



ESTIMATION OF AQUIFER TRANSMISSIVITY FOR TYPICAL OIL PRODUCING COMMUNITIES OF WESTERN NIGER DELTA USING ELECTRICAL RESISTIVITY SURVEY

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Abstract

Geophysical electrical resistivity method (Vertical Electrical Sounding) using Schlumberger configuration was employed to investigate subsurface formations and aquifer transmissivity in Agbarotor, Agbarha-Otor and Edoiede Agbarha-Otor in Ughelli North Local Government Area in Delta State, Southern Nigeria with VES evenly carried out in the aforementioned study areas. ABEM Signal averaging system (SAS) 1000 Terrameter, was one of the major equipments used in obtaining the resistivity field data with a maximum current electrodes spreading of 500m done with the aid of a tape. The interpretation of the data gotten from the field was done using WINRESIST software coupled with the qualitative and quantitative curve matching to obtain modelize parameters and curves type for various VES points. The model parameters displayed up to six formations layers which include topsoil, laterite, clay and sand (fine, medium and coarse) formation. The resistivity of the confined aquifer ranges from 1037.6-4986.5 Ω m with thickness varying interval of 16.3m and 42.9m. The investigation denote that VES 1 of Agbarotor, VES 6 for Agbarha-Otor and VES 7,9,10 of Edoiede Agbarha-Otor are the best locations for citing boreholes in the studied areas since they are characterize with higher resistivity (low corrosivity) and moderate or higher transmissivity. Thus aquifer transmissivity in the cited areas are of good quality and the produce can sustain the people of the areas and neighboring environs for long period of time. I recommend that the samples of VES water locations should be tested from time to time to ascertain its Level of contaminations for future remedial measure and a water system for the general public should be drilled in the aforementioned VES points.

Keywords: Schlumberger, Confined aquifer, Electrical conductivity, Corrosivity, Transmissivity, Ughelli North.

Introduction

Drilling of boreholes without adequate geophysical and geochemical data has resulted to adverse threat to human, arboreal, terrestrial and aquatic life. To explore quality water for the teeming population, geophysical method, specifically, the electrical resistivity which has been employed by several notable researchers (Atakpo et al., 2008; Adeoti et al., 2012; Okolie and Akpoyibo, 2012;

Anomohanran, 2013; Ohwoghere-Asuma et al., 2017; Akpoyibo et al., 2022) due to its low cost in data acquisition was used to determine the aquifer transmissivity, as well as other properties in parts of Ughelli North Local Government Area in Delta State, Southern Nigeria, to predict locations where boreholes could be sited devoid of contaminations.

The electrical resistivity method provides

information on the electrical conductivity of the subsurface formations in relation to groundwater potential. It is also suitable for the investigation of saltwater intrusion within the coastal environments (Egbai and Asokhia, 1998). The vertical electrical sounding technique was used for this investigation as it probes deeper through the subsurface emphasizing its effectiveness in the assessment of groundwater resources (Okiongbo et al., 2011) compared to other techniques (Olurunfemi, 1985; Zohdy and Martin, 1993; Egbai 2011a; Anomohanran, 2014; Atakpo et al., 2008). Vertical electrical sounding for identical layers indicates that current penetration depth increases as current electrodes increases (Adeoti et al., 2012). Drilling operations have been done in several places in Ughelli North local Government areas of Delta State without the applications of geophysical methods using the first hand or available information from the State Water Board. The three communities namely: Agbarotor, Agbarha-Otor and Edoiede Agbarha-Otor, investigated for Aquifer transmissivity in this work have recorded rapid increase in population due to Private University recently established in the area and their proximity to Ughelli; a crude oil producing metropolitan city. As such, there will be high demand for potable water in the areas for household, farming and industrial uses. Thus, the need to carry out adequate geophysical survey to provide useful information will aid the siting of boreholes that will access quality groundwater to cater for the growing population.

Renowned authors have studied extensively the relationship that connects electrical parameters with aquifer properties of formation layers (Niwas and Singhai, 1981; Onuoha and Mbazi, 1988; Egbai and Isierhien-Emekeme, 2015; Ohwohere-Asuma and Esi, 2017), subsequently, establishing that aquifer transmissivity is

computed from key aquifer properties such as longitudinal conductance, transverse resistance, hydraulic conductivity etc derived from the combination of aquifer characteristics (properties). The transmissivity of an aquifer is computed as the product of its thickness and hydraulic conductivity of its layer pore grain space (Egbai, 2013). Hence, quality and fertile (productive) aquifers are obtained with higher values of transmissivity of the aquifer bearing zone (Egbai, 2013).

Niwas and Singhal, (1981) applied the vertical electrical sounding in evaluating aquifer transmissivity using Dar Zarrouk parameters in determining variation in water quality and quantity. Anomohanran (2013) also employed electrical resistivity method to investigate subsurface water potential in Ukelegbe Southern Nigeria and recommended suitable locations for drilling boreholes in the area. Egbai (2011b) also utilizes the vertical electrical sounding to calculate aquifer transmissivity by employing Dar Zarrouk parameters to determine zones of corrosive in Agbor and its environs. Since the importance of groundwater cannot be overemphasized, it is essential to ensure appropriate exploration, exploitation, estimation, monitoring and proper management. To ensure constant availability of quality water, hydrogeologic parameters such as aquifer resistivity, aquifer thickness, aquifer transmissivity, transverse resistance, longitudinal conductance, and hydraulic conductivity of the aquifer zones underlying the study areas were evaluated for quality and high groundwater yield.

This research work was conducted to determine the quality of groundwater underlying Agbarotor, Agbarha-Otor and Edoiede Agbaraha-Otor within Ughelli North Local Government Area in Delta State, Southern Nigeria, taking into consideration its corrosivity and degree of salinity. Thus, this work is aimed at using the vertical electrical sounding technique to delineate

possible contamination-free locations for borehole drilling with possibility of high groundwater yield. Further work in this study areas and environs are traceable to: (Egbai, 2013; Atakpo and Ofomola, 2012; Ofomola et al., 2017).

Location, geological and hydrogeological setting of the study area

The study area is located in Ughelli North local government area of Delta State, Southern Nigeria, within longitudes 6.0864°E to 6.2708°E and latitudes 5.5872°N and 5.7464°N (Figure 1). It is situated in the Niger Delta area characterized with excess crude oil. Agbarotor, Agbarha-Otor and Edoiede Agbarha Otor lie in Niger Delta region of Nigeria with three formation sequence, the Benin, Agbada, and Akata formations. The Benin formation extends through the coastal plain sand which appears on the

surface of Benin and Onitsha varying from 0 to 2100 m thickness (Ofomola et al., 2022). The sandstone and sand differ from fine to coarse, partially consolidated, and nearly granular in texture and with high water bearing capacity. The Agbada formation lies underneath the Benin formation and comprises primarily of sandstone and siltstones (Short and Stauble, 1967). The thickness is about the range of 3001 m to 5001 m. The marine shale and sand beds are components of the Akata formation. The area under investigation unveils flat seaward slopping characteristics and unnoticeable Sombreiro-Warri Deltaic plain (Short and Stauble, 1967, Ofomola et al., 2017) which outline on the top of the Benin Formation. The prolific aquiferous layer of the fresh water source is accessible in the modern Niger Delta and is founded on the Benin formation (Short and Stauble, 1967; Ofomola et al., 2022).

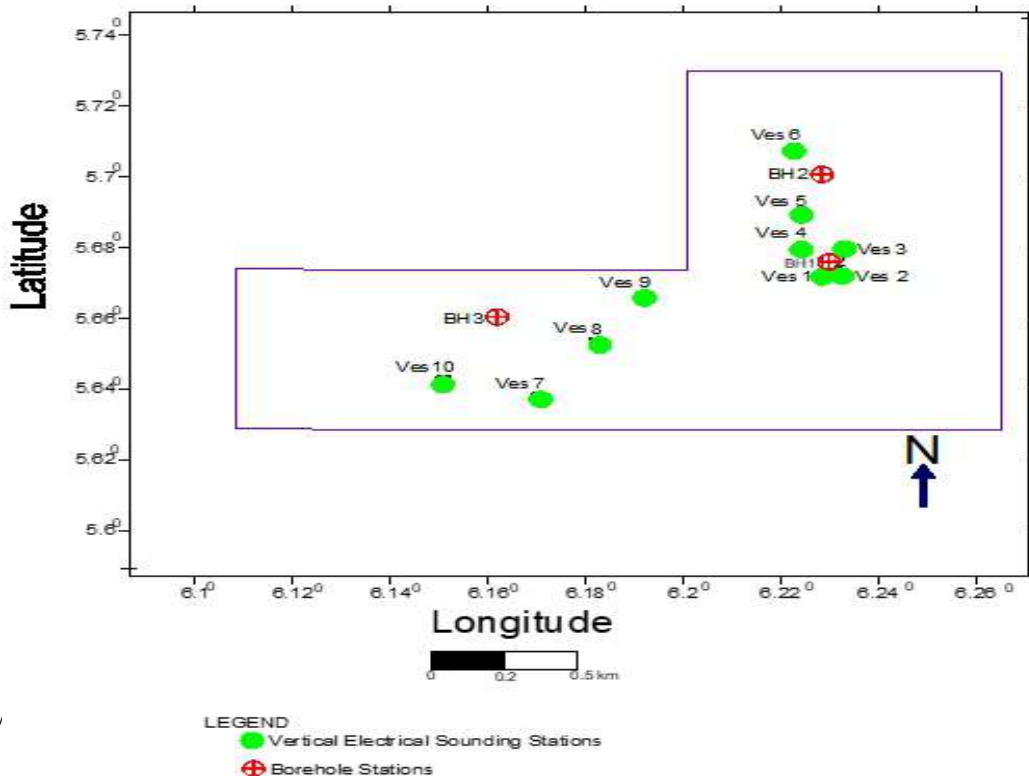


FIG 1: M

Figure 1: Data Acquisition Map of the Studied Areas showing Vertical Electrical Sounding and well logging stations

Materials and Method

The ABEM Terrameter (SAS 1000) equipment was used for data acquisition. The Vertical Electrical Sounding (VES) measurements were carried out using Schlumberger electrodes configuration to determine variations in the ground resistivity with depth. These measurements were accomplished by expanding the inter-electrode spacing about a fixed center of array. A total of ten VES points were surveyed with three VES measurements each taken at Agbarotor and Agbarha-Otor while four were carried out within Edoiede Agbarha-Otor all in Ughelli North LGA of Delta state. Each sounding involved stepwise expansion of half current electrode separation (AB/2) from minimum of 1 m to maximum of 250 m depending on the space available for the spreads.

The VES data acquired were plotted on bi-logarithmic sheet with AB/2 on the x-axis and apparent resistivity ρ_a values computed for each sampling point using equation (1) on the y-axis.

$$\rho_a = \frac{\pi V}{4 I} \left(\frac{L^2 - a^2}{a} \right) \quad (1)$$

The initial layer models, number of layers and its associated apparent resistivity curve types, and initial or starting layer parameters, resistivity and thickness, were obtained employing traditional curve matching technique involving a comparison and matching of the computed ρ_a curves with a set of theoretically calculated master curves (Orellana and Mooney, 1966).

The initial layer parameters obtained were then subjected to computer iteration technique using winResist version 1.0

(Vander-Velpen, 1988) to obtain subsurface final layer parameters as presented in Table 1. The depth and resistivity values obtained were used to produce the lithologic sections of the study areas, while the resistivity values were also used to identify the aquifers (Dodds and Ivic, 1998, Lashkaripour, 2003 and Deming, 2002).

Aquifer transmissivity values were further calculated for each VES points to describe the characteristics of the groundwater aquifer underlying the areas. According to Niwas and Singhai (1981), the relationship between longitudinal conductance and aquifer transmissivity is as stated below.

$$Tr = \frac{KS}{\delta} \quad (2)$$

Where Tr is the Aquifer transmissivity, K is the hydraulic conductivity, S is the longitudinal conductance and δ , the electrical conductivity.

Hydraulic conductivity (K) measured in feet per day, can be mathematically expressed as the transmissivity (Tr) of a confined aquifer divided by the corresponding aquifer thickness as stated below.

$$K = Tr/h \text{ (Egbai, 2011b)} \quad (3)$$

According to Ministry of Work and Transport (1974), the mean hydraulic conductivity for the boreholes drilled in the three communities was calculated 10m/day. Following the application of traditional curve matching and computer iteration techniques, the vertical electrical sounding data were presented as curves (Figure 2-11). Table 1 shows the obtained layer parameters and different curve types, while Table 2 emphasizes on the characteristics of each aquifer unit within the study areas.

Table 1: Showing the results of the layer parameters and various curve types obtained from the study areas

VES Number	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve Type
1	1	829.2	0.5	0.5	Topsoil	AKQ
	2	2770.0	22.8	23.4	Fine sand	
	3	2956.5	21.8	45.1	Fine sand	
	4	1037.6	29.4	74.5	Medium-coarse grain	
	5	247.0	-----	-----	Medium-coarse grain	
2	1	42.6	5.4	5.4	Topsoil	QHA
	2	11.5	5.0	10.4	Lateritic clay	
	3	1.2	32.7	43.1	Clay	
	4	23.3	31.4	74.5	Clay	
	5	91.3	-----	-----	Fine sand	
3	1	2358.8	0.2	0.2	Topsoil	KQQ
	2	3060.8	33.4	33.6	Fine sand	
	3	286.6	23.4	57.1	Fine sand	
	4	204.3	28.2	85.3	Medium-coarse grain	
	5	76.7	-----	-----	Clay	
4	1	168.7	1.3	1.3	Topsoil	QHA
	2	18.6	4.5	5.8	Lateritic clay	
	3	7.0	18.1	23.9	Clay	
	4	100.7	25.8	49.7	Fine sand	
	5	104.9	-----	-----	Medium-coarse grain	
5	1	1715.0	0.7	0.7	Topsoil	KQH
	2	2544.0	43.7	48.0	Fine sand	
	3	1196.6	16.3	64.3	Fine sand	
	4	384.5	15.7	80.0	Medium-coarse grain	
	5	859.0	-----	-----	Medium-coarse grain	
6	1	2207.0	1.1	1.1	Topsoil	AKH
	2	2315.7	13.9	15.0	Laterite	
	3	5587.1	32.6	47.7	Fine sand	
	4	1726.6	13.3	61.0	Fine sand	
	5	4815.1	---	---	Medium-coarse grain	
7	1	485.8	1.5	1.5	Topsoil	HKQ
	2	403.9	12.0	13.5	Laterite	
	3	2305.3	39.1	52.6	Fine sand	
	4	545.3	10.1	62.8	Fine sand	
	5	273.4	5.8	68.5	Medium-coarse grain	
	6	1864.6	-----	-----	Medium-coarse grain	
8	1	440.5	2.8	2.8	Topsoil	KHAA
	2	1011.7	15.3	18.1	Laterite	
	3	628.3	12.4	30.5	Medium-coarse grain	
	4	881.2	12.1	42.6	Medium-coarse grain	
	5	973.3	15.4	58.0	Fine sand	
	6	2480.7	-----	-----	Fine sand	

9	1	1280.3	0.7	0.7	Topsoil	HKQQ
	2	408.7	2.9	3.6	Laterite	
	3	4986.5	42.9	46.5	Fine sand	
	4	308.6	41.7	88.2	Medium -coarse grain	
	5	80.6	17.6	105.9	Sandy clay	
	6	34.5	----	----	Clay	
10	1	207.8	1.3	1.3	Topsoil	AKQ
	2	876.1	11.6	12.9	Laterite	
	3	3126.3	37.3	50.1	Fine sand	
	4	585.2	33.5	83.6	Medium -coarse grain	
	5	249.8	----	----	Medium -coarse grain	

Results and Discussion

Electrical soundings

The field data were subjected to interpretation by curve matching and the produce data that undergo qualitative interpretation using computer iteration was utilized as input parameter. The field curves were the outcomes of the iteration depicting the relationship between the half current electrode and the apparent resistivity (inverse conductivity). The curves gotten in this investigation are unveils in fig 2-11. The lithologic logs (borehole logs) were used in correlating the vertical electrical soundings results to show the subsurface layers.

Six different geologic layers were delineated from top to bottom namely top soil, laterite soil, sandy clay/clayey sand, fine sand, medium grained sand and coarse sand. The geoelectric section show distinct layers with top soil in Agbarotor with resistivity value estimate ranging from 42.6 to 2358.8 Ω m with thickness changing from 0.2m to 5.4m. The top soil for Agbarha-Otor has thickness ranging between 0.7m and 1.3m with its resistivity values varying from 168.7 to 2207.0 Ω m. Edoiede-Agbarha-Otor also have topsoil values ranging from 0.7m to 2.8m and resistivity values varying from 207.8 Ω m to 1280.3 Ω m.

The second and third layers of Agbarotor

constituents are fine sand and clay formations (Lateritic clay and clay). The fine sand has a resistivity and thickness values varying from 286.6 - 3060.8 Ω m and 21.8 – 33.4 m respectively. The clay formation values for both resistivity and thickness for these layers range is between (1.2 and 11.5 Ω m) and (5.0, 32.7) m respectively. The second and third layers for Agbarha-Otor have laterite, clay and fine sand formation. The laterite has a numerical resistivity of 2315.7 Ω m and a thickness of 13.9m, the lateritic clay and clay has resistivity of 7.0 and 18.6 Ω m with thickness of 18.1 and 4.5 m while the fine sand constitute a resistivity values which vary from 1196.6-5587.1 Ω m with thickness ranges of 16.3-47.3m. Edoiede Agbarha Otor has laterite and sand formation (fine and medium sand) for second and third layers. The laterite delineates a resistivity values that ranges within 403.9 and 1011.7 Ω m and a thickness values within 2.9- 15.3m. The resistivities of fine sand, medium-coarse grain sand values ranging from 628.3 Ω m to 4986.5 Ω m and thickness from 12.4m to 42.9m. (Fig.15 and 16).

Clay, fine sand and medium to coarse sand constitute the fourth and fifth distinct layers for Agbarotor. Both layers are the aquiferous units (unconfined and confined Aquifer). Clay of these layers has a resistivity of 23.3 and 76.7 Ω m with thickness of 31.4m in VES 2

and infinite value in VES 3. Fine and medium-coarse sand has resistivity values which range between 91.3 Ωm and 1037.6 Ωm with thickness of 28.2 m and 31.4 m. The fourth and fifth layers for Agbarha-Otor are fine and medium to coarse sand formation with resistivity values ranging from 100.7 Ωm to 4815.1 Ωm with thickness varying from 13.3 m to 25.8 m. Edoiede Agbarha-Otor have both sand and clay formation in the Fourth, fifth and sixth layers. The clay formation has a resistivity value of 34.5 Ωm and 80.6 Ωm with thickness of 17.6m composition of sandy clay and infinite value of clay in the last layer. Fine and medium-coarse sand values ranges from 308.6 Ωm to 2480.7 Ωm with thickness between 5.8 m to 33.5 m. The fifth and sixth layers contain quality water (prolific Aquifer) for the studied areas. Aquifer of Vertical Electrical Sounding (VES) 1 only has the highest resistivity of 1037.6 Ωm in Agbarotor indicating low corrosivity

(little or no contamination) with transmissivity of 294 m^2/day (Fig 12).

VES 2 and 3 in Agbarotor have low resistivities of 91.3 Ωm and 204.3 Ωm with low transmissivity indicating high contamination of Aquifer (high corrosivity) which denotes that water from these sounded areas required high priority attentions for remedial measures (high water treatment) to obtain good water quality in those contaminated areas before consumption.

Despite the aquifer thickness, the best area for borehole drilling in Agbarha-Otor is VES 6 with high resistivity of 1726.6 Ωm and transmissivity of 133 m^2/day (Fig. 12 and Table 2). All sounded areas with high resistivity and high transmissivity are cited for boreholes drilling due to low corrosivity and low salinity which indicates that aquifer is not polluted (Egbai, 2013). Thus, increasing conductivity indicates increasing aquifer pollution (contamination).

Table 2: Showing the Characteristics of the aquifer units underlying the study areas

VES Point	Latitude Degree	Longitude Degree	Elevation M	Resistivity Ωm	Thickness m	Depth M	Conductivity (Ωm) ⁻¹	Longitudinal Conductance S	Transmissivity Tr
AGBAROTOR									
1	5.6656	6.2617	47.05	1037.6	29.4	74.5	0.000964	0.0283	294
2	5.6653	6.2708	47.1	91.3	----	80	0.010000	-----	----
3	5.6689	6.2692	47.2	204.3	28.2	85.3	0.004895	0.13804	282
AGBARHA-OTOR									
4	5.6836	6.2519	38.1	100.7	25.8	49.7	0.009930	0.2562	258
5	5.7047	6.2522	47.9	1196.6	16.3	64.3	0.000836	0.01363	163
6	5.7464	6.2494	38.6	1726.6	13.3	61.0	0.000579	0.00701	133
EDOIEDE-AGBARHA OTOR									
7	5.5872	6.1308	36	2305.3	39.1	52.6	0.000434	0.01697	391
8	5.6225	6.1580	37	973.3	15.4	58.0	0.001030	0.015862	154
9	5.6519	6.1806	45.1	4986.5	42.9	46.5	0.000201	0.008623	429
10	5.5978	6.0864	56.7	3126.3	37.3	50.1	0.000320	0.011936	373

VES 9 and 10 are best cited for boreholes drilling at Edoiede Agbarha-Otor with high resistivities of 4986.5 Ωm and 3126.3 Ωm with Aquifer transmissivity of 429 m^2/day and 373 m^2/day respectively (Fig. 12 and Fig. 14). High resistivities values in

contaminated areas also denote that only shallow water (Perched aquifer) has been polluted in the study areas (Uchegbulam and Ayolabi, 2014). The resistivity method is useful in determining areas that are prone to groundwater pollution. Recent (shallow)

pollution can also show high resistivity value while matured (ageing) pollution indicates a lower resistivity value than fresh

pollution (Sauck, 2000; Uchegbulam and Ayolabi, 2014).

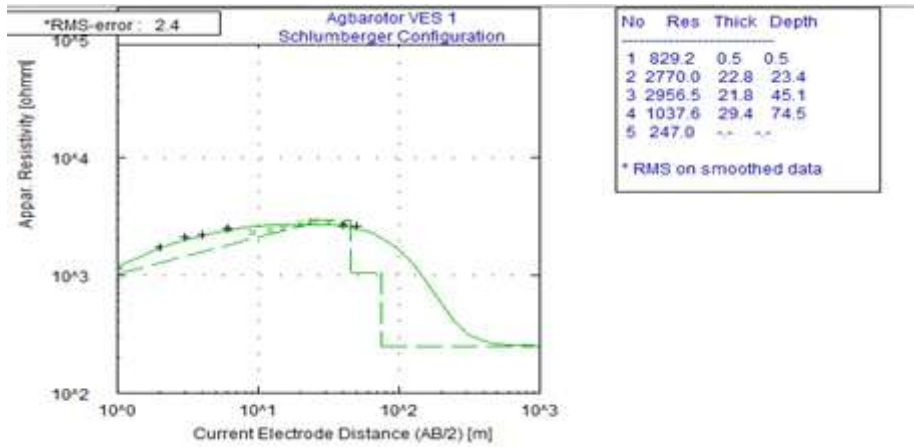


Figure 2: Vertical Electrical Sounding Curve for Agbarotor VES 1

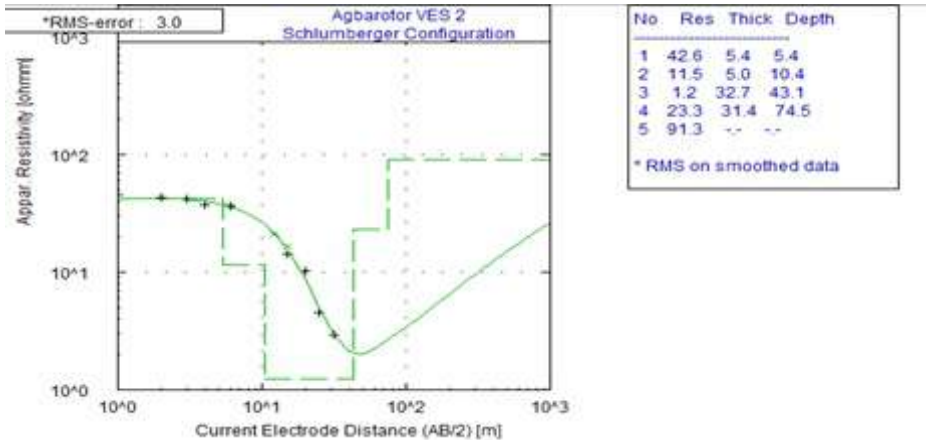


Figure 3: Vertical Electrical Sounding Curve for Agbarotor VES 2

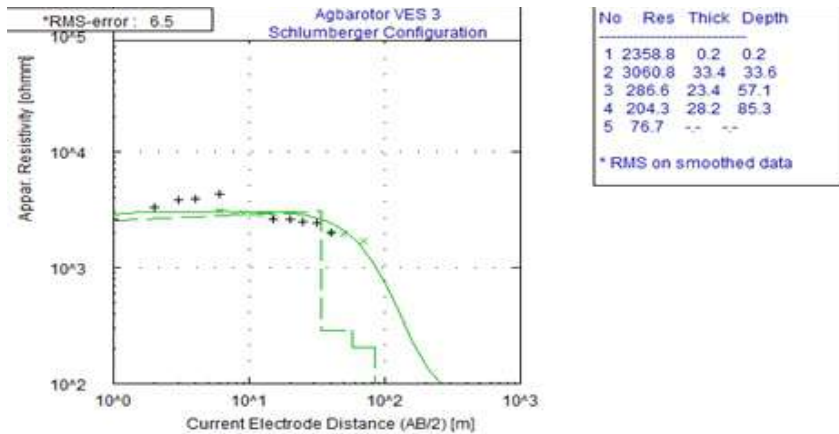


Figure 4: Vertical Electrical Sounding Curve for Agbarotor VES 3

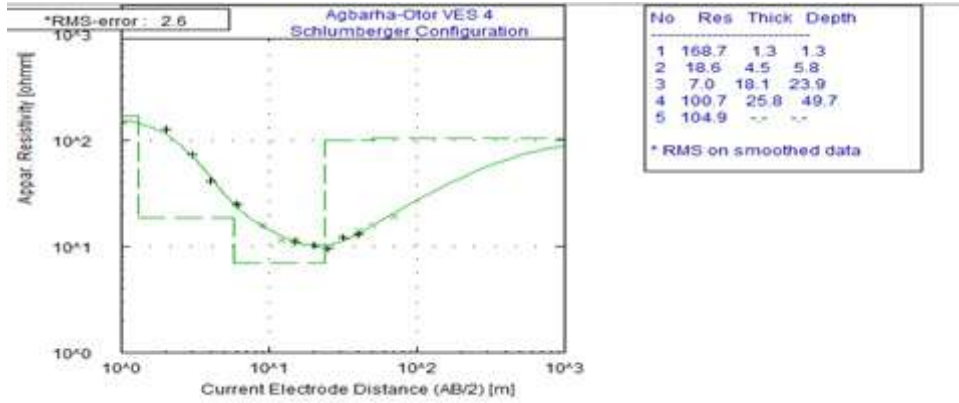


Figure 5: Vertical Electrical Sounding Curve for Agbarha-Otor VES 4

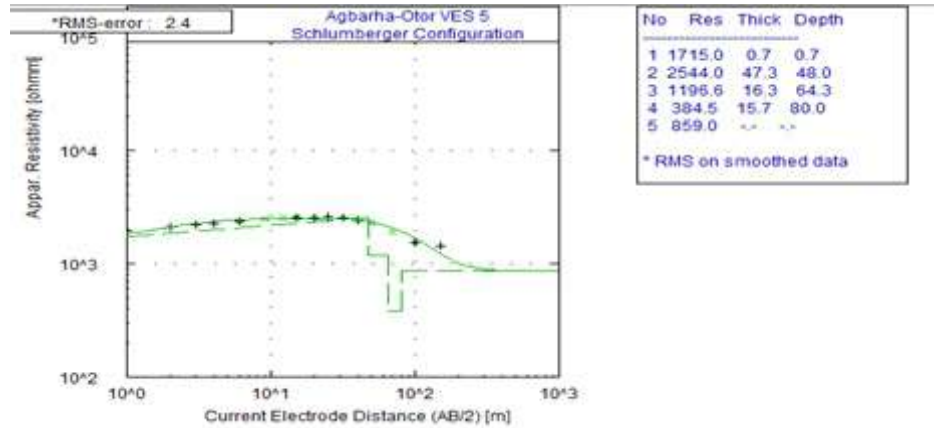


Figure 6: Vertical Electrical Sounding Curve for Agbarha-Otor VES 5

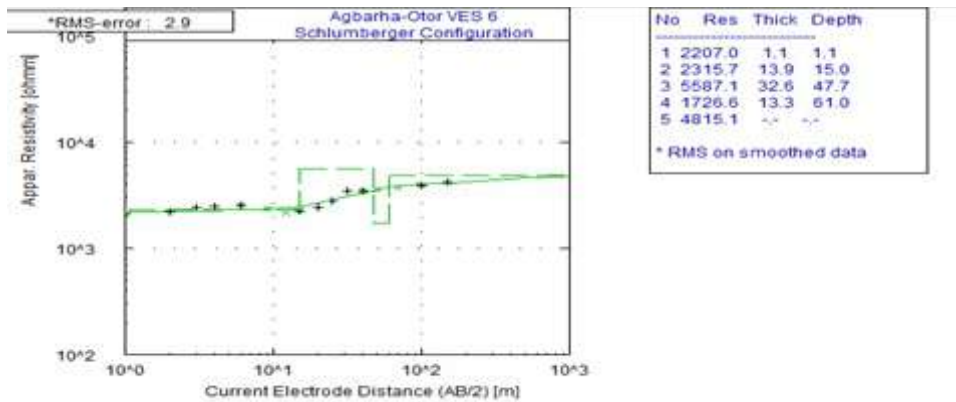


Figure 7: Vertical Electrical Sounding Curve for Agbarha-Otor VES 6

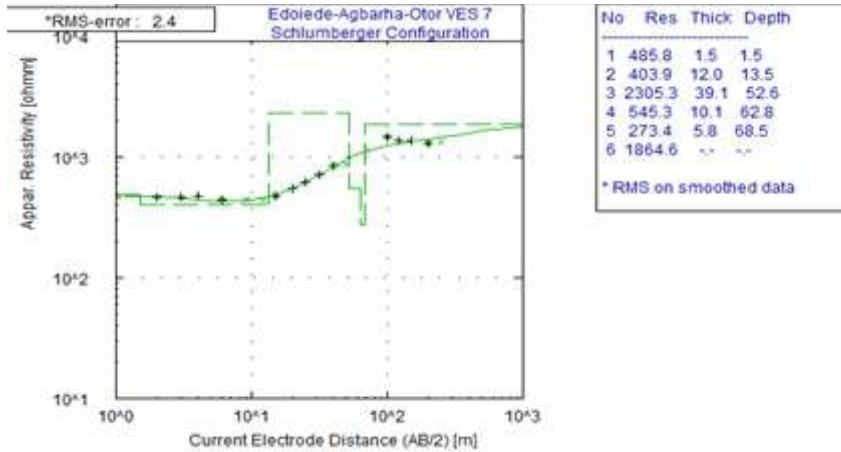


Figure 8: Vertical Electrical Sounding Curve for Edoiede Agbarha-Otor VES 7

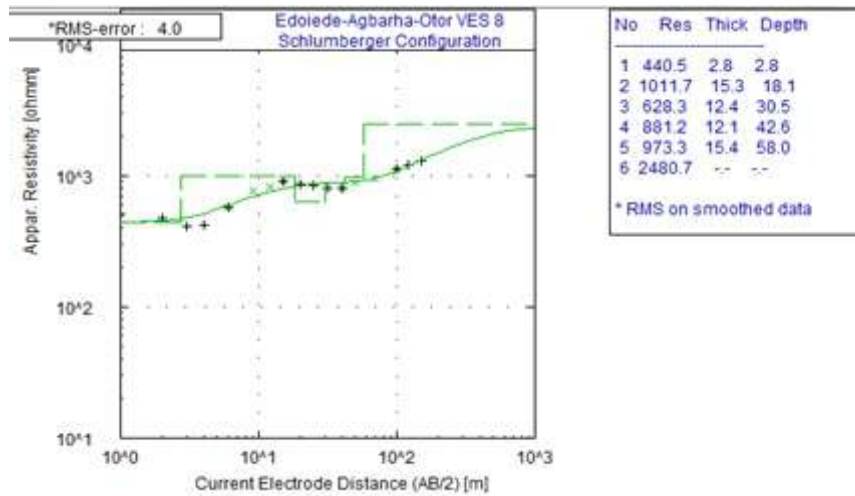


Figure 9: Vertical Electrical Sounding Curve for Edoiede Agbarha-Otor VES 8

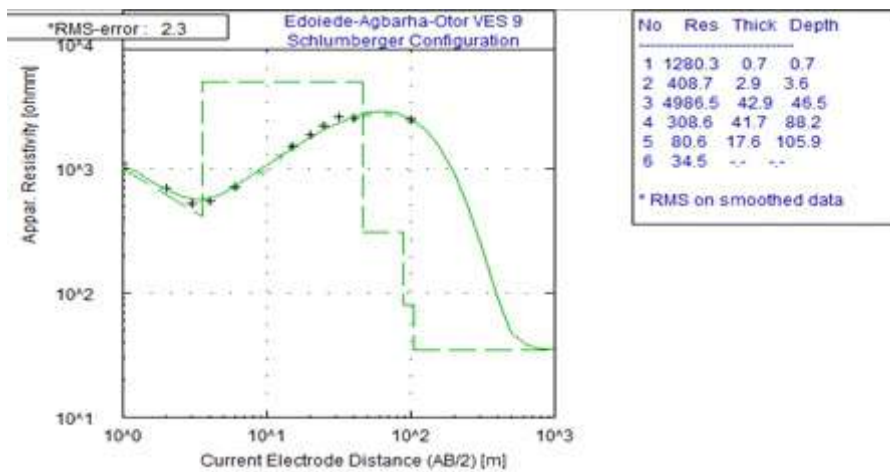


Figure 10: Vertical Electrical Sounding Curve for Edoiede Agbarha-Otor VES 9

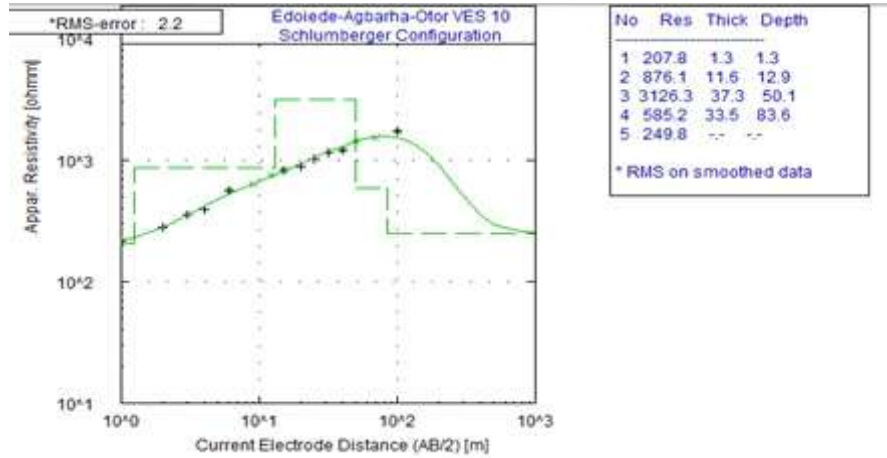


Figure 11: Vertical Electrical Sounding Curve for Edoiede Agbarha-Otor VES 10

Figure 12, 13 and 14 show the contour map for transmissivity for aquifer layer, aquifer depth and resistivity of aquifer in the study areas. The various contour maps will be very useful in locating the best sites in the studied areas to drill boreholes and the depth to get a quality and reliable aquifer. The aquifer depth map shown in figure 13 represents the prospective prolific groundwater zone depth. The depth to the aquifer via the surface varied from 46 to 88 m. This map is useful and evident in identifying the proper depth to wellspring of ground water in the area. The aquifer depth map reveals that the depth to aquifer

increases towards the west-eastern direction of the survey area. The aquifer transmissivity map indicates that it is higher at the central part and lower in other portions of the study area. Hence, the central part is more productive and vulnerable for groundwater exploration and exploitation. Thus, the central part is most suitable for setting public water system for the people in the area. Quality water can be continuously obtained when wastes are deposited in a well design and recommended areas for waste landfill to avoid aquifer contamination in the various communities.

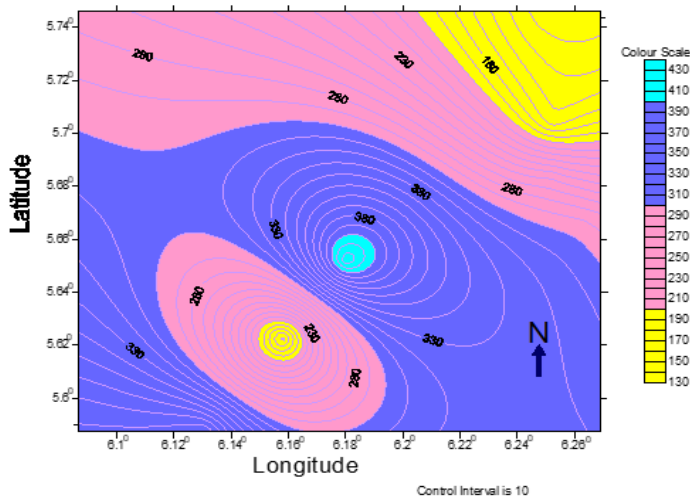


Figure 12: Contour Map of Transmissivity of the aquifer layer in the study areas

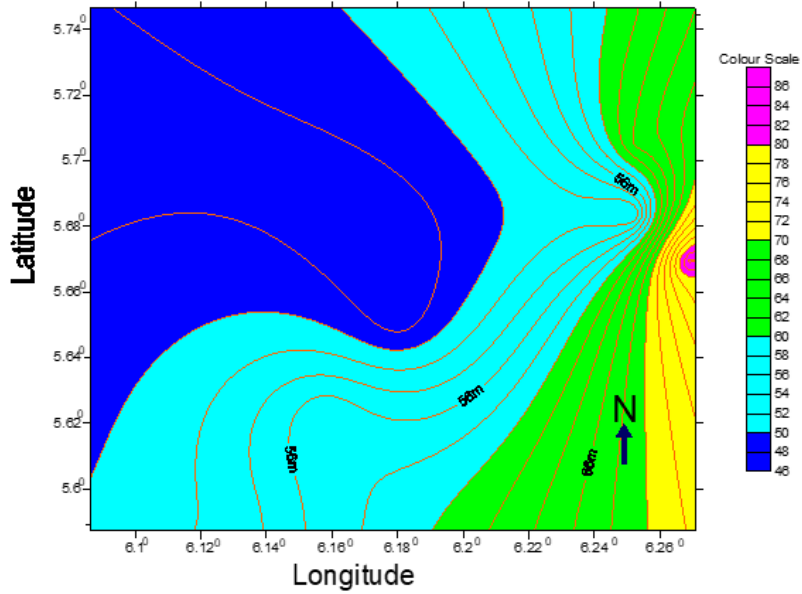


Figure 13: Contour Depth Map of Aquifer layer of the studied areas

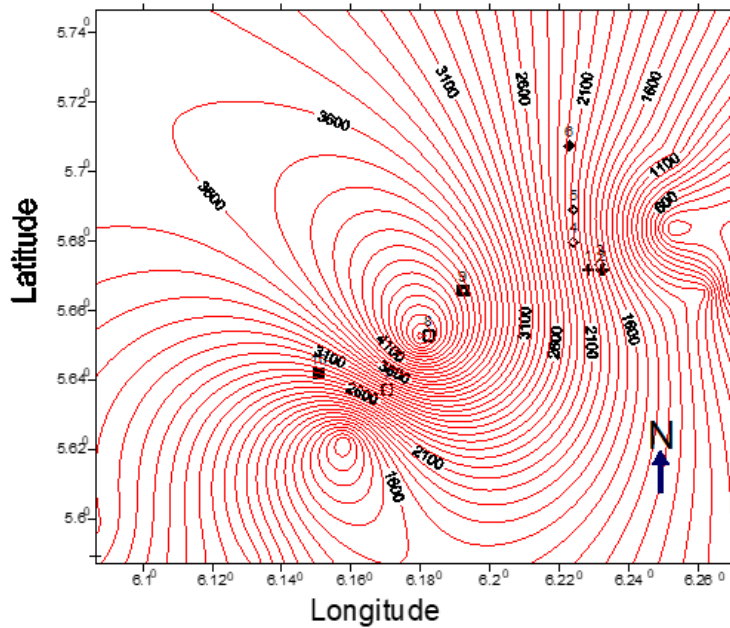


Figure 14: Contour Resistivity Map of Aquifer Layer of the study areas

Lithology logs and geoelectric sections

The lithologic logs of the drilled boreholes were correlated with the Sounding results to create the geoelectric sections of the study areas as shown in Figure 15 and 16. The

boreholes were drilled to a depth of 75 m with various subsurface formations ranging from topsoil to coarse sand which corroborate the electrical sounding results that produces the designed geoelectric sections.

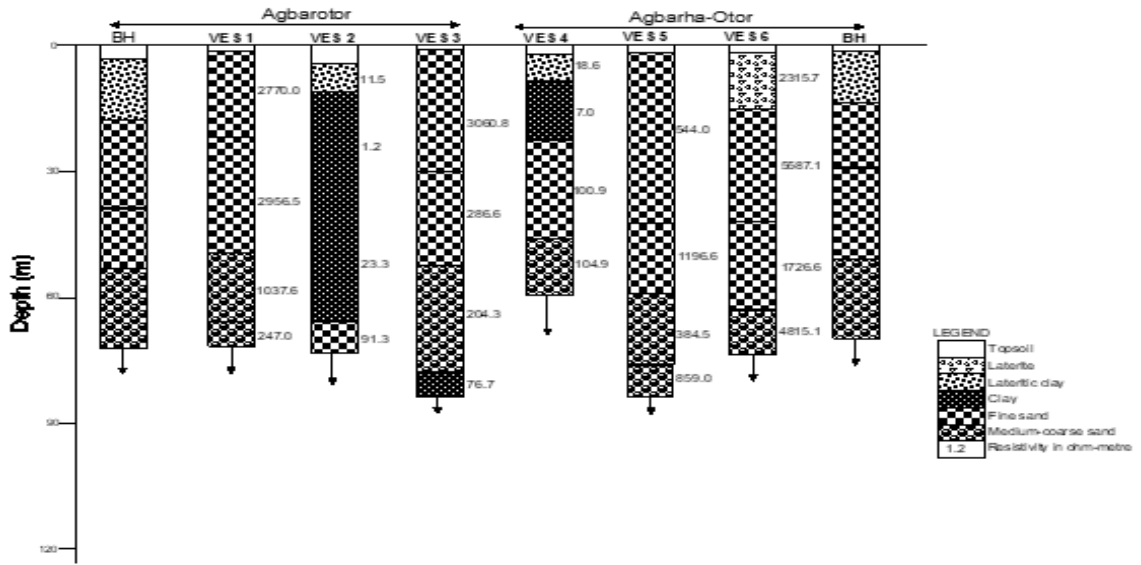


Figure 15: Geoelectric section of Agbarotor and Agbarha-Otor

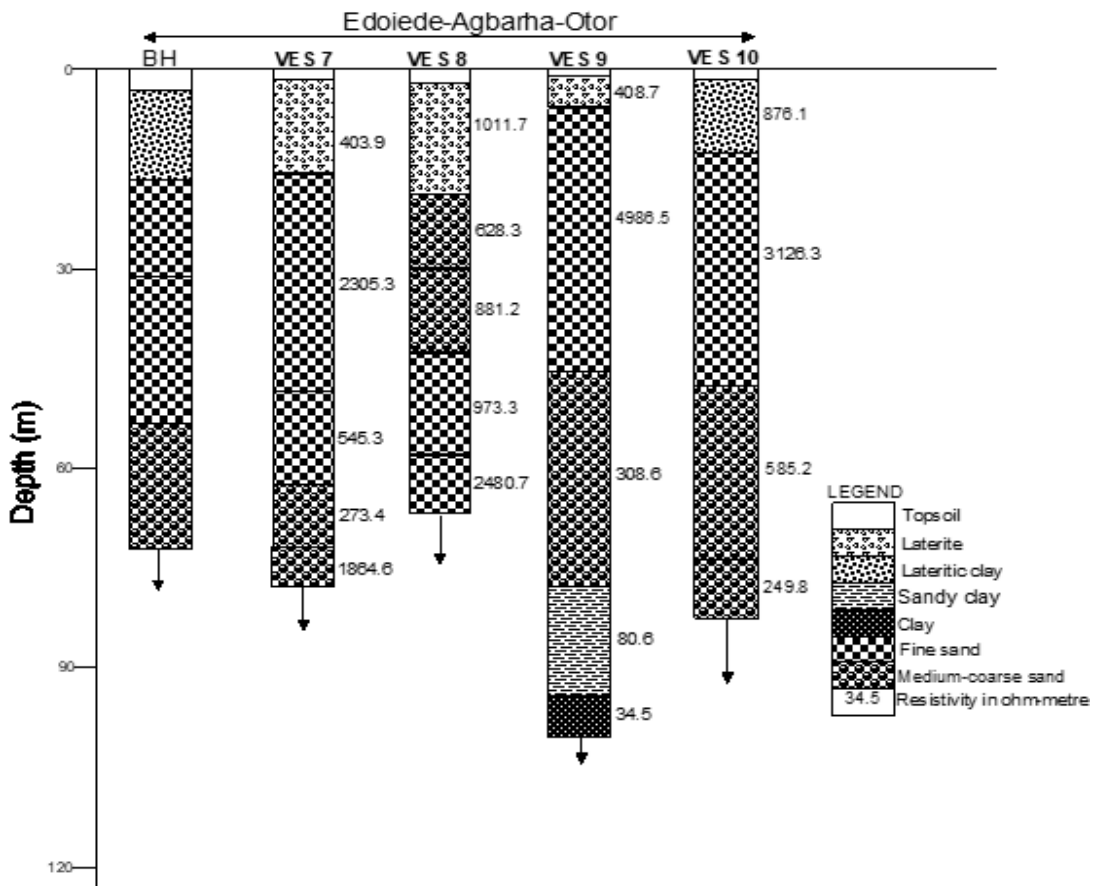


Figure 16: Geoelectric section for Edoiede-Agbarha-Otor

Conclusion

Resistivity method and well logging data were used in investigating Aquifer behaviour in the study areas. The results of the formations of Agbarotor, Agbarha-Otor and Edoiede Agbarha-Otor show six distinct layers with different lithology. The three locations have perched and unconfined aquifer in the third, fourth and fifth layers (fine, medium and coarse sand). The resistivity survey method shows that the depth and the resistivity of the various Aquifers of the studied areas lie between 46.5-85.3 metres and 91.3-4986.5 ohm-metres respectively. The results show that aquifer transmissivity is of acceptable quality in VES 1,6,7,9 and 10 in respective study areas and could transmit significant quantity of water for areas under study. The study shows that VES 1 is the best VES location for citing boreholes in Agbarotor, VES 6 for Agbarha-Otor and VES 7, 9, 10 as the best site locations for Edoiede Agbarha-Otor. They are the best locations due to the fact that they have higher resistivity which denote lower corrosivity and also higher transmissivity since the thickness capacity is high (Fig 5). I strongly recommend that remedial measure of purified water scheme should be cited in areas with lower resistivity. The water board scheme when cited in the areas will provide job for fraction of people in the areas which will serve as a means of livelihood and the water scheme will provide treated water for people within and outside the areas that required remedial measure.

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