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Delineation of depth to Groundwater in parts of Federal University of Petroleum Resources Effurun, Delta State using One-Dimensional resistivity inversion

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ABSTRACT

Geophysical survey using the 1-D electrical method was carried out in a location at the Federal University of petroleum Effurun (FUPRE) campus in Ugbomro Delta State in order to determine the depth to prolific aquiferous layers for groundwater production. The Schlumberger configuration was used with a current electrode separation of about 300m. Five (5) VES profiles were occupied in the surveyed area labelled as VES1, VES2, VES3, VES4 and VES5, with VES2 and VES3 acquired within the same location to check for instrumental coupling in the resistivity meter. The resistivity data was inverted using the resistivity modeling software (IPI2Win.v.2.1) application to generate the layer parameters (resistivity, depth and thickness), from which hydrological properties (transverse resistance) which was taken as transmissivity was extracted from the geoelectric data and geologic sections of the subsurface were drawn. The result of the interpretation showed four to five geoelectric layers and six lithologies namely clay, sandy clay, clayey sand, fine sand, medium sand, coarse sand (which is gravely) and a high resistivity carbonate bed. In the study area, along profiles VES2 and VES4 lies prolific aquiferous layers which are favorable for groundwater development. In VES2 five layers were delineated, it was observed that within the second and fourth layers along this profile lies high resistivity materials (with resistivity >2200Ωm) which depicts coarse sand. The coarse sand observed within the fourth layer in VES2 has a thickness of about 26.9m at a depth of 6.27m below the subsurface and is sandwiched between two low resistivity materials at the third and fourth layers (with resistivity values of about 405Ωm at the third layer) which depicts clayey sand and (resistivity values <50Ωm within the fifth layer) which depicts clay. This shows that the coarse sand observed within the fourth layer in VES2 is a good aquifer zone with high transmissivity value of about 60,444Ωm^2 making it highly productive and favorable for groundwater abstraction. Also in VES4, four layers were delineated with coarse sand observed within the second layer with a thickness of 1.78m at a depth of about 1.72m which is shallow and medium sand observed within the third layer at a depth of about 3.5m, and considering its thickness (about 43.8m) this layer will be favorable for groundwater abstraction as observed from its transmissivity value (of about 44,150Ωm^2). Aquifer zones delineated within the second and third layers for VES1 and VES5 even though they have a reasonable thickness of about 30.83m and 28.3m respectively are not good aquifer zones because they lie within shallow depths of about 0.77m and 1.48m respectively. Therefore, within the surveyed area the aquifer zones of high productivity lies within the third and fourth layers in VES4 and VES2 at a depth of about 3.5m and 6.27m respectively which lies within and below the water table (about 3.0 ± 0.5m) as reported by previous studies.

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

1. Introduction

Hidden beneath the varied landscapes of the Niger Delta is a treasured and important natural resource. This hidden treasure is called water, and to be more specific, groundwater. Water is one of the essential natural resources that necessitated the existence of life on earth. It is for this reason that the world celebrates "World‟s Water Day" on 22nd March every year. Groundwater occurs everywhere but sometimes its availability in economic quantity depends solely on the distribution of the subsurface rock materials that are referred to as the aquifers. This implies that where groundwater is not potentially available, may be either due to complete lack of it or inadequacy arising from increasing industrial and domestic needs (George et al., 2014). Many cities, towns and communities rely on borehole source since it is one major renewable source of water. Unfortunately, water from borehole sources is non potable because they are either contaminated or extinct after a short period of supply and sometimes are totally non-existing. Although groundwater is a renewable resource, fear is being nursed about the danger arising from inadequacy or lack of it. The universality of its use heightens the degree of fear as no other fluid can replace the uncountable roles played by water in our communities.

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. Resistivity methods are frequently used in groundwater investigation, mapping of geological formations favourable for groundwater accumulation 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.

One dimensional (1D) electrical method popularly known as Vertical Electrical Sounding (VES) has been employed over the years to characterize aquifers in different geologic environments and to map fractures in basement areas (Eze et al., 2018; Oseji et al., 2006; Ayolabi et at., 2003; McDowell 1979 and Koefoed, 1979). The advantage of the VES technique is that it senses resistivity change with respect to depth, from which the subsurface lithology and hydrogeology can be stratified for effective siting of reliable boreholes for optimal harnessing of groundwater from prolific aquifers at profound depths. In this study, Vertical Electrical Sounding (VES) was used to delineate depth of aquifers and determine their hydrogeological properties in a location at the Federal University of Petroleum resources Effurun with the aim to deduce potential areas for groundwater abstraction within the surveyed location that will serve a number of student's resident within the University premises.

2. Climate and Geology of the Study Area

2.1 Climate and topography

The study area, Federal University of Petroleum Resources Effurun (FUPRE) campus is located in Warri. Warri shares boundaries with Udu and Uvwie Local government area of Delta State, Effurun serves as the gateway to and the economic nerve of the city. Geographically, Warri and Effurun are located between latitudes 05°30'N and 05°35'N longitudes 005°29'E and 005°48'E. The climate of the area is the tropical equatorial type dominated by two seasons, a long wet season (April to October) and a short dry season (November to March), in response to the interplay between the southwest and the northeast trade winds that blows over Nigeria. Annual rainfall is usually in excess of 3000mm (Meteorological Report of 1999-2015), as no month of the year is entirely devoid of rainfall. Temperature is above of 28°C and humidity is about 80%. The Effurun area is a low-lying slightly undulating deltaic plain. The plain is generally flat and rises only very gently towards the North and Northeast with gradient of about 1:960 (Odemerho and Ejemejovwi, 2007). The Ugbomro creek drains the area. The study area lies on the Somebreiro-Warri Deltaic plain which overlies the coastal plain sands (Ohaji and Akuizeje, 1989).

2.2 Geology of the Area

The Geology of Effurun region is seen to be same as the Niger Delta, comprising of three lithological units (stratigraphy) known as: The Akata Formation which is the oldest is overlain by Agbada Formation. The Agbada formation is overlain by the Benin Formation being the youngest formation. This is based on the works of Short and Stauble (1967).

The Benin Formation covers 80 % of the rocks seen on the surface in the study area. It is underlain by the paralic Agbada Formation. The sedimentary units of the Benin Formation is comprised of inter fingering units of lacustrine and fluvial loose sands, pebbles, clays, and lignite streaks of varying thicknesses while the alluvial units is comprised of tidal and lagoon sediments and beach sands which are mostly found along the river banks.

The Agbada Formation consists of the sands intercalated by clays and shales while the Akata Formation occurs beneath comprising predominantly of shales rich in organic matter. Existing literature on the geology of the area are well documented from the exploration activities of oil and gas companies in the area Short and Stauble (1967).

The Benin Formation is overlain by thin laterites overburden with varying thicknesses at some locations but is massively exposed near the shorelines. The Somebreiro-Warri Deltaic plain sands is quaternary to recent in age and directly underlies the study area. The major aquifer unit in the area lies within the sands of the upper deltaic top lithofacies. The Benin Formation is comprised of continental (fine, medium and coarse) sands and occasionally gravely (Ohaji and Akuizeje, 1989). The sequence is locally stratified with peat and lenses of soft and plastic clay that could be sandy and shaly. It generally does not exceed 120m in thickness and is predominantly unconfined.

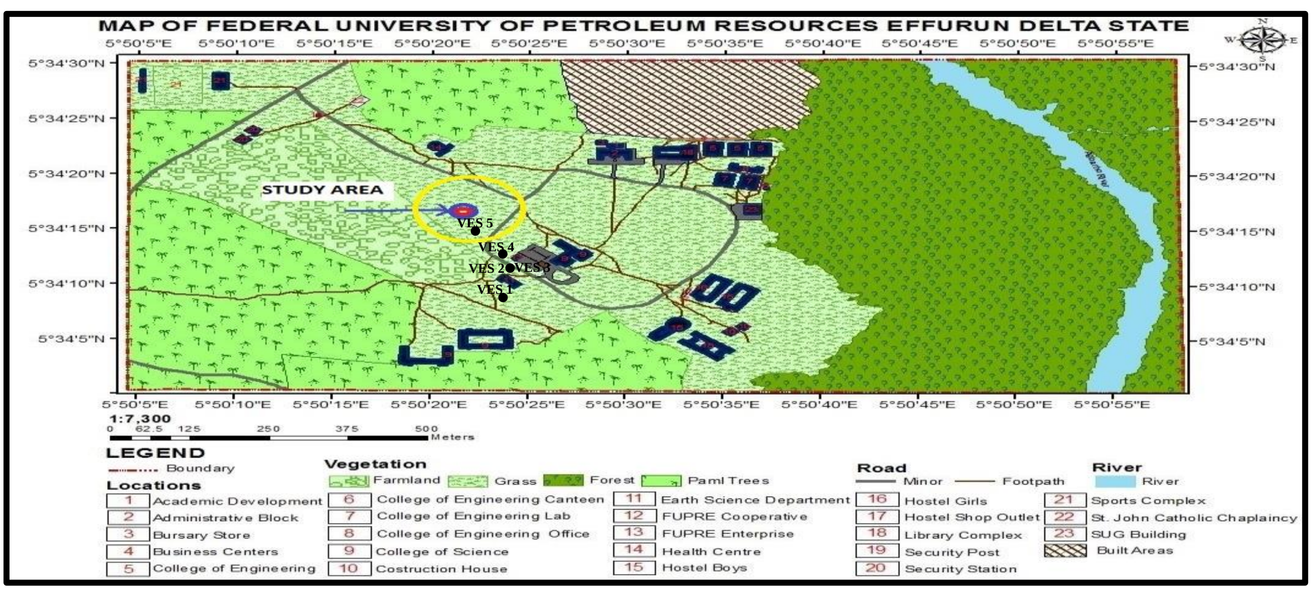

Figure 1: Base map of data acquisition showing the sampled locations occupied in the study area.

3. MATERIALS AND METHODS

The electrical resistivity method was used for this study. Five Vertical electrical soundings (VES) were occupied in the area using the Schlumberger technique and labelled as VES1 with co-ordinates N05°34'05.1" and E005°50'30.6"; VES2 with co-ordinates N05°34'07.7" and E005°50'35.7"; VES3 with co-ordinates N05°34'07.7" and E005°50'35.7"; VES4 with co-ordinates N05°34'09" and E005°50'38.6" and VES5 with co-ordinates N05°34'22.2" and E005°50'35.2". VES profiles VES2 and VES3 were acquired within the same geographic co-ordinate (N05°34'07.7" & E005°50'35.7") to check for instrumental coupling in the resistivity meter and as such their resistivity values were similar. The VES data was acquired with a maximum current electrode spacing (AB) of 300m. In each case ground resistivity data acquisition were made using OHMEGA TERRAMETER Resistivity Meter and the co-ordinates of each sampled location was taken using a GPS (global positioning satellite). 1D resistivity data was inverted using the IPi2Win.v. 2.1 application program to generate the resistivity model and curve type which were curve matched with the standard curves and interpreted quantitatively to generate the layer parameters 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 H-curve ($\rho1>\rho2<\rho3$). After resistivity inversion, hydrological properties of the aquifer were computed from the layer parameters (resistivity and thickness) obtained from 1-D resistivity inversion. An aquifer is characterized by its transmissivity which is the 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).

For this study, the hydrological parameter that was computed is the transverse resistance (*RT*) which was used to infer on aquifer transmissivity.

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

$$RT = \rho h \qquad (1)$$

Where h 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 (Oladapo and Akintorinwa, 2007). After obtaining quantitative values of transverse resistance from the geoelectric data which was taken as the transmissivity (Oladapo and Akintorinwa, 2007), a bar chart of transmissivity versus aquifer thickness was plotted using grapher 11 software application.

4. RESULTS, INTERPRETATION AND DISCUSSION

4.1 VES Geo-electric model curves and Iteration results after interpretation

The geoelectric models curves and iteration results for VES profiles VES1, VES2, VES4 and VES5 is shown in figures 2 to 5 below. Table 1 is a summary of the resistivity inversion results and hydrological properties computed from the geoelectric data. 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 4 to 5 geoelectric layers.

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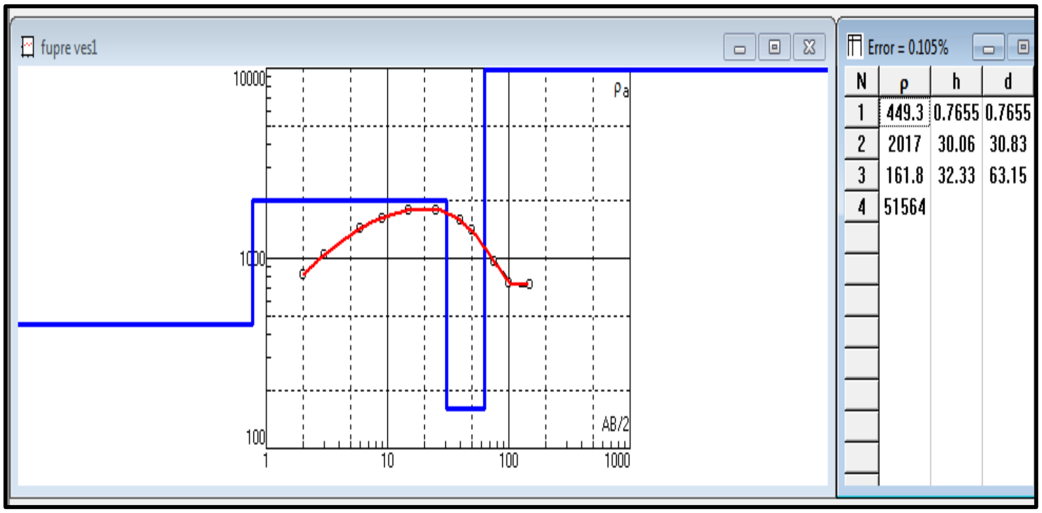


Figure 2: Geo-electric model curve & layer parameters showing four layers for VES 1 (Curve type is K).

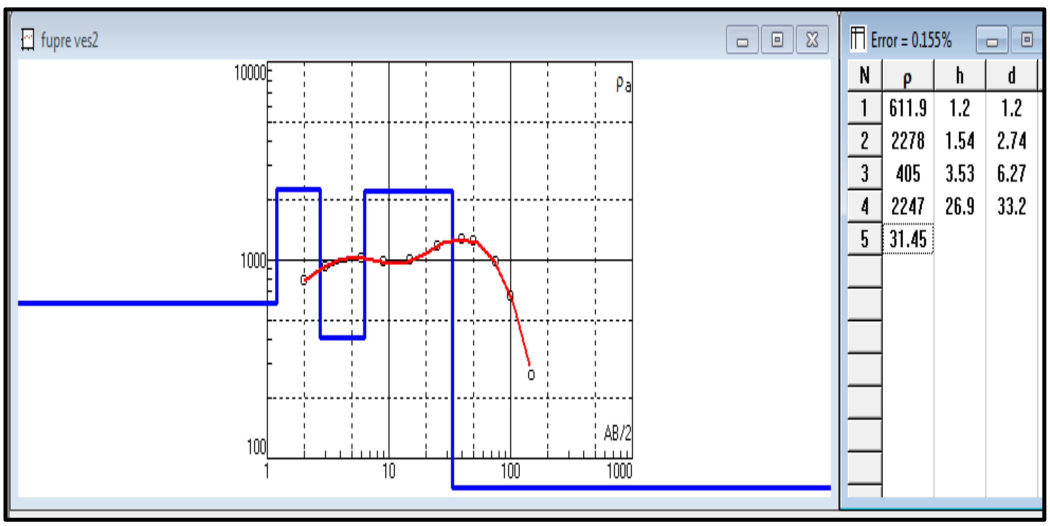


Figure 3: Geo-electric model curve & layer parameters showing five layers for VES 2 (Curve type is KH).

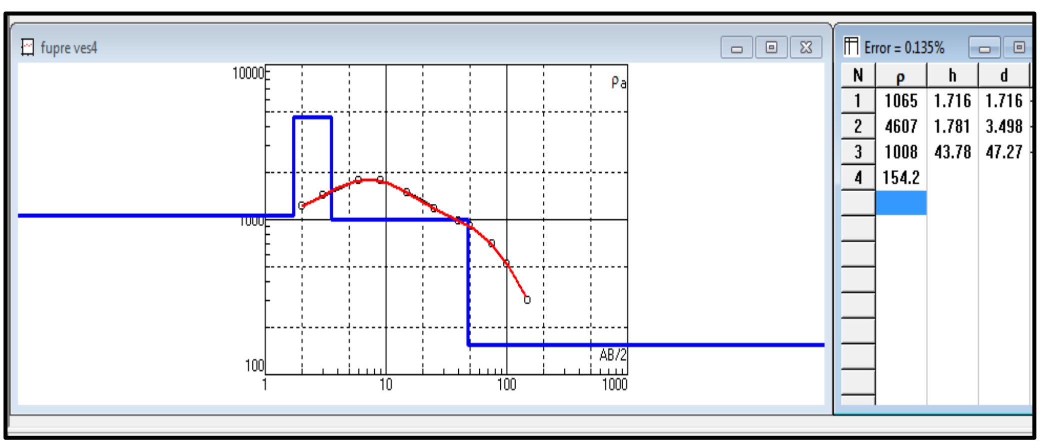


Figure 4: Geo-electric model curve & layer parameters showing four layers for VES 4 (Curve type is K).

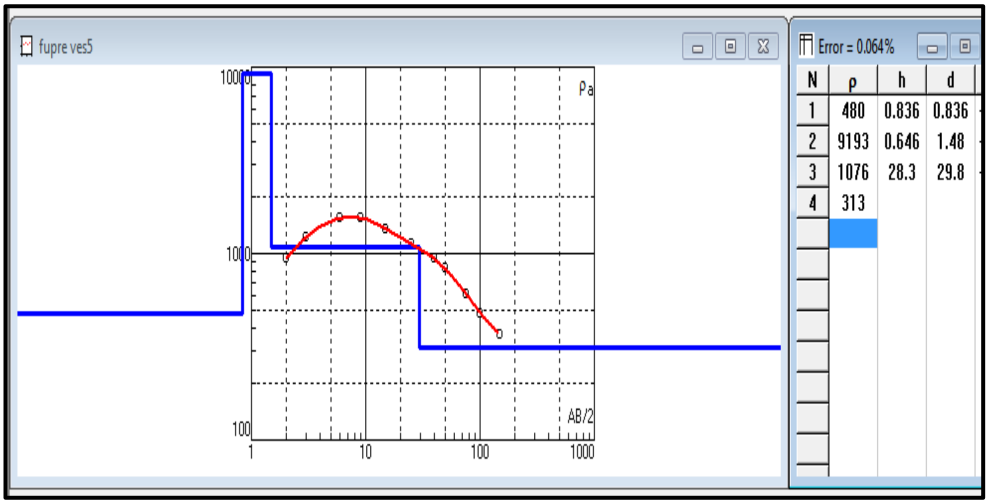


Figure 5: Geo-electric model curve & layer parameters showing five layers for VES 5 (Curve type is K).

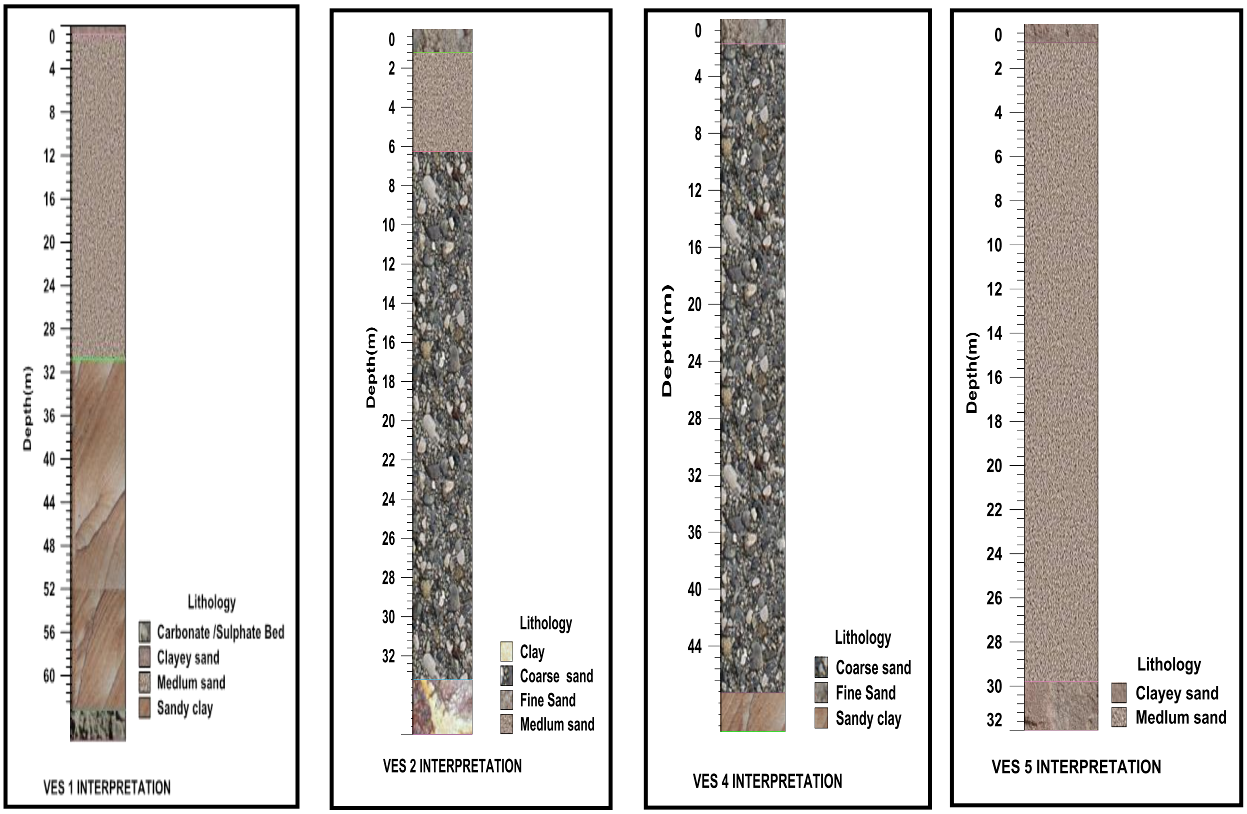
Table 1: Showing summary of resistivity iteration results, inferred Lithology and transmissivity values computed for VES profiles 2, 4 and 5 within the 3rd and 4th layers for VES 2, 3rd layer for VES 4 and 4th layer for VES 5.

Geoelectric Layer	Resistivity (Ωm)	Depth To Top (m)	Thickness (m)	Inferred Lithology	Remark	Transmisivity (Ωm²)
VES1						
1	449.3	0	0.77	Clayey Sand		
2	2017	0.77	30.83	Medium sand	The sandy unit is probably graded, and has equivalent resistivity and considerably thickness (30.83m) within its second geoelectric layer. However, the depth of occurrence is shallow (0.77m), thus not favorable for groundwater abstraction.	
3	161.8	30.06	32.33	Sandy clay	Low productivity	
4	51654	63.15			Highly resistive bed, probably carbonate bed.	

VES2						
1	611.9	0	1.2	Fine Sand		
2	2278	1.2	1.54	Coarse Sand	Shallow moist zone	
3	405	2.74	3.53	Clayey sand	Water saturated zone	1430
4	2247	6.27	26.9	Coarse Sand	Highly productive water saturated zone	60444
5	31.45	33.2		Clay		
VES4						
1	1065	0	1.72	Medium Sand	Moist zone	
2	4607	1.72	1.78	Coarse sand	Shallow water saturated zone	
3	1008	3.5	43.8	Medium Sand	Productive water saturated zone	44150
4	154.2	47.3		Sandy clay	Low productivity	
VES5						
1	480	0	0.84	Clayey sand		
2	9193	0.84	0.65	Coarse sand	Dry	
3	1076	1.48	28.3	Medium Sand	The sandy unit is graded, and has equivalent resistivity and considerably thickness (28.3m). However, aquifer depth is shallow (1.48m), therefore it is not favorable for groundwater abstraction.	30451
4	313	29.8		Clayey Sand	Fairly productive	9327

4.2 VES Geologic Sections

One-dimensional geological model was drawn using stata-4 software which shows the various lithological sequence inferred from resistivity inversion.



a. VES 1 b. VES 2 c. VES 4 d. VES 5

Figure 5 (a-d): 1-D Geologic section of the subsurface for VES profiles 1, 2, 4 and 5. Showing a Confined aquifer within the third layer sand unit.

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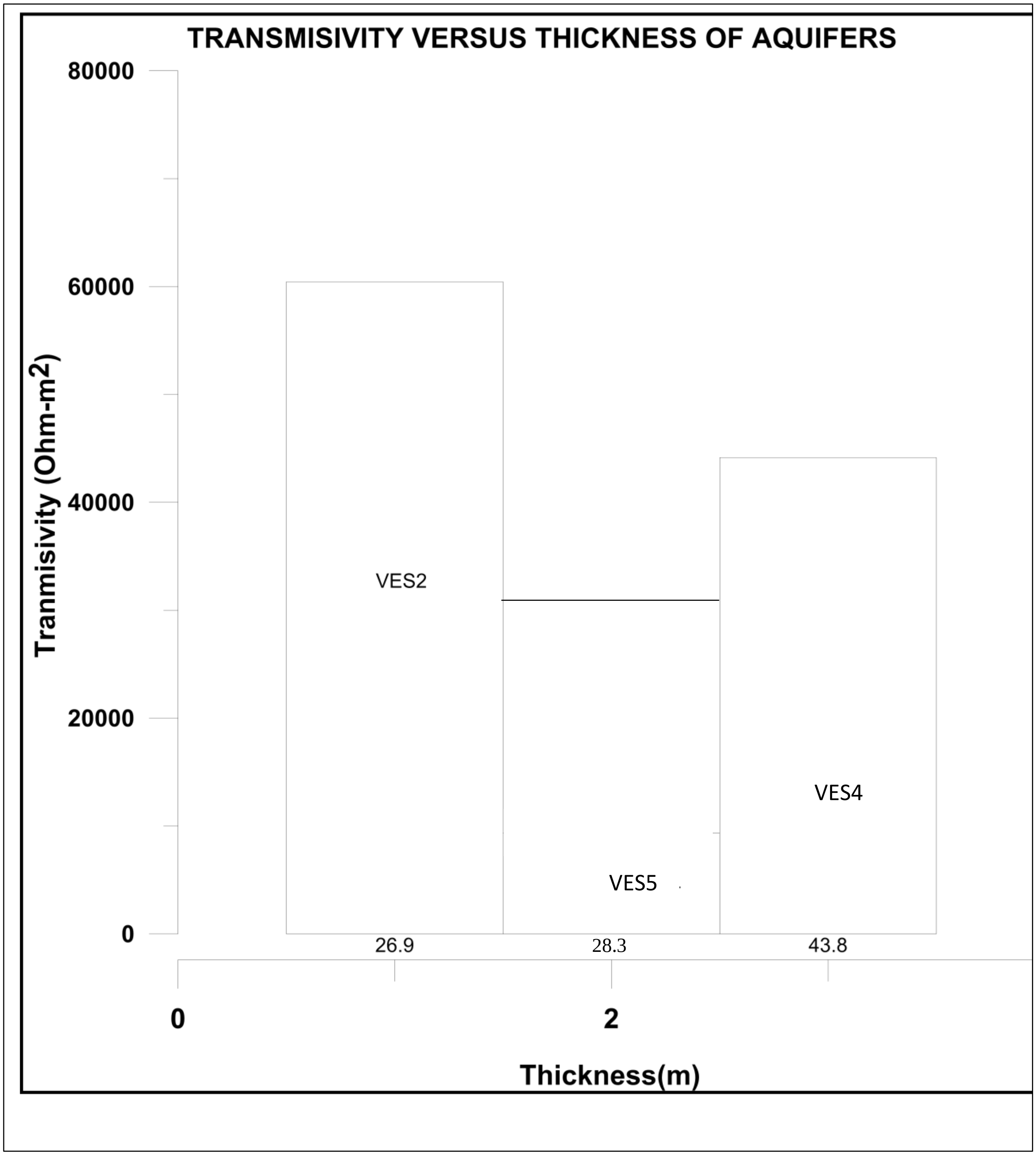

Figure 6: A Bar chart of transmissivity versus thickness of VES Geologic section of the subsurface for VES profiles 1 to 5. Transverse resistance (RT) computed from geoelectric data was taken as the transmissivity (Tr), (After Oladapo and Akintorinwa, 2007).

4.3 Discussion of results

The results of the computer aided quantitative interpretation (VES iteration) used for delineating the layer parameters (resistivity, thickness, and depth) within the subsurface in figures 2 to 5 shows that the model curves obtained consists predominantly of K curves ($\rho1<\rho2>\rho3$) and KH curve ($\rho1<\rho2>\rho3<\rho4$). These curves are descriptive of an aquifer unit (confined) sandwiched between two low resistivity layers i:e clay or sandy clay in a vertical succession. Six lithologies where delineated and based on their resistivity values were interpreted as clay, sandy clay, clayey sand, fine sand, medium sand, coarse sand (which is gravely) and a high resistivity carbonate bed. These lithologies were coined from the works of Olobaniyi and Owoyemi (2006) and Ohaji and Akuizeje, (1989). In VES1, four layers were delineated and interpreted as clayey sand in layer 1 (with resistivity value of about 449.3Ωm), medium sand in layer 2 (with resistivity value of about 2017Ωm), sandy clay in layer 3 (with resistivity value of about 161.8Ωm) and a high resistivity carbonate bed in layer 4 (with resistivity value of about 51,654Ωm). The medium sand observed within the second layer and sandwiched between two low resistivity layers at the first and third layers, has a thickness of about 30.83m which is considerable for an aquifer but at a shallow depth of 0.77m below the subsurface, thereby making this layer not favourable for sitting a productive borehole. In VES2 five layers were delineated. It was observed that within the second and fourth layers along this profile lies high resistivity materials (with resistivity >2200Ωm) which depicts coarse sand. The coarse sand observed within the fourth layer in VES2 has a thickness of about 26.9m at a depth of 6.27m below the subsurface and is sandwiched between two low resistivity layers above and below it. Above it is a layer of low resistivity (about 405Ωm within the third layer) with thickness of about 3.53m and depicts clayey sand and below it is underlain a low resistivity layer (< 50Ωm within the fifth layer) at a depth of about 33.2m, which depicts clay. This shows that the coarse sand observed within the fourth layer in VES2 is a good aquifer zone with high transmissivity value of about 60,444Ωm^2 making it highly productive and the aquifer is confined between two low permeable geoelectric layers making it favourable for groundwater abstraction. In VES4, four layers were delineated. Coarse sand was observed within the second layer with a thickness of 1.78m at a depth of about 1.72m which is shallow. Within the third layer, medium sand was observed at a depth of about 3.5m, and considering its thickness (about 43.8m) will be favourable for groundwater abstraction as observed in its transmissivity value (of about 44,150Ωm^2). In VES5, four layers were delineated with coarse sand observed within the second layer with a thickness of 0.65m at a depth of about 0.84m which is shallow and not favourable for groundwater development and medium sand observed within the third layer at a depth of about 1.48m, and thickness of 28.3m. Although this layer has a reasonable thickness which makes its transmissivity high (about 30,451Ωm^2) it is still not a good aquifer zone because of its depth of occurrence of about 1.48m below the subsurface. Figure 6 is a bar chart plot of transmissivity (Tr in Ωm^2 on the vertical) against thickness (m) on the horizontal (not to scale) of aquifer zones delineated within the fourth layer in VES2, third layer in VES4 and VES5 respectively. The plot shows the variation of thickness of the delineated aquifer layers against their transmissivty. It is observed that the transmissivity values is highest in VES2 (>60,000Ωm^2) at a depth of 6.27m, within its fourth layer and followed by VES4 whose transmissivity is also high (>40,000Ωm^2) at a depth of 3.5m within its third layer. Therefore, within the surveyed area the aquifer zones of high productivity lies within the third and fourth layers in VES4 and VES2 at a depth of about 3.5m and 6.27m respectively which lies within and below the water table (about 3.0 ± 0.5m) following the works of Olobaniyi and Owoyemi (2006) were water table was proposed to lie between 0 to 4 metres. The results obtained corresponds with the works of Alile et al., (2008) on underground water exploration in a sedimentary basin.

5. CONCLUSION

1-D electrical resistivity method using the Schlumberger technique carried out at some parts of the Federal University of Petroleum Resources Effurun Delta state have delineated the subsurface lithological setting, depth to prolific aquiferous layers and estimated relevant hydrological parameters that was used to appraise for the productivity of the aquiferous zones. The result shows that the area under study is characterized by a thick and prolific aquiferous zones as observed in the high transverse resistance (transmissivity) values which reflects high productivity of groundwater at depths of about 3.5m and 6.27m along VES4 and VES2 profiles respectively. Also it is recommended that further geophysical studies should be carried out at other locations within the university premises to deduce more prolific zone suitable for groundwater development within the university premises.

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