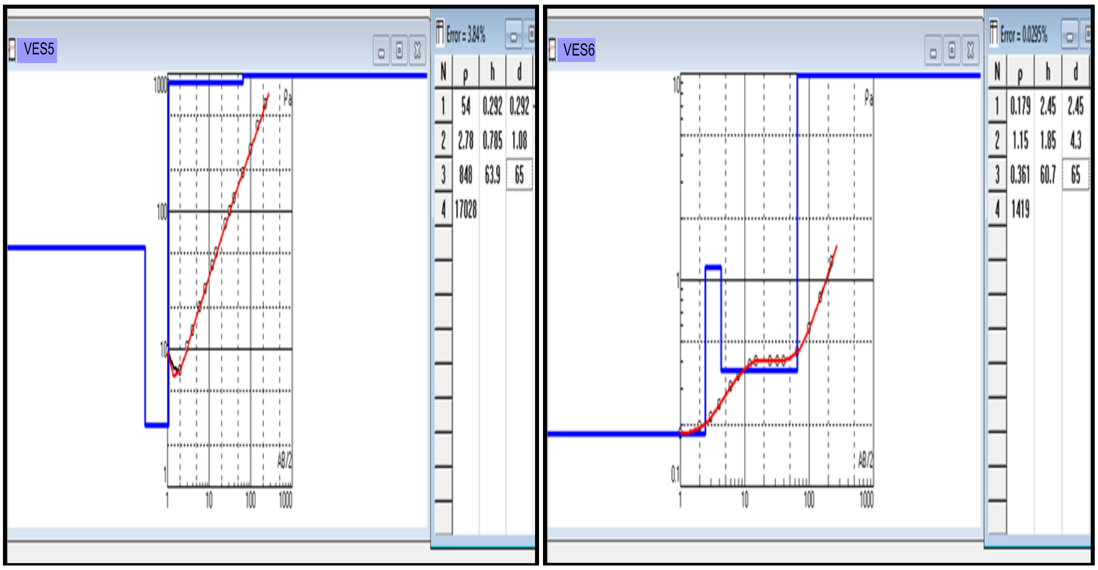


Figure 4 (F): Geo-electric model &layer parameters for VES 6(KH curve type).**Figure 4 (E):** Geo-electric model &layer parameters for VES 5 (HA curve type).

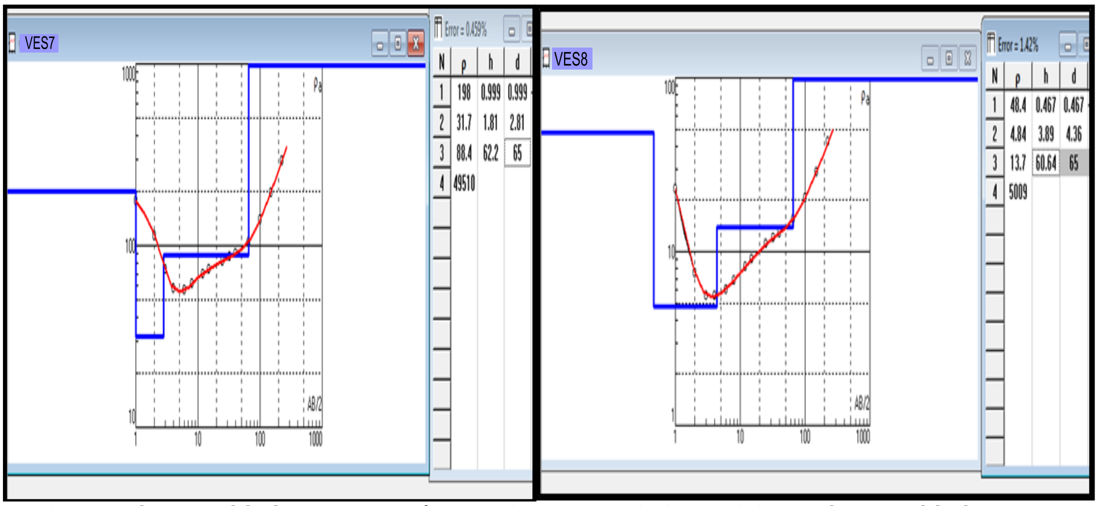


Figure 4 (H): Geo-electric model &layer parameters for VES 8(HA curve type).**Figure 4 (G):** Geo-electric model &layer parameters for VES 7 (HK curve type).

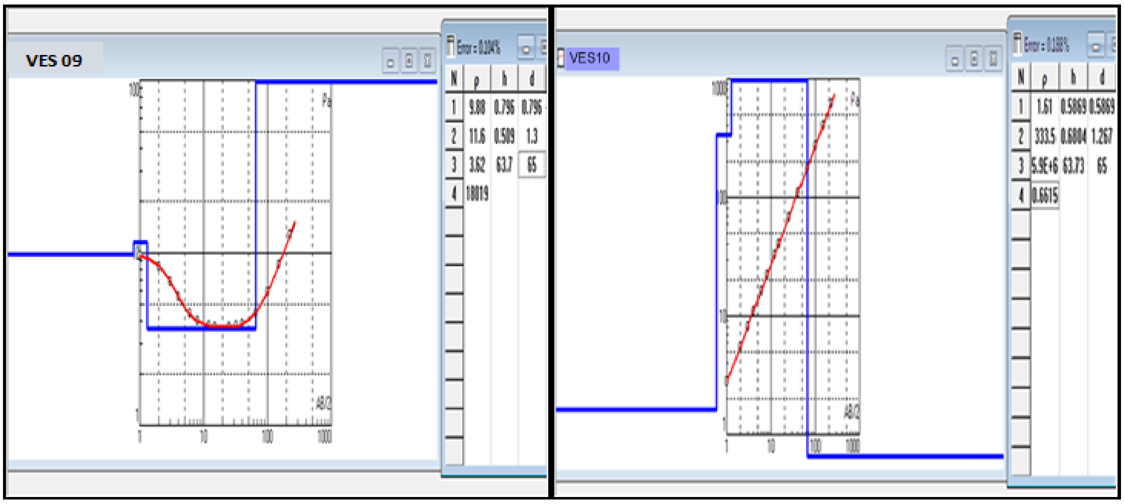


Figure 4 (J) : Geo-electric model &layer parameters for VES 10 (KQ curve type)Figure 4 (I): Geo-electric model &layer parameters for VES 9 (KH curve type).

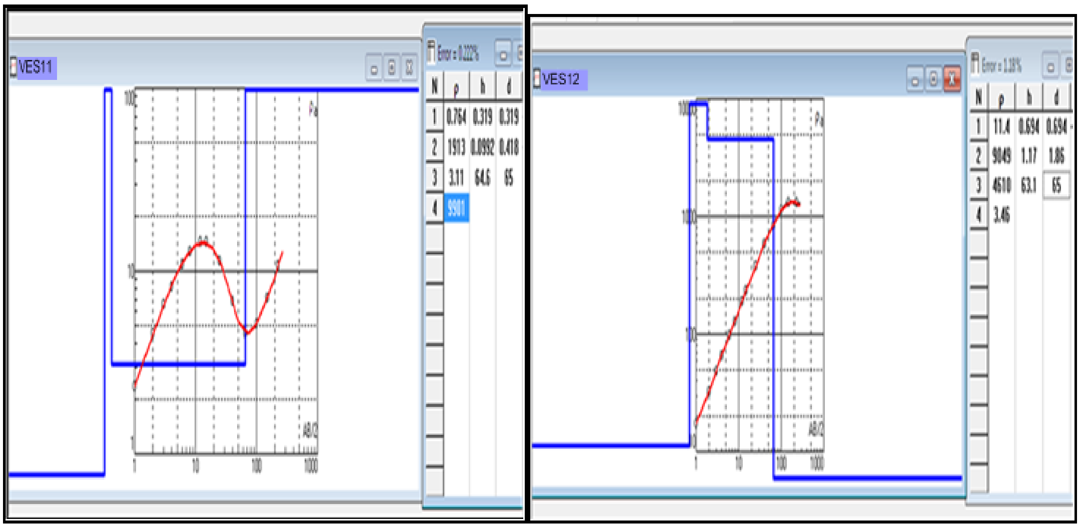


Figure 4(L): Geo-electric model &layer parameters for VES 12 (KQ curve type)Figure 4 (K): Geo-electric model & layer parameters for VES 11 (KH curve type)

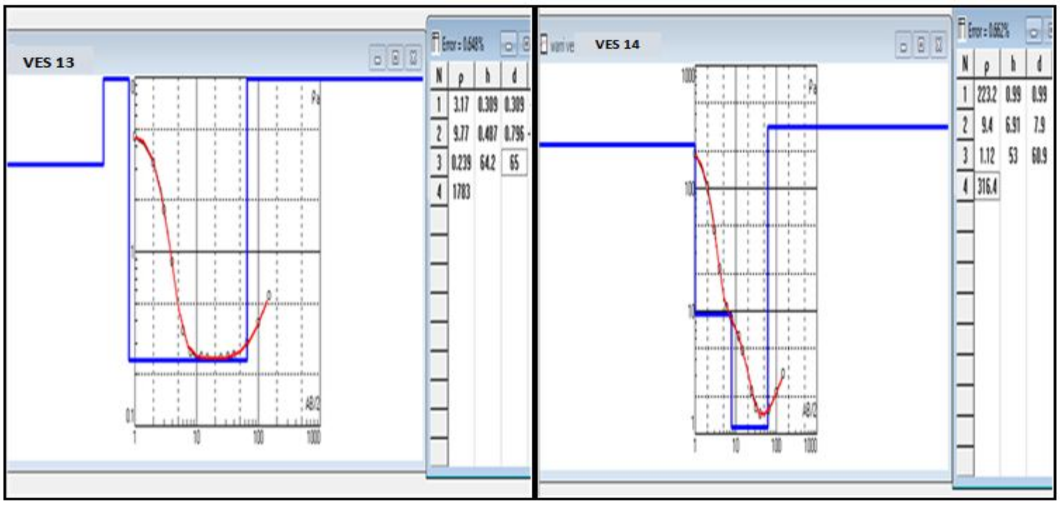
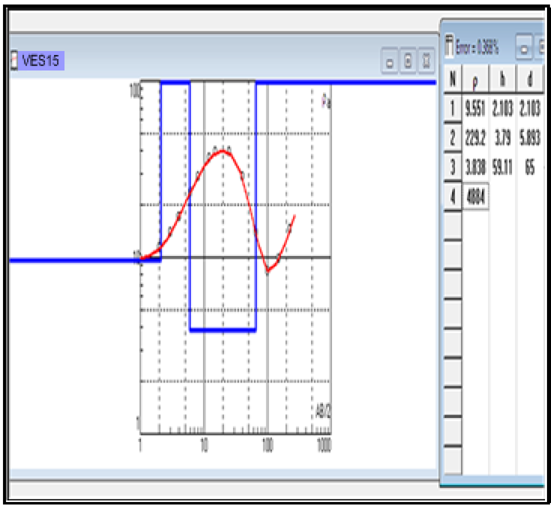


Figure 4 (N) : Geo-electric model & layer parameters for VES 14 (QH curve type)Figure 4 (M): Geo-electric model &layer parameters for VES 13 (KH curve type)



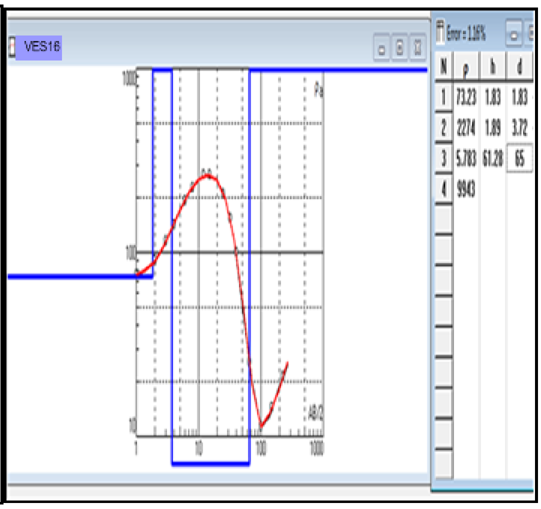
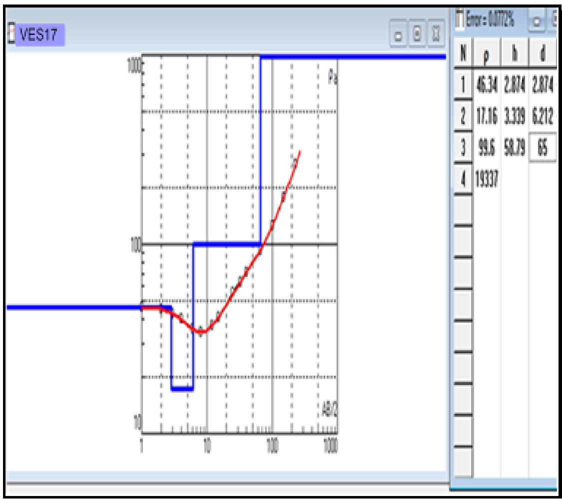


Figure 4 (O): Geo-electric model &layer parameters for VES 15 (KH curve type)**Figure 4 (P):** Geo-electric model &layer parameters for VES 16 (KH curve type).



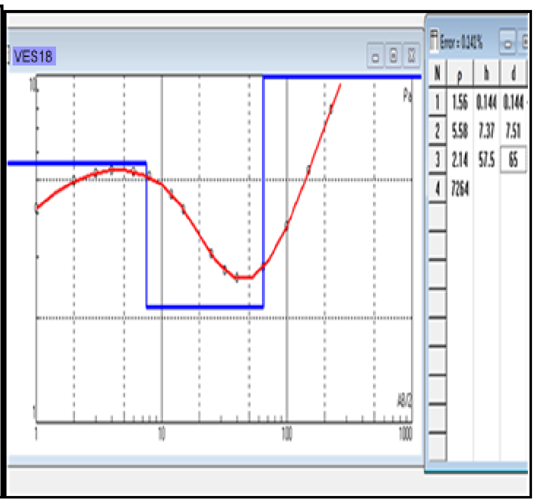
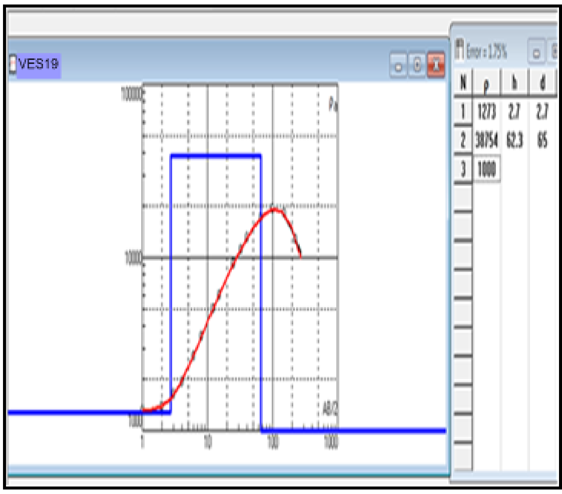


Figure 4 (R): Geo-electric model &layer parameters for VES 18 (KH curve type). Figure 4 (Q): Geo-electric model & layer parameters for VES 17 (HA curve type)



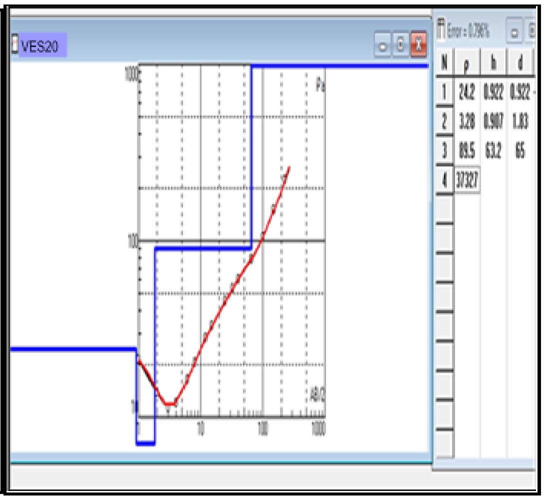


Figure 4 (T): Geo-electric model & layer parameters for VES 20 (HA curve type). Figure 4 (S): Geo-electric model &layer parameters for VES 19 (K type curve).

4.21D Geo-electric Sections

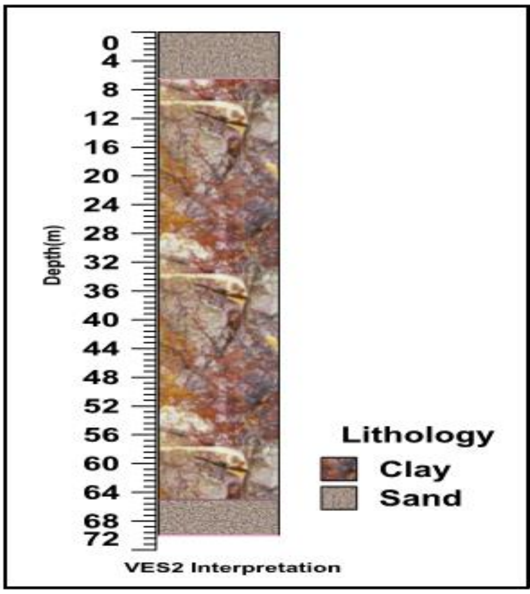


Figure 5: 1-D Geologic section of the subsurface for VES profile 2. Showing a Confined aquifer within the third layer sand unit

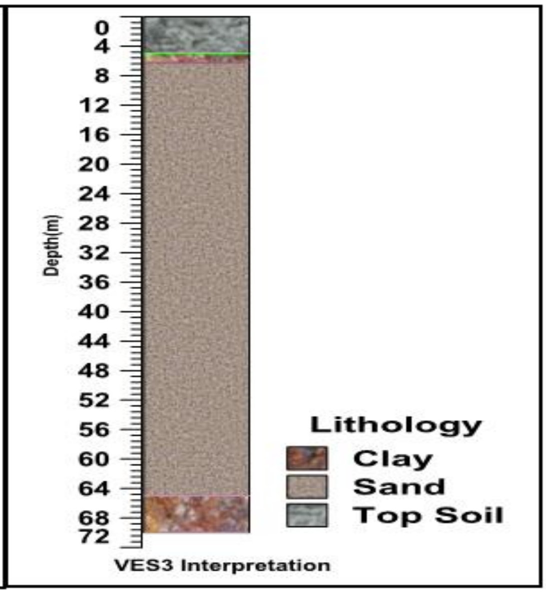


Figure 6: 1-D Geologic section of the subsurface for VES profile 3. Showing a Confined aquifer within the third layer sand unit.

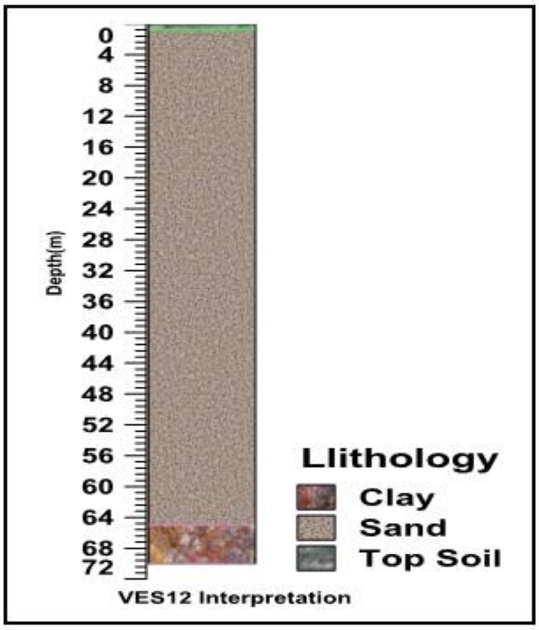


Figure 7: 1-D Geologic section of the subsurface for VES profile 12. Showing an unconfined aquifer within the second layer sand unit.

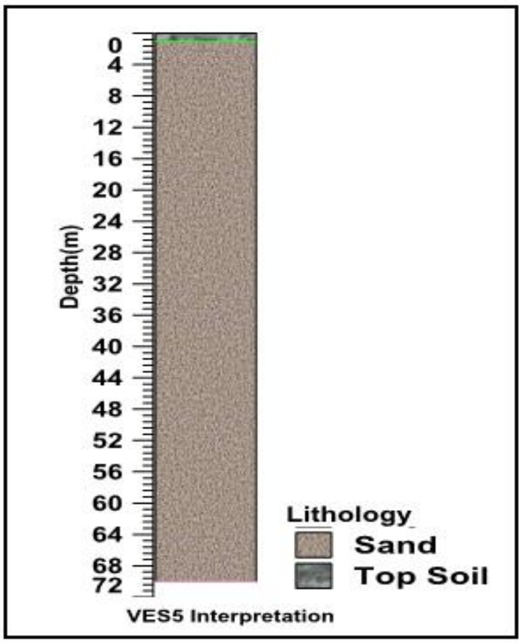


Figure 8: 1-D Geologic section of the subsurface for VES profile 5. Showing an unconfined aquifer within the second layer sand unit.

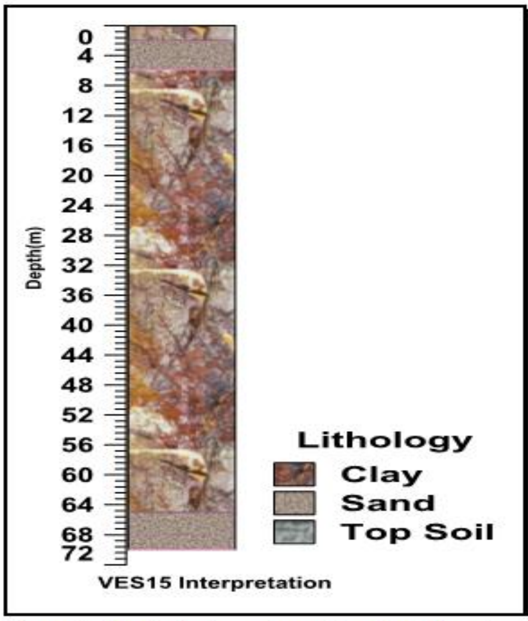


Figure 9: 1-D Geologic section of the subsurface for VES profile 15. Showing a Confined aquifer within the second and fourth layers.

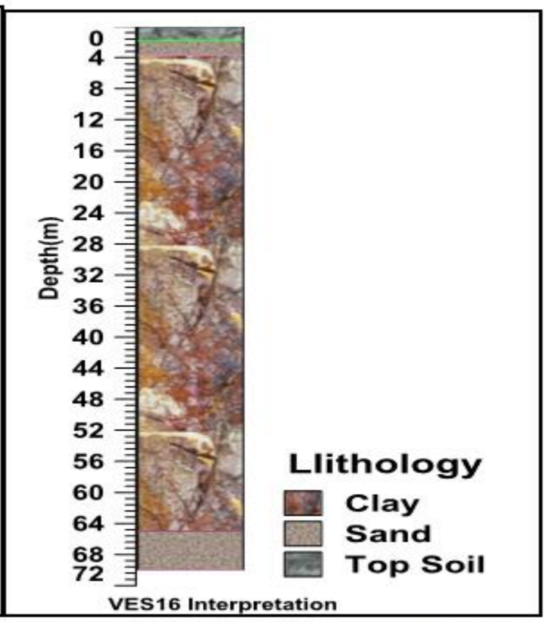


Figure 10: 1-D Geologic section of the subsurface for VES profile 16. Showing an unconfined and confined aquifer within the second and fourth layers.

The results of the computer aided quantitative interpretation (VES iteration) used for delineating the layer parameters (resistivity, thickness, and depth) within the subsurface in Obigbo area of Portharcourt is shown in figures 4 (A to T). The model curves obtained consists predominantly of KH, HA, QH and KQ curves from VES profiles 1-20. Three lithologies where delineated which consists of topsoil, clay and sand, with sand acting as the aquifer unit. 1-D geologic sections computed for VES profiles 02, 03, 12, 05, 15, and 16 in figures 5 to 10 show that within the subsurface of the study area lies both unconfined and confined aquifers. Unconfined aquifers were observed within the second geoelectriclayer with thickness of 0.6m for VES 02, second and third geoelectric layers with thicknessof 1.17-63.1m for VES 12, second layer with thickness of 68m for VES 05, and second layer with thickness of 3.0m for VES 16; while confined aquifers were observed within the third geoelectric layer for VES 02 with thickness of 7.0m, third geoelectric layer for VES 03 with thickness of about 56m, second and fourth geoelectric layers for VES 15 with thickness of about 3.0m and 7.0m respectively, and fourth geoelectric layer for VES 16 with thickness of about 6.0m and beyond. The confined aquifers observed at the fourth geoelectric layers for VES 15 and VES 16 at about 65.0m are both overlain by a thick layer of clay at their third geoelectriclayer which acts as a protection cover, which suggests that the sand aquifers at these VES locations are well protected from surface runoffs and contaminantsand is favourable for groundwater development in the area.

4.3 Results of hydrologic properties of aquifer computed from layer parameter

The layer parameters obtained from the quantitative interpretation were used in computing hydrologic properties such as total transverse resistance (Tr) and total longitudinal conductance (S) using equations (1) and (2) stated in the methodology. Table 1 summarizes the results of hydrologic properties of the geoelectric layers.

Table 1: Showing results of aquifer type and hydrologic properties for VES profiles 02, 03, 12 15, and 16.

VES	Lithology	Resistivity (Ωm)	h (m)	D (m)	Aquifer Type	S (Mhos)	Tr (Ohm-m^2)	Remarks
2	Sand	5919	0.6	6.5	Unconfined	-	3480	The aquifer has high transverse resistance-high yield.
3	Clay	45.7	5.74	6.25	-	0.126	-	Longitudinal conductance of the overlying clay layer is between 0.1-0.19Mhos. Therefore, the sand aquifer is weakly protected (has risk of contamination).
	Sand	230	5.7	65	Confined	-	1320	
12	Sand	4610	63.1	65	Unconfined	-	290891	The aquifer has high transverse resistance-high

								yield.
15	Sand	2992	3.8	5.9	Unconfined	-	11340	The aquifer has high transverse resistance-high yield.
16	Sand	2274	1.8	3.7	Unconfined	-	4298	The aquifer has high transverse resistance-high yield.

Transverse resistance (Tr in Ohm-m^2) is a measure of the rate of water transmitted through a given thickness of an aquifer is a function of the aquifer yield under gravity; while Longitudinal conductance (S in Mhos) is a measure of the protectivity of the aquifer which is confined by an impermeable overlying layer above it i:e clay layer (Oladopo and Akintorinwa, 2007).

For VES 02 whose aquifer is unconfined within the second geoelectric layer Tr is about 34,800ohm-m^2 with thickness of 0.6m which indicates high yield; for VES 03, confined aquifer is seen within the third geoelectriclayer with thickness of 56m and Tr of about 13,200ohm-m^2. The aquifer is confined by a thin layer of clay sediment whose longitudinal conductance (S) is between 0.1 to 0.19Mhos overlying the sand unit. Therefore, the sand aquifer within this layer is weakly protected (has risk of contamination). In VES 12, within its second and third geoelectric layers are unconfined aquifers with thickness of 1.17-63.1m below the subsurface and Tr is about 290,891ohm-m^2 indicating high yield, however this aquiferis vulnerable to contamination from surface runoffs. In VES 15, two confined aquifer units exists within the second and fourth geoelectric layers. Within the second layer is a confined aquifer with thickness of 3.0m whose Tr of about 11,340ohm-m^2 and overlain by a thin layer of clay. The sand aquifer within this layer is weakly protected and has a risk of contamination. However, within the fourth layer for VES 15 is another confined aquifer with thickness of 7.0m which is overlain by a thick layer of clay, suggesting that the sand unit below this clay layer is well protected and the layer is favorable for groundwater development. In VES 16 also, two aquifer units were delineated within the second and fourth geoelectric layer. Within the second layer the aquifer is unconfined with thickness of 3.0m, and Tr of about 4298ohm-m^2 which indicates high yield, but is vulnerable to contamination from surface runoffs; also within the fourth geoelecric layer is a confined aquifer with thickness of about 6.0m, suggesting that the sand unit is favorable for groundwater development.

4.4Resistivity map of the second and third geo-electric layers

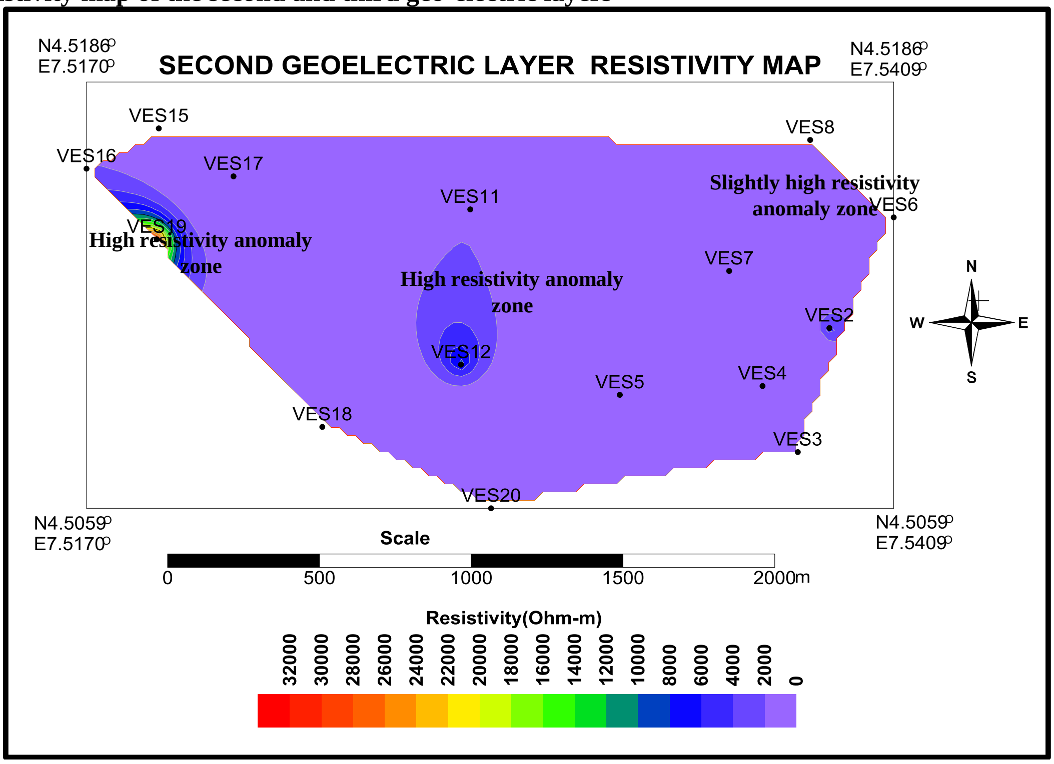


Figure 11: Second layer resistivity Map, used for imaging the second geoelectric layers from VES profiles 1 to 20 in ObigboPortharcourt. From the Map, resistivity distribution in the area within the second geoelectric layers consists of slightly high to high resistivity anomaly zones and this pattern is homogenously distributed.

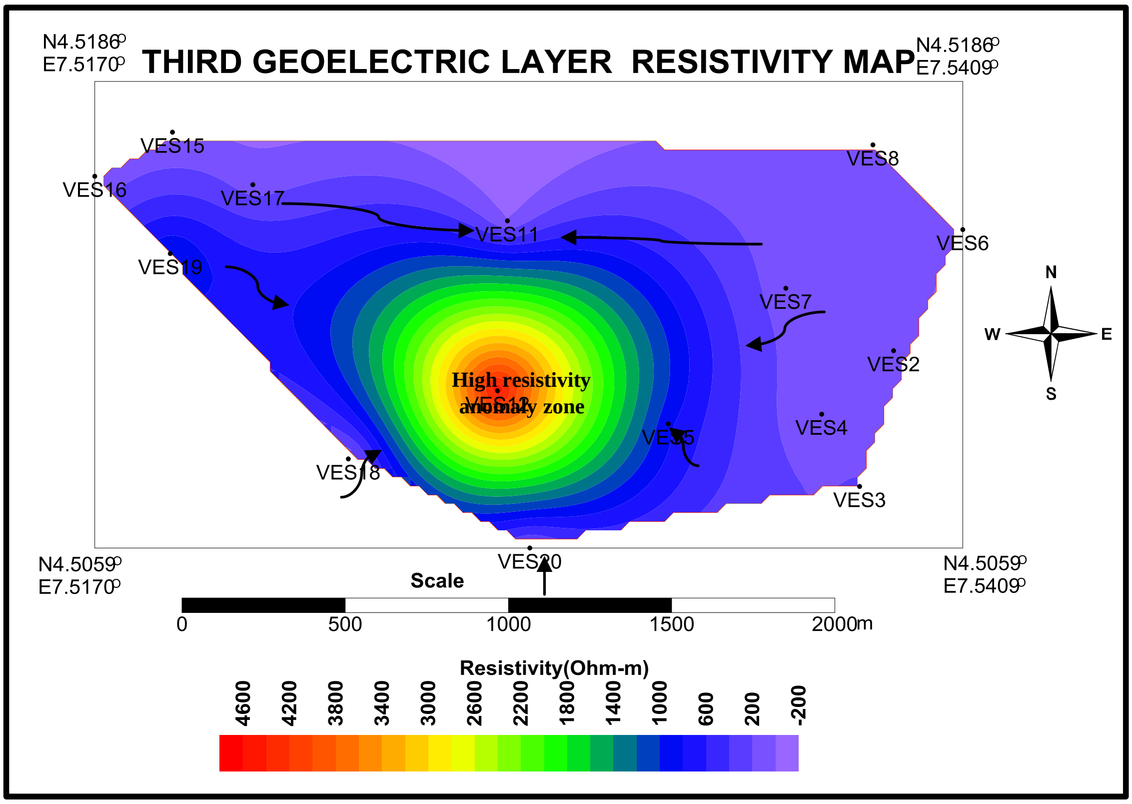


Figure 12: Third layer resistivity Map, used for imaging the third geoelectric layers from VES profiles 1 to 20 in ObigboPortharcourt. From the Map, resistivity variation within the third geoelectric layer is non homogenous due to the presence of a high resistivity anomalyzone at VES 12 location.

In figures 11 and 12 is a resistivity map drawn to image the second and third geoelectric layers from VES 1 to 20 in the study area (Obigbo). In figure 11 (second geoelectric layer resistivity map) we observed that the resistivity values of the second layers delineated from VES 1-20 is relatively homogenous with resistivity values predominantly ranging from 2000-3000ohm-m in most VES locations except in VES 12 and VES 19 where high resistivity values was observed. Homogeneity in resistivity values is an indication of similar fluid content and pore fill within the second geoelectric layer. In figure 12 (third geoelectric layer resistivity map) the resistivity distribution is not uniformly homogenous. The map showed areas with low, medium and high resistivity values within the third geoelectric layers of the study area as observed in the high resistivity anomaly zone in VES 12. This variations in resistivity within the third layer is caused by changes in lithology (sediments), fluid content and pore fill, which affects flow characteristics of groundwater in aquifers delineated within the third layer. In VES 12 location within its second and third geoelectric layers is an unconfined aquifer with thickness of about 1.17-63.1m and very high transverse resistance (Tr) which suggest that flow characteristics of water (as shown in the black arrows) within the third geoelectric layer in the area is towards VES 12. Thesefindings were not observed in the VES (1-D) geoelectric sections computed for the various VES surveys. Therefore, imaging a particular geoelectric layers delineated from a vast grid of VES surveys is another way to improve interpretation of VES data and study the variations (homogeneity and non-homogeneity) in resistivity values within the various geoelectriclayers in a different pattern other than the conventional vertical trend usually delineated from VES surveys.

V. Conclusion

We have applied the electrical resistivity sounding (VES) technique to image aquifers within the second and third geoelectric layers by computing resistivity map for second and third layers from VES 1 to 20, and hydrologic properties of aquifer computed from VES interpretation to show the flow characteristics of the aquifer delineated during VES surveys.2D resistivity map for second and third geoelectric layers was computed to image aquifers within these layers which is a form of imaging (tomography) because of its ability to show variations (homogeneity and non-homogeneity) in resistivity values within the various geoelectric layers in a different pattern other than the conventional vertical pattern usually delineated from VES surveys. These variations in resistivity values could indicate presence of subsurface geological structures favorable for groundwater accumulation in the study area. VES results show that within the third geoelectric for VES 03, VES

5, VES 11, VES 12, VES 15, VES 16, and VES 17 at about 65m below the subsurface are favorable locations for groundwater development in the area. Also aquifer properties i:e transverse resistance (Tr in Ohm-m^2) and Longitudinal conductance (S in Mhos) values show that the aquifers within this depth have a high yield and their protectivity is between 0.1 to 0.19Mhos, which shows low protectivity, hence aquifer system is vulnerable to risk of contamination. However, aquifer sand layers delineated within the fourth geoelectriclayers for VES 15 and VES 16, have good aquifer properties (resistivity, thickness and transverse resistance) and therefore are most favorablefor groundwater development in the area.

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