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DETERMINATION OF GROUNDWATER POTENTIAL USING ELECTRICAL RESISTIVITY SURVEY AND BOREHOLE LOGGING IN SITES I AND III OF DELTA STATE UNIVERSITY, ABRAKA NIGERIA

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Abstract

This study examines the aquifer properties and lithological structure of Abraka, Nigeria, specifically the Delta State University Site I and III environs. Ten Schlumberger geoelectric soundings, geophysical well logging and pumping test method were employed using an ABEM Terrameter. A drilled water well and existing borehole data were used for this study. The result of the lithological study revealed that the subsurface formations consist of topsoil, lateritic sand, fine and medium grain sand mixed with clay. The topsoil is brownish with thickness of 2 m, the laterite is reddish with thickness of 4 m, the fine sand is whitish with thickness of 10 m, and the medium sand is also whitish with thickness >12 m. The results of the evaluation of the geoelectric data using curve matching and Win Resist computer iteration was in strong agreement with that of the well record, with a subsurface that is composed of 4 to 6 geo-electric layers. The depth ranges from 13.5m to 97.8m while the resistivity ranges from 1021.2 Ωm to 9092.4 Ωm. A core soil sample collected at an interval of 5m, spontaneous potential and resistivity logs were carried out on the well. The hydraulic conductivity, well's transmissivity, storativity, and specific capacity are 102.7m^2/day, 5.14 m/day, 0.00062 and 0.39 m^3/m respectively. It is recommended that a drill depth of 30 m and above should be accessed for potable water in the area. From the result of this survey, we infer that this aquifer is confined and capable of supplying the people with adequate and good quality drinking water.

Keywords: *Geoelectrical method, Pumping test method, spontaneous potential, hydraulic conductivity, transmissivity, specific capacity*

INTRODUCTION

Population growth, industrialization, and agricultural development all contribute to a high global demand for potable water, making it difficult for people to access safe drinking water. In coastal regions, groundwater generally serves as the primary source of freshwater both for domestic use and industry. Nevertheless, access to freshwater is very difficult in most developing nations, and many people lack access to potable water. Jimoh *et al*., (2018). Groundwater is described as the water found beneath the surface of the earth in underground streams and aquifers. Anomohanran, (2011). The majority of the groundwater comes from rainwater that infiltrates into the earth. According to observations, a large part of excess rainfall runs-off over the surface of the ground, while the remainder infiltrates underground and becomes the groundwater that feeds the springs, lakes, and wells Oseji *et al.*,(2006). In general, groundwater is found in the pores of rocks and sediments, and can be collected in wells, tunnels, drainage galleries, or it can flow naturally to the surface in the form of seeps or springs. Salding and Exner, (1993). As compared to surface water, groundwater moves very slowly. Consequently, any contaminants entering groundwater are flushed away very slowly Oseji, (2010). Aquifers are the source of groundwater, which can store and discharge a large amount of water due to their permeability and porosity. The unconsolidated, thick, medium to fine-grained nature of the sand contributes to the hydraulic properties of the aquifer Arshad, *et al.*, (2007).

Groundwater exploration is most commonly carried out by using electrical resistivity method of geophysical exploration. VES (vertical electrical sounding) is a geoelectrical technique for detecting vertical changes in electrical resistance. The method has been recognized to be more suitable for detailed hydrogeological study of sedimentary basin. Iserhien-Emekeme, *et al.*, (2004); Alabi, *et al.*, (2010). In fact, many researchers have used this method for aquifer boundary determination. There are several reasons for a wide spread use of this instrument, including its simplicity; the instrument is straightforward and easy to use, while the analysis of the data is less tedious and less costly. Such researchers as Egbai, (2011), Anomohanran, (2013), Olowofela *et al.*, (2005), Oseji *et al.*, (2005, 2006), Iserhien-Emekeme *et al.*, (2004), Okolie *et al.*, (2005), Omosuyi *et al.*, (2007), Batayneh (2009), Ezeh & Ugwu (2010), Nwankwo (2011).The most common applications of the geophysical logging technique are to explore the lithological features of a given area and to assess the quality of groundwater. Saluja & Niwas, (2007); Anomohanran, (2013b). Because they provide information on the lithology the borehole crossed and the resistivity of the subsurface formations, electrical resistivity logs have been frequently employed in geophysical logging of water boreholes. Spontaneous potential (SP) and resistivity logs are included in the category of electrical logs. The resistivity log is generally used to identify lithology and correlate stratigraphy while the spontaneous potential log is used to ascertain the quality of the water. Electrical logs are useful tool for evaluating subsurface conditions, and the results are consistent, even if the field approaches are nondestructive. Saluja and Niwas, (2007); Kamble et al., (2012).

An in-depth understanding of an aquifer's hydraulic features is vital for maximizing the use of the groundwater resource Ataie-Ashtiani et al., (1999). Pumping tests are useful for identifying these characteristics. The test is used to estimate the ability of the well to provide the needed quantity of water to the people. Aquifer properties which are usually estimated by pumping test include transmissivity, specific coefficient, specific yield, specific capacity and hydraulic conductivity. Anomohanran, (2014b); Todd, (2004). Other parameters associated with electric well logging are resistivity of mud filtrate (Rmf) and water resistivity (Rw). This paper is aimed at Integrating well-log-based estimates of water resistivity (Rw) into resistivity interpretation of surface-based soundings to help determine the nature and quality of the aquifer in the University environment and Abraka community in general and its ability to provide sufficient quantity of water for the students and occupiers of the area while maintaining cost-effective exploration and also determining groundwater flow direction by combining field data from both sites of the University. In general, This study combines, compare and contrast between resistivity survey method and borehole logs in delineating formations and aquifer zones in the subsurface of the study area; hence, it will guard and eliminate all uncertainty for a cased well during drilling for water exploitation, provide subsurface

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lithology information, nature of aquifer present and estimate an in-situ water quality at the production zone and groundwater flow direction that help in the management and monitory of groundwater resource of the research field.The research is accessed through Eku-Obiaruku road and Agbor-Eku road on the Benin formation with aquifer system of fine sand, medium sand and coarse sand; however the in-situ geology shows the medium sand serves as the primary aquifer unit in the study area. Abraka is an agricultural area and now it has been developed. It was suggested that a research on geophysics analysis using the electrical resistivity method can be conducted at this area. The area is characterized by moderate vegetation cover, resulting in variances in groundwater occurrences. As a result, geophysical data must be linked with logging data.

MATERIALS AND METHOD

This study was carried out in Delta State University Sites (III) and (I) premises, Abraka, situated in the Niger Delta area of Nigeria (Figure 1). It is located within longitude 6.08° and 6.12° North and latitude 5.77° and 5.82° East. As discussed by Short and Stauble (1967). The lithology of the Niger Delta is separated into three formations, each of which is differentiated by its sand and shale content. Benin, Agbada, and Akata are three stratigraphic formations. Avbovbo, (1978).

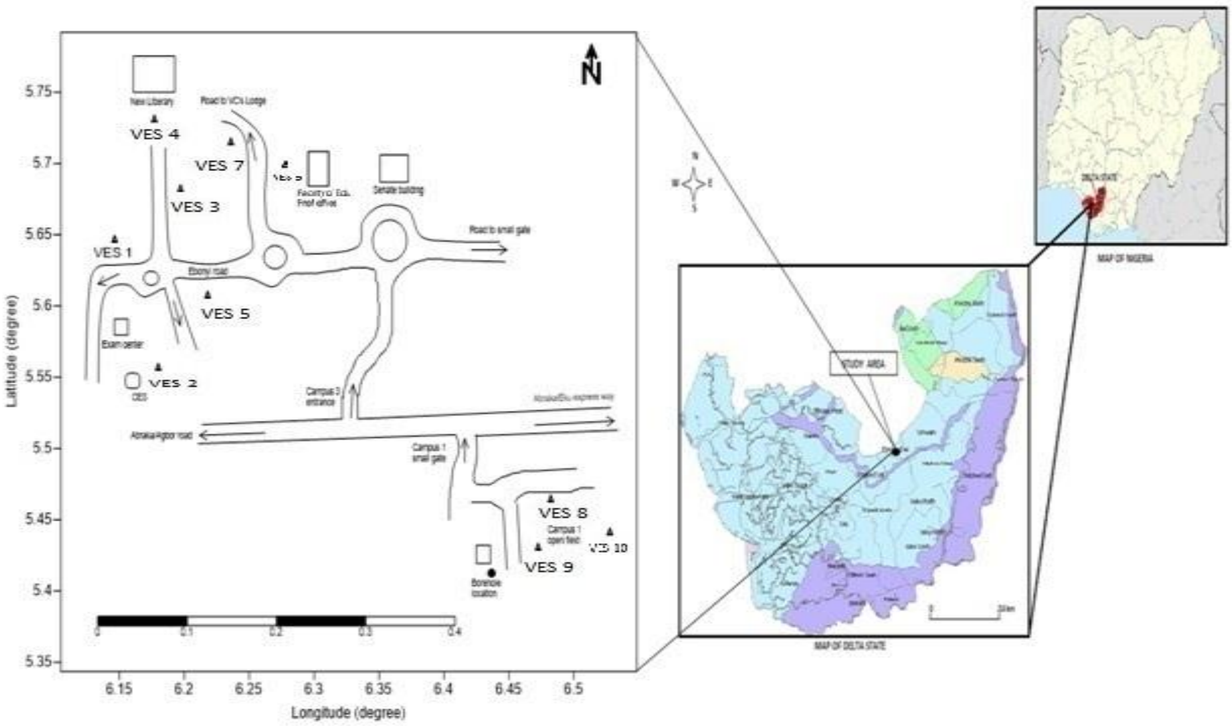

Figure 1: Map of Nigeria region of the Study Area

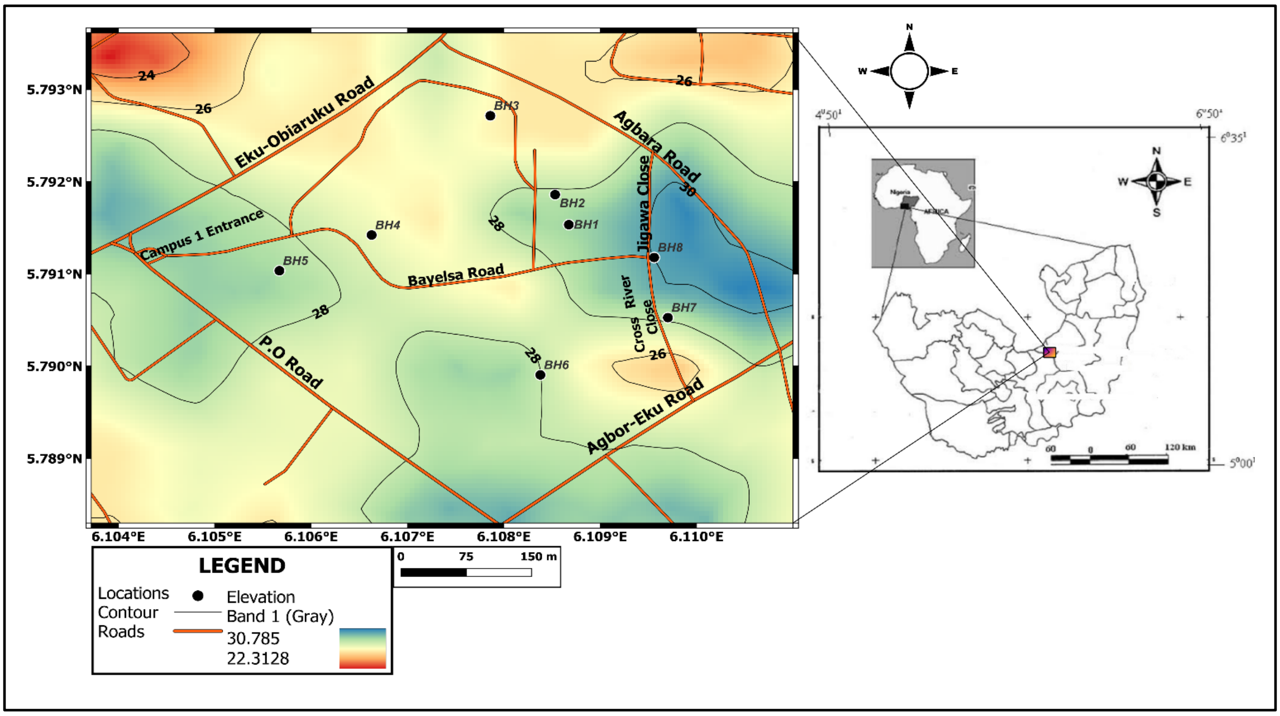

Figure 2: Map of the Borehole locations

Ten geoelectric sounding using the vertical electrical sounding technique was conducted in the study area as indicated in the figures 1 The Schlumberger array was employed using average current electrode separation of 400 m. The purpose for using the vertical electrical sounding Schlumberger array is that it is faster in the field than other methods. The Schlumberger array is also better at discriminating between lateral and vertical resistivity differences. Plotting the sounding curves involved using the records of the apparent resistivity acquired during the investigation along with the records of the current electrode separation. The result obtained from the curve matching were employed as input data in a computer based interpretation with the Win Resist software to obtain the resistivity and thickness of the subsurface layers.

Theory of Electrical Resistivity Method

The generalized form of electrode configuration in resistivity survey is shown in figure 3

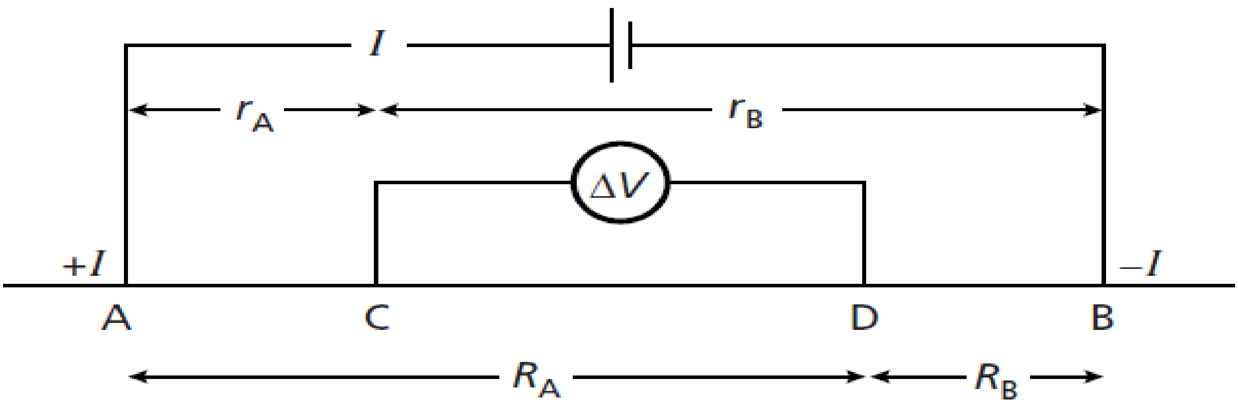

Figure3: The generalized form of the electrode configuration used in resistivity measurements

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The potential at the electrode C and D are in equation 1 & 2 below,

$$V_C = \frac{\rho I}{2\pi}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) \quad (1)$$

$$V_D = \frac{\rho I}{2\pi}\left(\frac{1}{R_A} - \frac{1}{R_B}\right) \quad (2)$$

Absolute potentials are difficult to monitor so the potential difference V between electrode C and D is therefore shown in equation 3 to 5

$$\Delta V = V_C - V_D = \frac{\rho I}{2\pi}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \frac{\rho I}{2\pi}\left(\frac{1}{R_A} - \frac{1}{R_B}\right) \quad (3)$$

$$\Delta V = V_C - V_D = \frac{\rho I}{2\pi}\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right] \quad (4)$$

Therefore, solving equation 4 we have;

$$\rho_a = \frac{2\pi\Delta V}{I\left\{\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right\}} \quad (5)$$

Where

$$G = \frac{2\pi}{\left\{\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right\}} \quad (6)$$

Therefore,

$$\rho_a = G\ X\ R \quad (7)$$

Where G is the geometric factor or Known value and R the resistance. Thus equation (7) show the apparent resistivity for schlumberger configuration.

Figure 3: In operation of the borehole drilling in the field in site 1

We dug a borehole as shown in figure 3and seven existing borehole data were used for this study to evaluate the aquifer quality and characteristics and to determine the subsurface lithology. An SAS 1000 Terrameter, logging equipment, a calibrated cable, and a logging probe were used to conduct electrical resistivity logs in the drilled well. The logs, which included spontaneous potential and resistivity logs, were performed by lowering the probe into the borehole at two-metre intervals and determining the formation electrical potential and electrical resistivity values. The borehole (BH2) was designated observation well drilled at E6.110055°, N5.790694° from which measurement of the water level was taken at an intervals of time. Surrounding wells at close locations in the research field was also utilized for the purpose of this research and was marked test well from which downhole measurements were completed utilizing a flowmeter aimed at finding the flow directions of groundwater in the area. Pumping using a water pump was performed at a constant pump rate of $0.1598m^3$/min in the test well. At a determined interval of time, the water level in the observation well was measured using the calibrated cable. This was used to compute the drawdown which is the difference between the water level before pumping started and the water level after pumping has commenced. The drawdown was plotted against time of pumping on a semi-logarithmic graph sheet. The drawdown per log cycle of time Δl and the horizontal intercept were calculated using the graph. These results were then used to calculate the aquifer transmissivity and storativity using the Cooper-Jacobs equations, as indicated in equations (8) and (9) The Cooper-Jacobs equations are expressed as; Jiao and Rushton (1995); Anomohanran (2014a):

$$T = \frac{2.30Q}{4\pi\delta l} \qquad (8)$$

$$S = \frac{2.3Tto}{r2} \qquad (9)$$

where Q is the discharge, T is transmissivity, δl is the drawdown per log cycle of time, $l$is the drawdown, S is storativity and r is the radial distance from the test well.

In this work, the observation borehole was drilled in the study area to a depth of 60m. During the drilling, well cuttings were collected at a depth interval of 1.6 m, and the formation composition was noted and recorded. This was used to construct a lithologic strata of the well. At the end of the drilling spontaneous potential and resistivity logs were conducted on the well and the result presented. A graphical comparison was made for the three logs by plotting them side by side and the result is presented as Figure 9. Pumping was carried out in the drilled well and the water level after every 5 minutes was measured. This was used to determine the drawdown which is the difference between the water level after the pumping and the water level before pumping was carried out. At the end of the pumping the well was allowed to recover. The outcome of the pumping conducted in the well is presented as Table 1. Downhole log was also carried out at NUT road Abraka at E6.108825° N5.775461° to be comparable to that of the research area.

RESULTS AND DISCUSSIONS

The Dar-Zarrouk parameters of the area were studied to determine the aquifer parameters, and the ten VES data collected in this study area were plotted on a log-log graph paper with the generated potential on the y-axis and electrode spacing on the x-axis. They were then curved matched using standard curves. During the curve matching, the graph was moved onto the master curve as the case may

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be while ensuring both axes of the two curves are kept parallel until the best fit curve from among part of the curve was obtained. The intersection point of origin is marked and the value is read off. Broken lines are drawn out to meet the marked point from the auxiliary curve obtained from the master curve. The process is continued with the broken line passing through the point of origin.

Qualitative Interpretation

The qualitative interpretation was essentially the comparison of the resistivity field curves with the standard or characteristic curves. These standard curves are determined from three-layer earth model. Field curves/standard curves in vertical electrical sounding (VES) were classified into four types as shown in Figure 4. However, hybrid/combination curve also exist in a multiple layered structure consisting of generally more than three layers. The hybrids, HK and HKH curves etc. are obtained from the combination of different types of curves.

The depth and thickness of the different layers obtained from the curve were used as input data for computer iteration. The curves that were produced by the IPI2Win Resist computer iteration software is presented as figure 5.

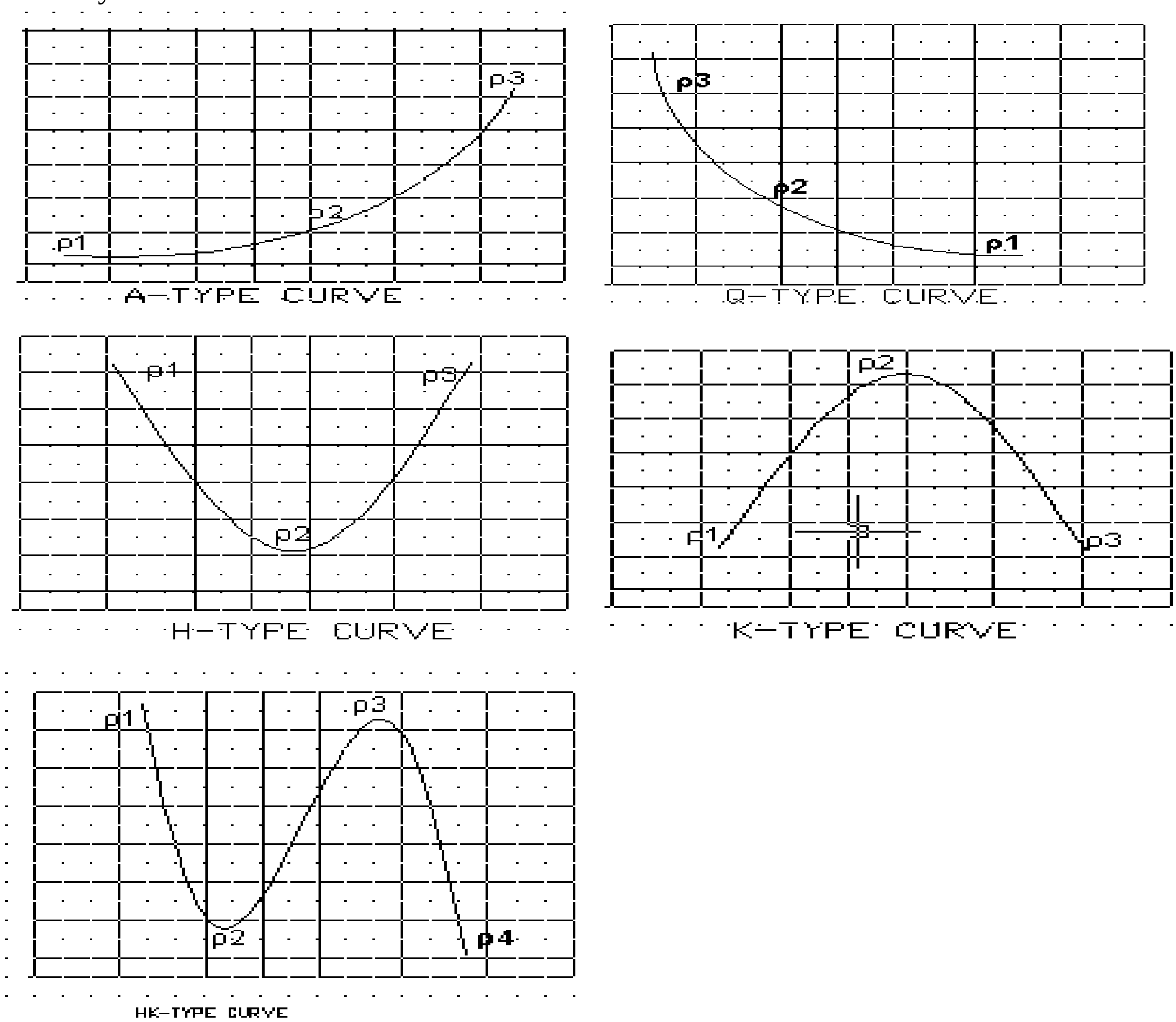


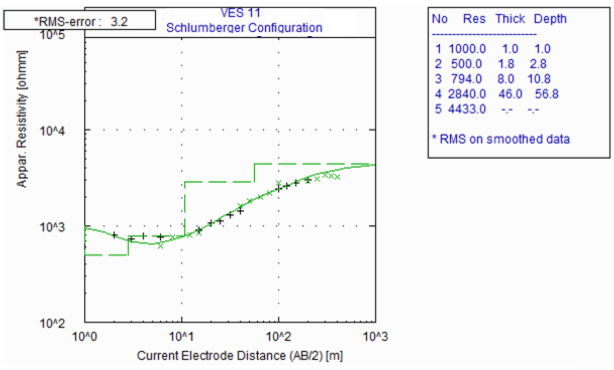
Figure 4: The Different Curve Types

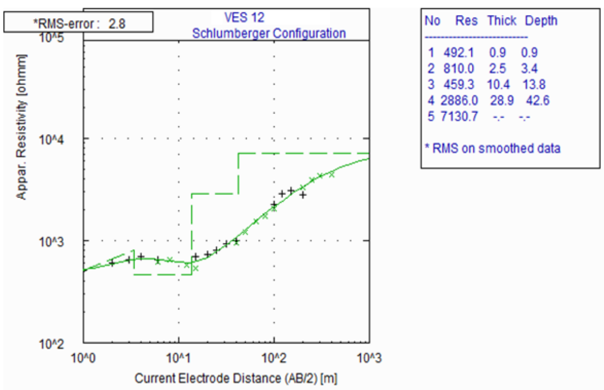
The result obtained from the computer modeling revealed that the area of study is composed of 4 to 6 geo-electric layers. VES 1 has 6 layers, VES 5 has 4 layers while other VES locations consist of 5 geoelectric layers. The subsurface lithology is of topsoil, lateritic sand, fine grain sand, medium coarse sand, and coarse sand.

The first layer topsoil has a resistivity ranging from 145 to 434 Ωm and thickness ranges from 0.6 to 3.7 m. The second geo-electric layer consist of laterite with resistivity ranging from 154 to 16,641 Ωm while the thickness ranged from 0.6 to 6.6 m. The third layer is made of reddish lateritic sand with resistivity ranging from 156 to 6236 Ωm while the thickness varied from 1.8 to 24.7 m with an exception to VES 5 and 9 has fine grained sand in the third layer. The fourth geo-electric layer is composed of fine-grained sand with resistivity ranging from 1354 to 7517 Ωm while the thickness ranged from 11.5 to 70.2 m.

The fifth geo-electric layer is identified as an aquifer which consist of medium grained sand, fine-medium grained sand in VES 1, the resistivity value of the layer ranges from 1741 to 9092 Ωm while the thickness ranged from 22.6 to 81.6 m. This layer constitutes an aquifer in all the VES as a result, we infer that a drill depth of this layer and above should be accessed for potable water in the area. The sixth geo-electric layer is composed of medium coarse sand in VES 1. The resistivity value of this formation 20829 Ωm with the depth 94 m. This formation is also identified as aquiferious. The result of the vertical electrical sounding was correlated with the result of a drilled borehole and the result correlate well.

Analysis showed that the aquifer depth ranged from 11.5 m to 94 m while the resistivity ranges from 1741 to 9092 Ωm. The depth map of the research field is as shown in Figure 7. The figure showed that the aquifer depth around the sites is about 30 m. the figure also revealed that the aquifer depth increases progressively on both sides of the river. This means that those who live far away from the river line will have to drill deeper to obtain groundwater. The resistivity map is presented as Figure 6. This figure revealed that the resistivity is highest at the south-east, northeast with traces of high resistivity around the south-south- and south-central areas, this is an indication that these areas might produce cleaner and more prolific groundwater than the areas shown to have the highest values. The transmissivity contoured map of the study area is presented in figure 8. This figure revealed that the transmissivity is highest at southern region. This indicate that the borehole location in site 1 has capacity to produce water.





VES 1 & 2

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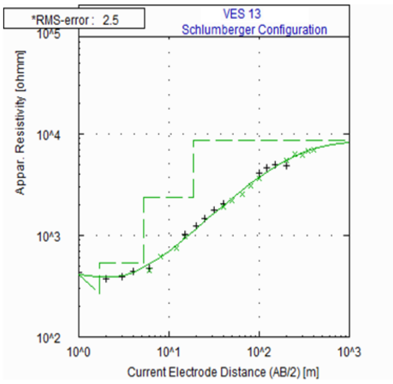
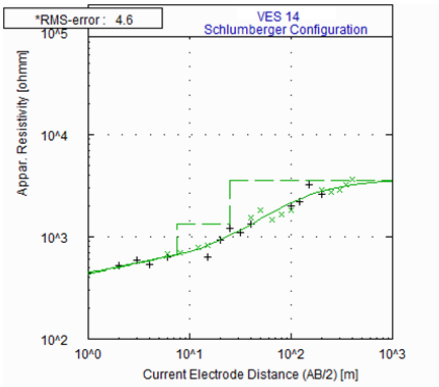


No	Res	Thick	Depth
1	420.6	1.0	1.0
2	264.7	0.7	1.7
3	533.0	3.5	5.3
4	2388.6	13.2	18.5
5	8750.0	-.-	-.-

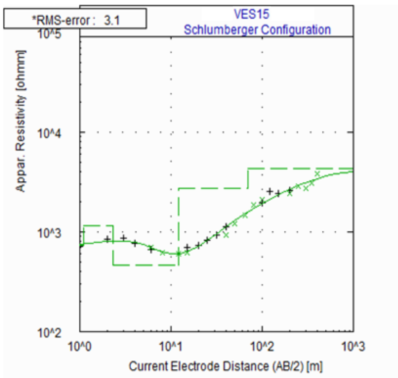
* RMS on smoothed data



No	Res	Thick	Depth
1	433.7	1.0	1.0
2	662.4	6.6	7.5
3	1349.4	17.5	25.0
4	3556.6	-.-	-.-

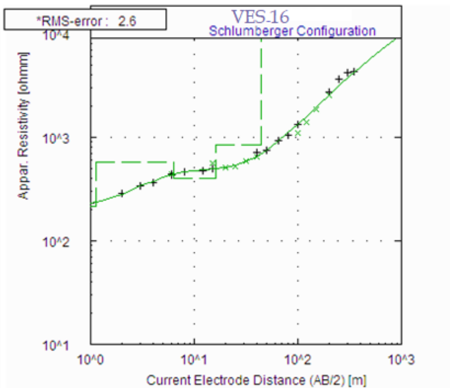
* RMS on smoothed data

VES 3 & 4



No	Res	Thick	Depth
1	738.7	1.1	1.1
2	1160.5	1.2	2.3
3	459.9	9.9	12.2
4	2720.2	57.5	69.7
5	4332.0	-.-	-.-

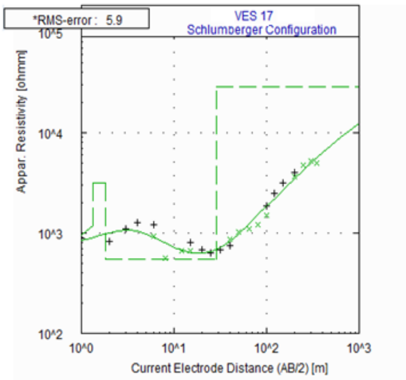
* RMS on smoothed data



No	Res	Thick	Depth
1	217.6	1.1	1.1
2	573.6	5.3	6.4
3	402.8	9.6	16.0
4	839.3	28.0	44.0
5	29395.4	-.-	-.-

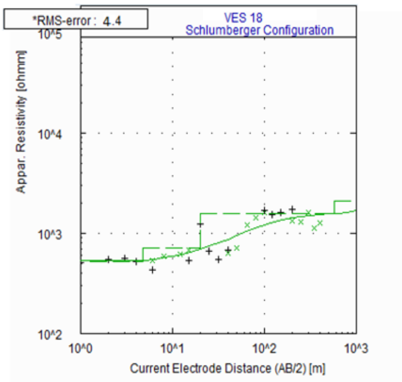
* RMS on smoothed data

VES 5 & 6



No	Res	Thick	Depth
1	780.5	0.7	0.7
2	1192.6	0.6	1.3
3	3178.7	0.5	1.8
4	550.2	27.2	29.0
5	28867.9	-.-	-.-

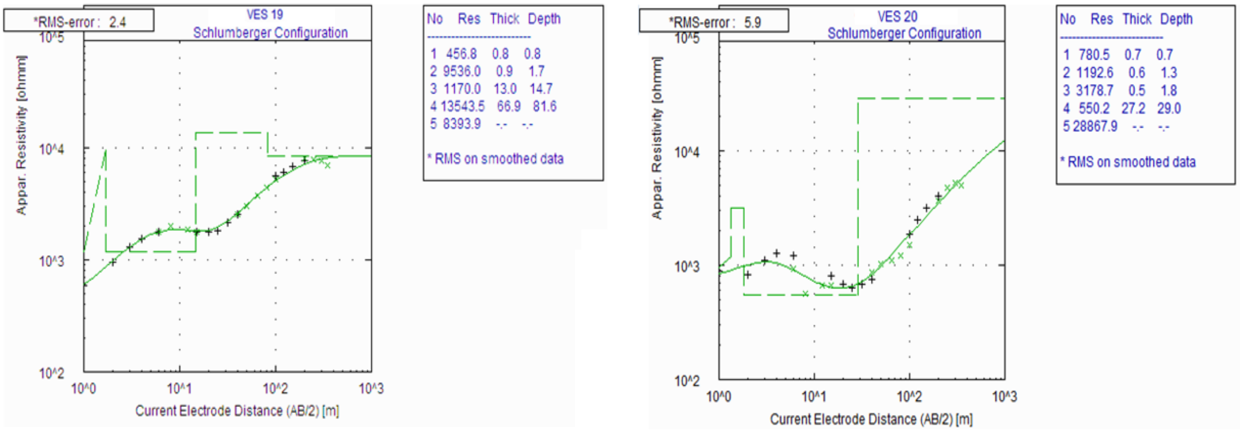
* RMS on smoothed data



No	Res	Thick	Depth
1	532.8	1.3	1.3
2	517.5	3.4	4.7
3	714.3	15.5	20.2
4	1562.9	550.7	570.9
5	2116.7	-.-	-.-

* RMS on smoothed data

VES 7 & 8



VES 9 & 10

Figure 5: Resistivity sounding curves for VES data obtained

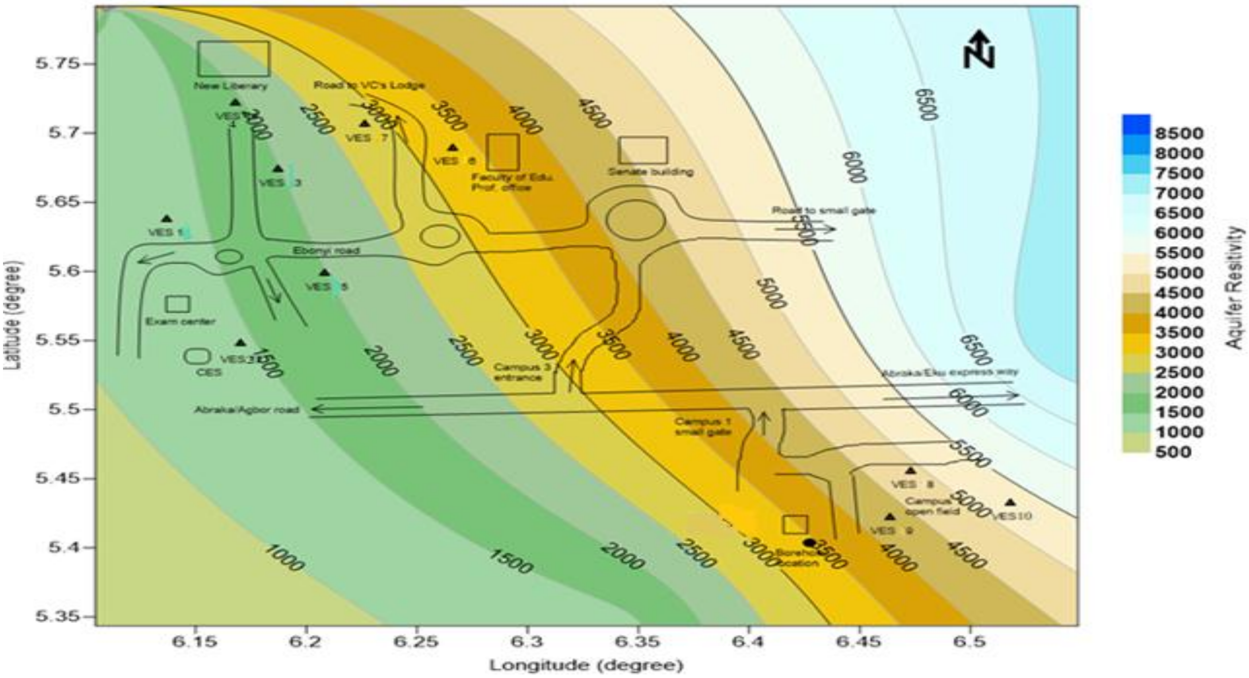


Figure 6: Aquifer resistivity of the study area

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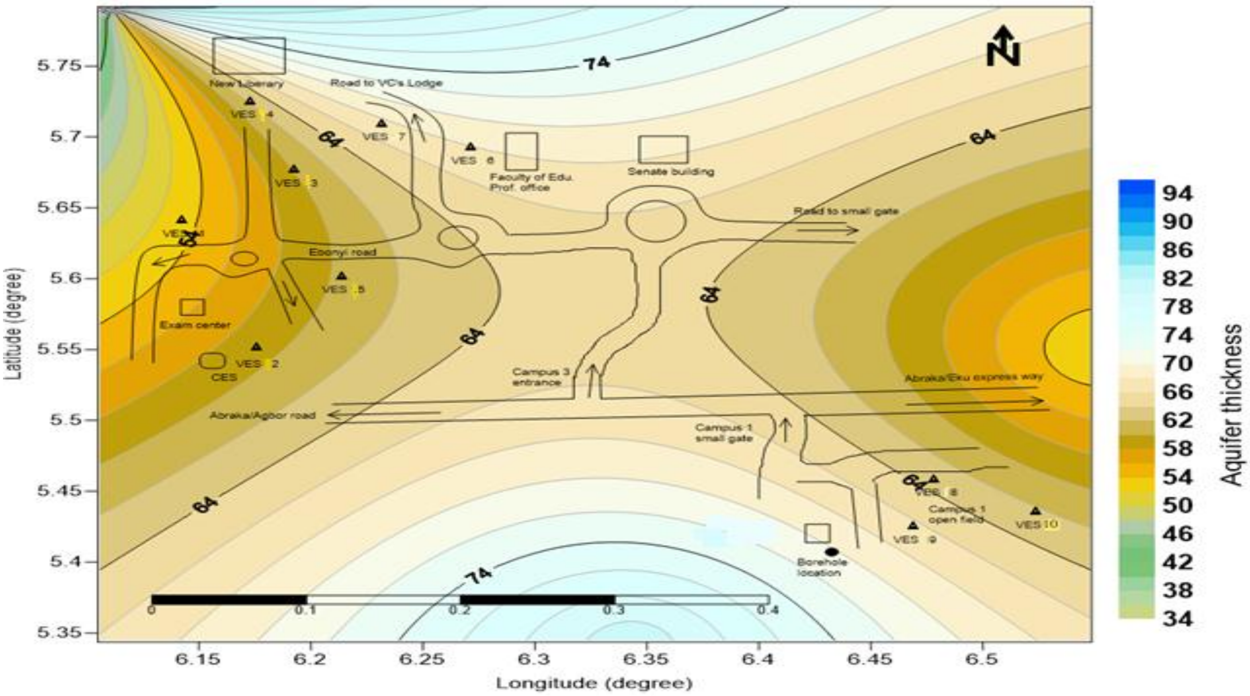

Figure 7: Aquifer thickness of the study area.

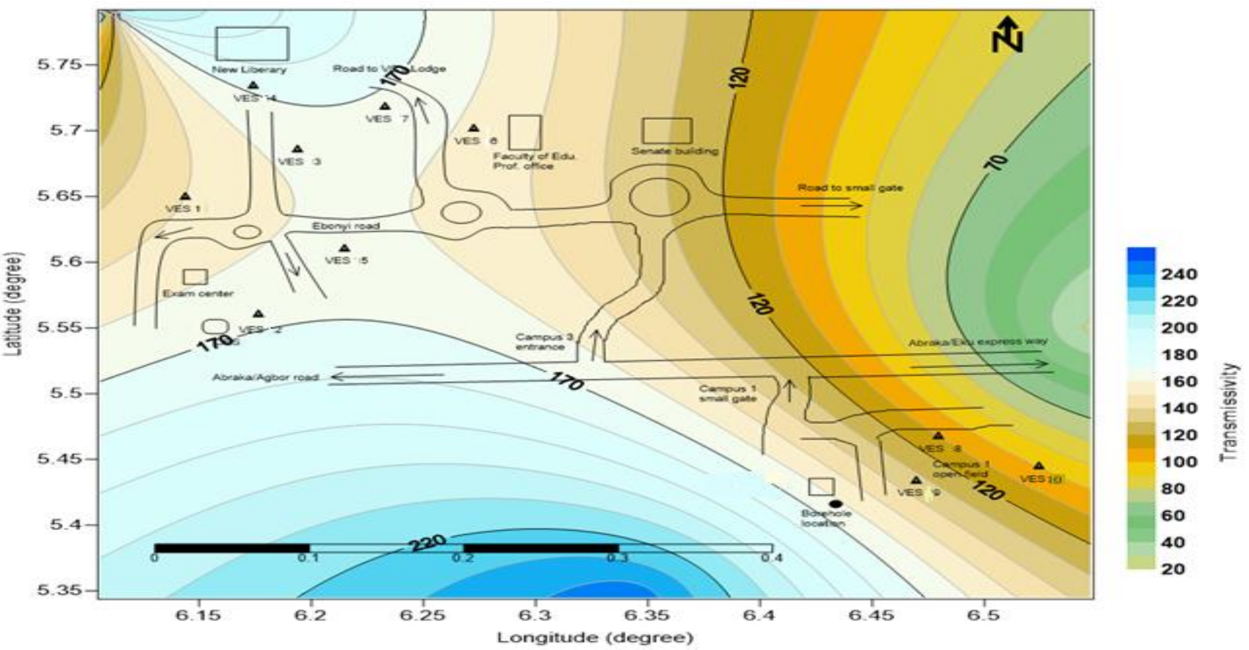

Figure 8: Transmissivity contoured map of the study area.

Pumping test result

A two-hour pumping test was conducted in the borehole using 1HP Astral pump with a uniform discharge rate of 0.1598m^3/min and the water level in the pumping well was measured at intervals using an electronic deep meter. The information from the drawdown was used to determine the hydraulic characteristics by first plotting the graph of drawdown against time on a semi-log paper and this is presented as Figure 9. The graph was used to obtain the drawdown per log cycle and substituted into the Cooper Jacob equation which is as shown in detail below.

The copper-Jacob (1946) equation is efficiently used to determine the aquifer parameters in a well using the
Transmissivity (T):

$$T = \frac{2.3Q}{4\pi\Delta s} \quad (10)$$

Specific Yield (Sy):

$$Sy = \frac{Q}{\Delta s} \quad (11)$$

Storativity (S):

$$S = \frac{2.3Tt_0}{r^2} \quad (12)$$

Hydraulic conductivity (K):

$$K = \frac{T}{b} \quad (13)$$

Where:

Q is volumetric flow rate, b is the aquifer thickness, r is radial distance of the pumping well, Δs is the change in drawdown per log cycle, t_0 is the intersection time on the horizontal axis

Table 1: Result obtained from pumping test

Drawdown Data			**Recovery Data**	
Time(min)	**Water level(m)**	**Drawdown(m)**	**Time(min)**	**Water level(m)**
3	16.2	0.1	61	16.10
5	16.16	0.06	61.5	16.10
6	16.21	0.11	62	16.10
7.5	16.24	0.14	65	16.10
12.5	16.32	0.22	70	16.10
17.5	16.36	0.26	75	16.10
22.5	16.40	0.3	80	16.10
27.5	16.45	0.35	85	16.10
32.5	16.48	0.38	90	16.10
37.5	16.53	0.43	95	16.10
42.5	16.58	0.48	100	16.10
47.5	16.55	0.45	105	16.10
52.5	16.58	0.48	110	16.10
57.5	16.62	0.52	115	16.10
60	16.65	0.55	120	16.10

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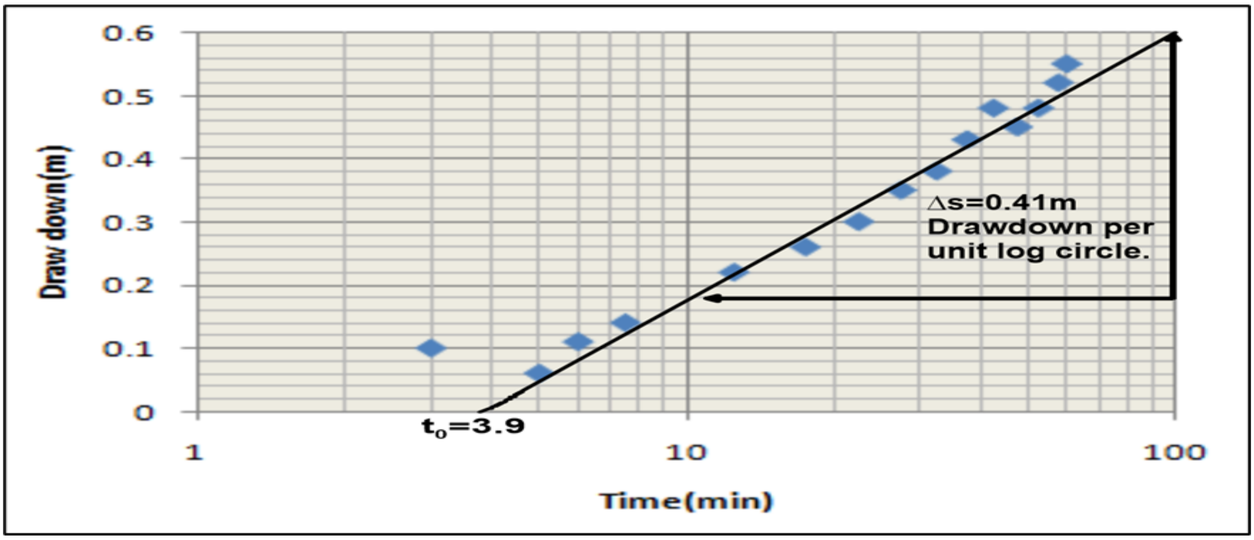

Figure 9: Drawdown against time of pumping: Showing the drawdown per log circle of time and intercept t_0. Constant pumping rate of 0.1598m^3/min was used in this study, drawdown per log cycle was estimated from the drawdown-time graph as Δs=0.41m. The transmissivity, storativity and hydraulic conductivity of the aquifer were calculated as follows.

i. The transmissivity

$$\mathrm{T} = \frac{2.3 \text{ x Q}}{4\pi \text{ x } \Delta s} = \frac{2.3 \text{ x } 0.1598}{4 \text{ x } 3.142 \text{ x } 0.41} = 102.7\ m^2/day$$

ii. The specific capacity of the aquifer is

$$\mathrm{S_y} = \frac{Q}{\Delta s} = \frac{0.1598}{0.41} = 0.39\ m^2/min$$

iii. The storativity

$$s = \frac{2.3 \text{ x T x } t_0}{r^2} = 0.00062$$

iv. Estimating the hydraulic conductivity of the aquifer was obtained as follows

$$K = \frac{T}{b} = 5.14\ m^2/day$$

Hydraulic characteristic of the groundwater aquifer

The result obtained was used to estimate the amount of water that can be transmitted vertically and horizontally which is given as 102.7m^2/day. The parameter shows that the transmissivity rate of the groundwater is high, hence the aquifer could be described as prolific. The result is an indication that enough pressure exists within the aquifer to produce substantial quantity of water for the residents of the area. Specific capacity of aquifer obtained as 0.39m^2/min can produce sufficient amount of water for the people in the area.

Hydraulic conductivity of the aquifer in the area is 5.14 m/day, the value also in agreement with the result of a similar survey using geoelectric soundings carried out at Orerokpe, shallow Benin formation in Western Niger Delta, Nigeria. Aweto and Akopborie, (2015). Which showed that the hydraulic conductivity values varied between 10.50m/day and 45.71m/day

Flow direction

The determination of water flow direction, measured hydraulic head of the wells distributed in the area was used to produce a contoured flow direction map as shown in Figure 10.

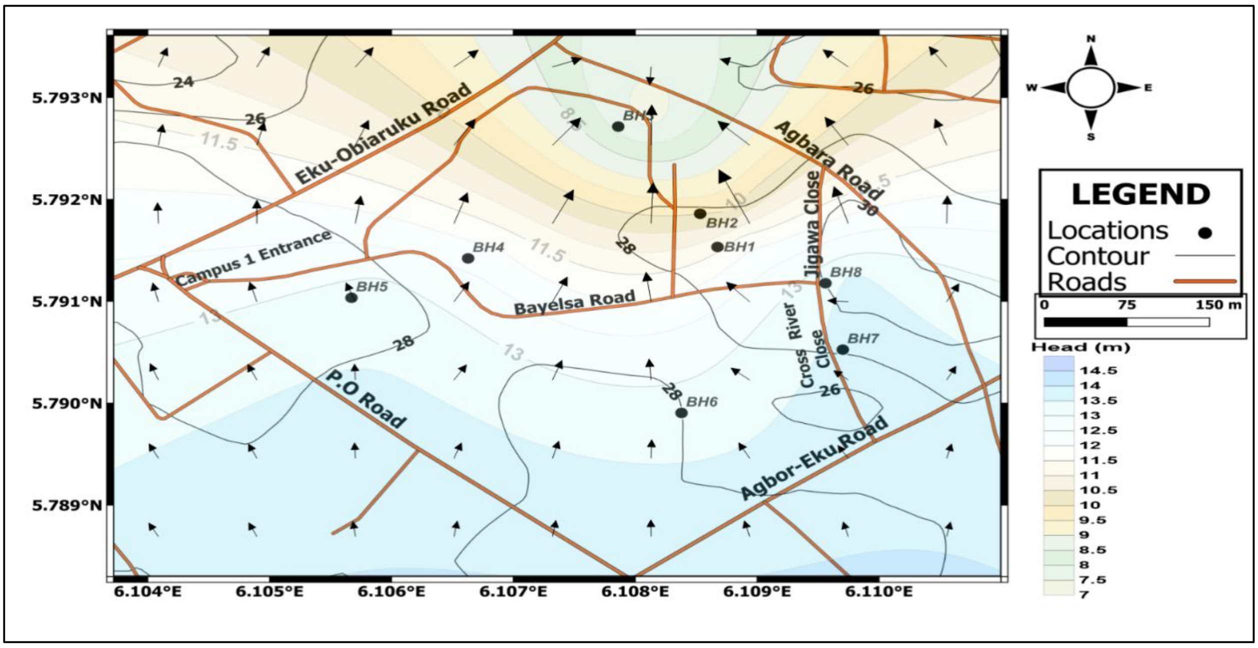

Figure 10: Flow direction of the study area of drilled borehole

From figure 10, the groundwater vector is flowing towards the Northern direction, the hydraulic head in the study area ranges from 7m to 15m. Since the groundwater is flowing towards the North, its management can therefore be easily determined in terms of contamination and dumpsite location within the study area. At a location of borehole (BH3), E6.104834°, N5.786368° (The Music Department) there is a little change in the flow direction due to high abstraction of water in the drilled water scheme of site (I) causing more waters to flow towards the wells.

In Figure 11, based on the hand lens observation of the drill cuttings, the research area's lithology from the top to bottom, the drilled lithological sediment sequence are topsoil, laterite, fine sand, and medium sand at the base. The topsoil is brownish with a thickness of 2 m, the laterite is reddish with a thickness of 4m, the fine sand is whitish with a thickness of 10 m, and the medium sand is also whitish with thickness >12m. The medium sand is the zone of saturation where the borehole screen is situated, hence, the primary aquifer of the drilled well having a high resistivity value and deflection curve towards the high value. However, an increase in the resistivity value starts from 12m as shown in site (I) downhole log in figure 11, the zone of high resistivity shows the conductivity of the formation fluid. The resistivity curve shows that the productive aquiferous zone is free from dissolved ions. The low resistivity is evidence of dissolved ions in formation fluid. The fine grain is of great help in natural attenuation process, that is the adsorption of contaminate onto aquifer grains or the surface preventing dissolve ion to percolate beneath the water table.

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Table 2: Downhole Log Data

Depth(m)	Site 1 Downhole		NUT Downhole	
	SP(mv)	Resistivity(Ωm)	SP(mv)	Resistivity(Ωm)
8	-0.213	-1.2041	-0.119	-1.918
10	-0.216	-0.6341	-0.115	-0.568
12	-0.29	3.40123	-8.114	2.24602
14	-3.44	3.2621	8.0334	2.9946
16	-3.446	4.436	3.402	9.4062
18	-3.501	4.5021	-6.341	9.9828
20	-3.512	4.513	-6.345	18.164
22	-3.514	4.5342	-6.348	18.24
24	-5.116	4.6721	-6.361	20.746
25	-5.391	4.6082	-6.369	20.941
26	-5.394	4.7861	-6.41	26.601
28	-5.396	5.8924	-6.412	26.711
30	-5.398	5.9031	-6.414	28.601
32	-5.382	6.741	-6.512	30.414
34	-5.393	6.8191	-6.514	33.816

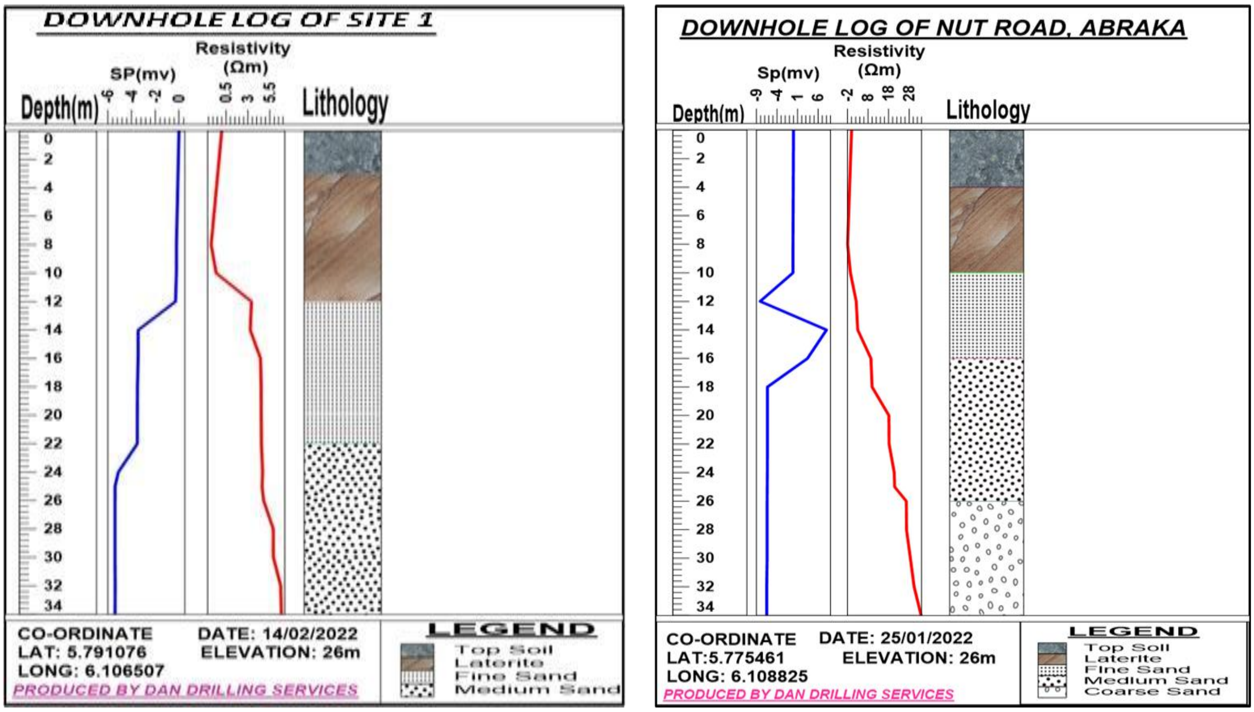

Figure 11: Borehole logs obtained from borehole drilled in Site 1 and NUT road Abraka in the study area

CONCLUSION

The aquifer hydraulic properties have been determined using vertical electrical sounding, well logging and pumping test. The result has shown that the aquifer is located at a depth range from 13.5m to 97.8m. The hydraulic conductivity, transmissivity, storativity and specific capacity of the well are 5.14 m/day, 102.7m^2/day,0.00062and 0.39 m^3/m respectively.The results shows that the aquifer is prolific and will be able to provide enough water for the people all year round.

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