GEOELECTRIC INVESTIGATION OF GROUNDWATER POTENTIAL IN SITE I AND III OF ABRAKA, DELTA STATE UNIVERSITY.

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Abstract

Geoelectric method and Geochemical analyses were implored to investigate the ground water potential in sites 1 and III of Delta State University, Abraka. Twenty (20) Vertical Electrical soundings (VES) with the aid of SAS 1000 Abem TERRAMETER were sounded using the Schlumberger configuration to determine the aquifer characteristics. The results reveal that most of the locations have four (4) layers except VES 8 which has five (5) layers. The result of the Lithostratigraphic study showed that the subsurface formations from the top to bottom consist of topsoil, lateritic sand, and medium sand at the base with resistivity ranging from 300 Ωm to 2800 Ωm. The aquifer protective capacity and hydraulic conductivity were determined using Dar-Zarrouk parameters. It is observed that the transmissivity value was mostly highest in VES7 at the Northern part of the study area which ranges from 160 to 440 m^2/day but lower in the other VES points. Most part of the survey shows that the aquifer is confined and capable of yielding adequate and good quality water. The analysis of the ground water reveled that nitrate ranged from 0.49 Mg/l to 1.27 Mg/l, total dissolved solid ranged from 10 Mg/l to 200 Mg/l, Chloride ranged from 22.5 Mg/l to 38.2 Mg/l, Calcium ranged from 5.2 Mg/l to 6.1 Mg/l. Consequently, the analyses' findings show that the numbers fall within Nigeria's and the WHO's standards. (WHO) for safe water. Hence, the water from the study area is good for human consumption and any other domestic usages.

Keywords: Vertical Electrical Resistivity Sounding (VES), Dar-Zarrouk parameters, Groundwater, Aquifer, Resistivity, Conductivity, Terrameter.

INTRODUCTION

One of the fundamental needs for maintaining life is potable water, therefore throughout history, methods have been created to ensure its availability (Karanth, 2006). To help determine where to locate groundwater wells, many groundwater research projects still rely only on geophysical techniques, particularly geoelectrical approaches, especially in poor nations (Boucher et al., 2009). A single technique might not be able to provide the information needed to estimate groundwater resource and flow dynamics in complicated geological or hydrological contexts, despite the fact that these methods have been proved to be quick and reliable. Hand-dug wells and boreholes can be used to access groundwater, which is the water that exists below the subsurface. Groundwater is present in pore spaces in all types of rocks, and the connection between these spaces and other sedimentary structures often regulates how much groundwater flows through them. Water that is found underground in the pores and fissures of rocks and sediments is known as groundwater (Shan, 2009) It is necessary to consider ground and water qualities including permeability, saturated and unsaturated zones, and porosity (a property of a rock holding pores or voids) in order to comprehend how groundwater arises. Additionally, knowledge of aquifers (geologic formations that are both sufficiently porous to retain water and permeable to allow water to flow through them in proportions that are economically viable) and the storage coefficient are required (the volume of water that an aquifer releases from or takes into storage unit surface area of aquifer per unit change in the component of area normal to surface).According to some experts, the geology, groundwater, and geophysical characteristics that were calculated for the aquifer are based on this premise (Olabaniyi. and Owoyemi. 2006; Kearey and Brooke 1984; Mazac et al, 1985). Hydraulic conductivity and transmissivity, two aquifer properties, are crucial for the management and development of water resources (Alile et al., 2008).

MATERIALS AND METHODS

This study was carried out in sites 1 and III of Delta State University Abraka, which is situated in the Niger Delta area of Nigeria. It is located within latitude 5°47N and 5°48N and longitude 6° 15 07.56 and 6° 07.57" E of the equator. The research area's map is displayed in figure 1 below.

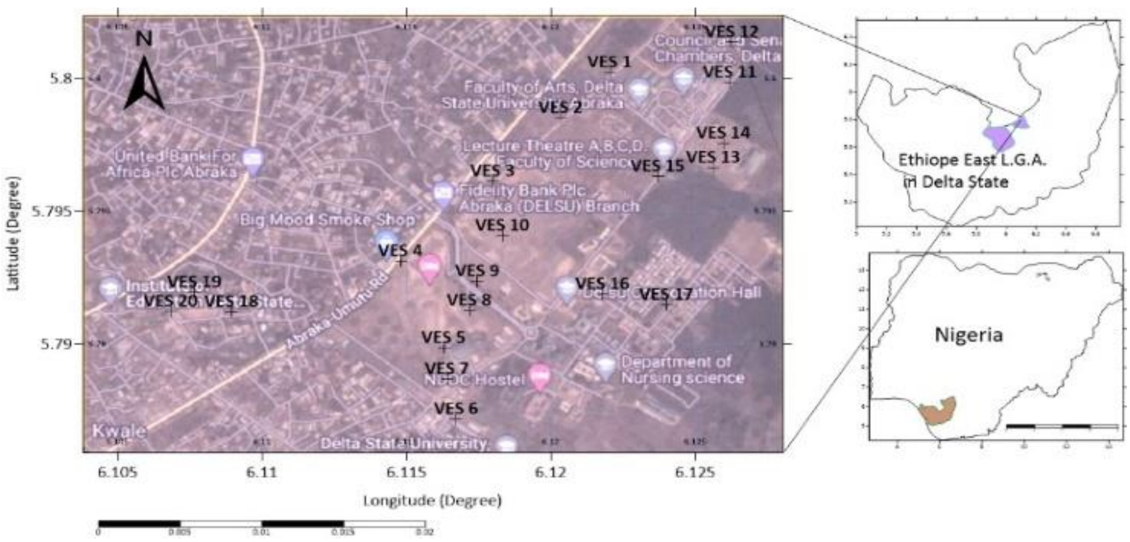


Figure 1: Map showing region of the Study Area.

The ABEM Terrameter SAS 1000 was used for the geoelectric survey. The electrical resistivity method combined with the VES methodology was used to achieve this (Zonge et al., 2005). By taking readings near the earth's surface, electrical resistivity surveys are often conducted to determine the electrical resistance of subterranean materials (Abdel-Azim, et al., 1996). The Schlumberger electrode configuration was employed, with a maximum current electrode spacing of 250 m (AB/2). The Terrameter, GPS, Measuring Tape, Sledge

Hammer, Four, Keel of Wire and Recording Sheet where research data were recorded and calculated, were all employed in this geophysical research. It's also known as a data sheet. In order to look into the quality of ground water in the study area, water analysis on various parameters, such as iron content, total hardness, total dissolve solid, calcium and magnesium hardness, chloride, and nitrate, were also carried out at Edo State University Uzairue and University of Ibadan advance learning research Laboratory Centre. Resistivity Surveys are conducted as either soundings or profiles. Resistivity profiling (constant separation traversing, trenching or mapping) was used to detect lateral variation activity. For profiling, the electrode spacing is fixed while the center of the array is varied. A sounding (electrical drilling or electrical depth sounding) was used to determine changes in resistivity with depth. The electrode spacing was varied for each measurement but the Centre point of the array was constant. The electrical resistivity method involving vertical electrical sounding (VES) was adopted for this survey since the interest was on knowing resistivity changes with depth.

Principle of method

Surface electrical resistivity surveying is based on the principle that involves the distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks (Keller and Frisckenecht, 1996).

The electrical resistivity measurements are normally made by injecting current into the ground through two current electrodes (A and B) and measuring the resulting voltage difference at two potentials (M and N). While this technique is being employed, the current (I) and voltage (v) values, an apparent resistivity *Pa* value was calculated.

Schlumberger Array

The Schlumberger technique was employed for reasons of logistic, manpower and deep surface penetrations. In this case, four electrodes are collinearly arranged and properly pinned into the ground to make good contact with the earth for effective current flow. In the Schlumberger array, the current electrodes spacing was much greater than the potential electrodes spacing so that the relation where AB is electrodes spacing and MN is potential electrodes spacing. The field array was made in line with the theory of resistivity which is derived from the first principle of resistivity investigations. The Schlumberger configuration is quite easy to carry out because it requires less manpower, as a result lying of field equipment are relatively easy, field curves are generally smoother and step free.

Schlumberger arrangement is shown in Figure 2 below (Abdullah 2006).

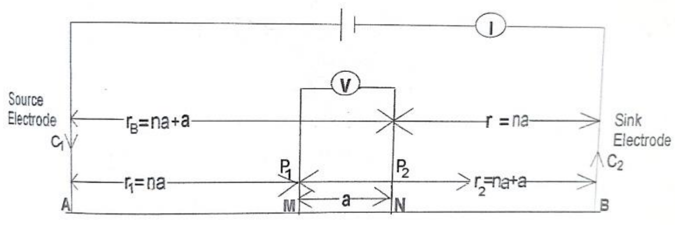


Figure 2: Schlumberger configuration (Abdullah 2006)

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

Where $G = \dfrac{2\pi}{I\left\{\left(\dfrac{1}{r_A} - \dfrac{1}{r_B}\right) - \left(\dfrac{1}{R_A} - \dfrac{1}{R_B}\right)\right\}}$ (2)

Therefore, $\rho_a = G \times R$ (3)

where ρ_a is the apparent resistivity, G is the geometric factor or known value and R is the resistance. Thus equation (3) also shows the apparent resistivity for Schlumberger configuration.

Note: $AM = L - l$ $MB = L + l$

$AN = L + l$ $NB = L - l$

Considering the Schlumberger configuration of Figure 2, and from equation (3),

$$\rho = \frac{\Delta V 2\pi}{I}\left(\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right)^{-1} \quad (4)$$

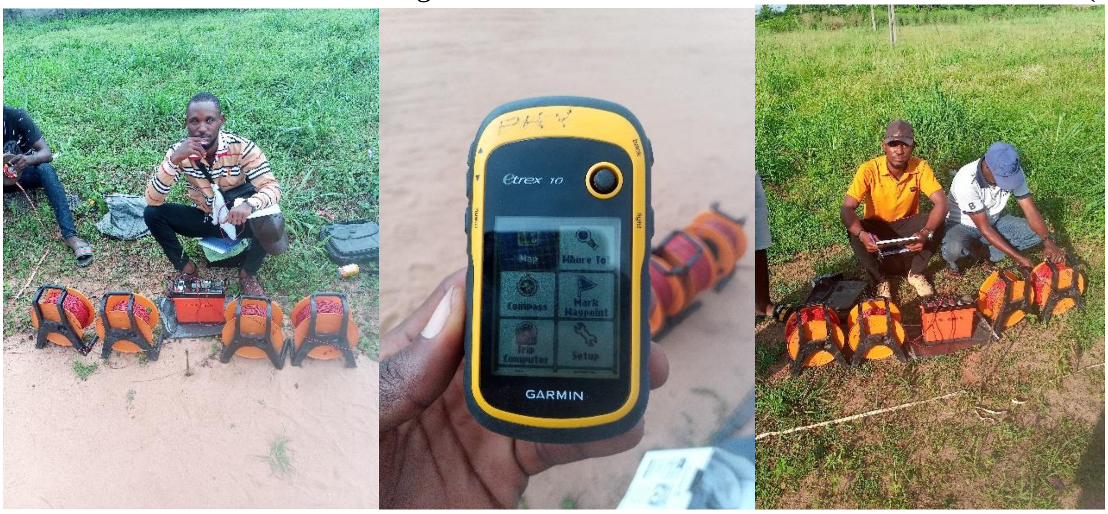
$$\rho = \frac{\Delta V 2\pi}{I}\left(\frac{1}{L-1} - \frac{1}{L+l} - \frac{1}{L+1} + \frac{1}{L-1}\right)^{-1} \quad (5)$$

Taking the L.C.M of the denominator and simplifying, noting that since $AB >> MN(L >> l)$

$$\rho = \frac{\Delta V 2\pi}{I}\left(\frac{4l}{L^2}\right)^{-1} \quad (6)$$

$$\rho = \frac{\pi R L^2}{2l} \quad (7)$$

In depth probing, the potential electrodes remain fixed while the current electrode spacing is expanded symmetrically about the center of the spread. For large values of L, it may be necessary to increase l in order to maintain a measurable potential. Equation (7) applies in this case. This procedure is more convenient than Wenner expanding spread because only two electrodes need move at a time.



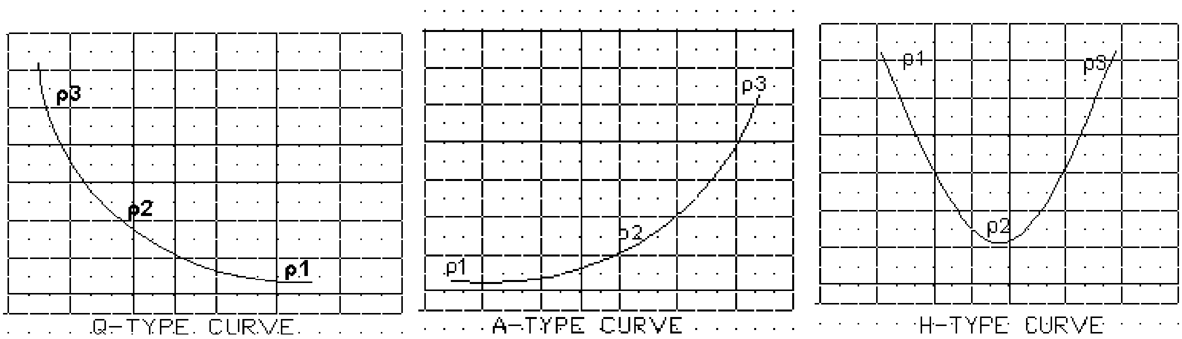
(a) Field data acquisitionequipment **(b)** Global Positioning System (GPS) **(c)** Equipment Setup

Plate 1: Pictorial view of field Data acquisition and equipment Used.

RESULTS AND DISCUSSION

The Twenty (20) VES data obtained in this study area of DELSU Sites I and III in Abraka were recorded and presented in Table 1. The Dar Zarrouk parameters of the area were also studied and presented in Table 2. The Vertical Electrical Sounding (VES) data obtained from the field was plotted on a bi-log paper with the apparent resistivity on the vertical axis and the electrode spacing (AB/2) on the horizontal axis. The sounding curve was interpreted by curve matching technique with relevant developed master and auxiliary curve. The thickness and depths as well as the apparent resistivity were determined for the subsurface with the aid of WinResist Software developed by vander Velpen, (1988) to obtain the true resistivity and thickness delineated. The interpretation of data obtained from the field using vertical electrical sounding (VES) was done qualitatively and quantitatively. Basically, the apparent resistivity curve for a 3-layer structure, generally, has one of four typical shapes determined by the vertical sequence of resistivity of the layers. Shapes of Common Curve Types are depicted in Figure 3 below (Van Nostrand and Cook, 1966).

Theoretically, these curves include the K-type, H-type, A-type and Q-type.



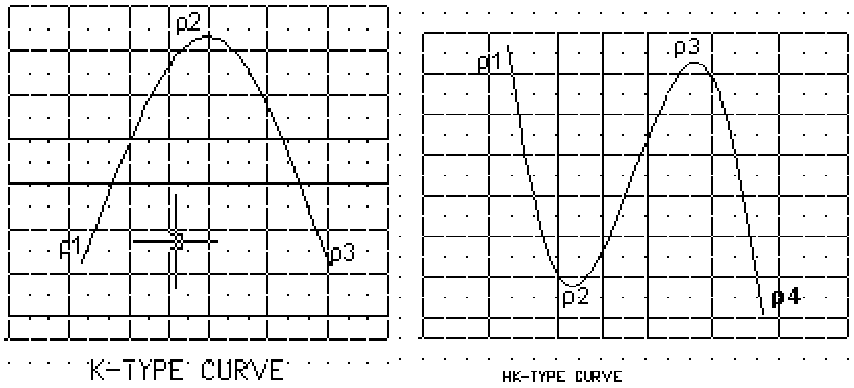


Figure 3: Shapes of Standard Curve Types (Van Nostrand and Cook 1966)

Table 1: Geoelectric parameters and Dar-Zarrouk parameters for the study of aquifer protective capacity rating

Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curves
VES1	1	955.6	1.7	1.5	Lateritic Topsoil	HK
	2	404.5	6.7	8.4	Laterite	$\rho_1 > \rho_2 < \rho_3 > \rho_4 >$
	3	302.4	13.7	22.0	Fine to Medium sand	
	4	1477.1	…….	…..	Medium Sand	
VES2	1	388.	0.9	0.9	Lateritic Topsoil	KH
	2	1015.5	18.6	18.7	Laterite	$\rho_1 < \rho_2 > \rho_3 < \rho_4$
	3	214.4	18.1	25.5	Fine to Medium sand	
	4	1812.4	…….	……..	Medium to Coarse Sand	
VES3	1	41.5	0.1	0.1	Lateritic Topsoil	KH
	2	1030.4	18.6	18.7	Laterite	$\rho_1 < \rho_2 > \rho_3 < \rho_4$
	3	151.8	23.1	41.8	Fine to Medium sand	
	4	1004.4	…..	….	Medium to coarse Sand	
VES4	1	912.4	1.3	1.3	Lateritic Topsoil	HAA
	2	350.8	5.7	7.0	Laterite	$\rho_1 > \rho_2 < \rho_3 < \rho_4 < \rho_5$
	3	1975.7	18.0	25.0	Fine to Medium sand	
	4	878.3	…..	…..	Medium to Coarse Sand	
VES5	1	929.0	1.1	1.1	Lateritic Topsoil	HA
	2	519.9	6.0	7.1	Laterite	$\rho_1 > \rho_2 < \rho_3 < \rho_4$
	3	1253.0	14.9	21.9	Fine to Medium sand	
	4	1873.5	……	…..	Medium Sand	
VES6	1	1478.2	1.1	1.1	Lateritic Topsoil	QQ
	2	941.0	5.7	6.8	Laterite	$\rho_1 > \rho_2 > \rho_3 > \rho_4$
	3	427.4	14.8	21.6	Fine to Medium sand	
	4	379.1	…..	…..	Medium Sand	
VES7	1	1488.7	1.3	1.3	Lateritic Topsoil	HA
	2	867.3	5.9	7.2	Laterite	$\rho_{21} > \rho_2 < \rho_3 < \rho_4$
	3	230.0	18.9	29.4	Fine to Medium sand	
	4	731.4	…….	…….	Medium Sand	
VES8	1	995.6	1.7	1.5	Lateritic Topsoil	KHK
	2	424.1	5.3	6.8	Laterite	$\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$
	3	1359.3	11.1	17.9	Fine to Medium sand	
	4	2808.4	14.5	32.4	Medium Sand	
	5	1453.9	---	---	Medium to Coarse Sand	
VES9	1	919.3	1.2	1.2	Lateritic Topsoil	HK
	2	363.9	6.2	7.5	Laterite	$\rho_1 > \rho_2 < \rho_3 > \rho_4$
	3	224.7	15.8	23.3	Fine to Medium sand	
	4	865.0	…..	…..	Medium Sand	
VES10	1	952.1	1.7	1.7	Lateritic Topsoil	HK
	2	3395.7	9.9	6.4	Laterite	$\rho_1 > \rho_2 < \rho_3 > \rho_4$
	3	3045.7	12.7	20.0	Fine to Medium Sand	
	4	1489.5	…..	…..	Medium Sand	
VES11	1	905.3	1.3	1.3	Lateritic Topsoil	HK
	2	341.8	5.7	7.0	Fine Sand	$\rho_1 > \rho_2 < \rho_3 > \rho_4$
	3	2190.4	15.7	22.7	Fine to Medium sand	
	4	876.4	…..	…..	Medium Sand	

VES12	1	1014.2	1.0	1.0	Lateritic Topsoil	KHAA	
	2	341.8	5.6	6.6	Laterite		$\rho_1 > \rho_2 < \rho_3 < \rho_4$
	3	937.0	11.3	17.7	Fine to Medium Sand		
	4	1843.0	…..	…..	Medium Sand		
VES13	1	395.9	1.0	1.0	Lateritic Topsoil	KH	
	2	1093.7	5.7	6.7	Laterite		$\rho_1 < \rho_2 > \rho_3 < \rho_4$
	3	222.1	18.2	24.9	Fine to Medium sand		
	4	1678.4	……	.....	Medium Sand		
VES14	1	1470.6	1.0.	1.9	Lateritic Topsoil	HAK	
	2	1024.1	4.6	5.6	Laterite		$\rho_1 > \rho_2 > \rho_3 > \rho_4$
	3	463.8	12.7	18.3	Fine to Medium sand		
	4	383.2	…..	…..	Medium Sand		
VES15	1	912.3	1.3	1.3	Lateritic Topsoil	HK	
	2	353.9	6.0	7.3	Laterite		$\rho_1 > \rho_2 > \rho_3 > \rho_4 <$
	3	2154.5	17.6	24.8	Fine to Medium sand		
	4	8489	…….	……	Medium Sand		
VES16	1	10195	1.0	1.0	Lateritic Topsoil	HA	
	2	234.5	9.3	10.7	Clayey Sand		$\rho_1 > \rho_2 < \rho_3 < \rho_4$
	3	261.9	19.1	19.1	Fine to Medium sand		
	4	533.8	…..	…..	Medium Sand		
VES17	1	962.5	1.6	1.6	Lateritic Topsoil	HA	
	2	415.6	6.9	8.5	Laterite		$\rho_1 > \rho_2 < \rho_3 < \rho_4$
	3	29089.7	14.5	23.0	Medium Sand		
	4	1476.9	…..	…..	Medium Sand		
VES18	1	1484.4	1.1	1.1	Lateritic Topsoil	KH	
	2	961.6	5.4	6.5	Laterite		$\rho_1 < \rho_2 > \rho_3 < \rho_4$
	3	450.1	13.7	20.2	Fine to Medium sand		
	4	351.6	…..	…..	Medium Sand		
VES19	1	380.7	1.0	1.0	Lateritic Topsoil	KH	
	2	1163.2	5.1	6.1	Laterite		$\rho_1 < \rho_2 > \rho_3 < \rho_4$
	3	244.4	20.4	26.5	Fine to Medium sand		
	4	1693	…..	…..	Medium Sand		
VES20	1	985.3	1.0	1.0	Lateritic Topsoil	HA	
	2	590.8	6.3	7.3	Laterite		$\rho_1 > \rho_2 < \rho_3 < \rho_4$
	3	1118.5	12.0	19.3	Fine to Medium sand		
	4	1805.5	…..	…..	Medium Sand		

Twenty (20) Vertical Electrical Sounding were obtained at the study area. The raw field data for VES were entered into the resistivity software program (WinResist) in a computer which in turn displays the automatically plotted graph without the curve.The VES partial curve matching was done by matching segment by segments of field data curve using both the theoretical master and auxiliary curves (ascending or descending curve type).The curves obtained from the plot of the VES were interpreted quantitatively using partial curve matching and computer iteration, resulting in Table 1 above. The result of resistivity survey shows geoelectric parameters of the Twenty vertical electrical soundings presented in Table 2. The results were analysed to determine the aquifer protection and the delineation of the lithology of the study area. The resistivity values were iterated and used to interpret the curve typed and the lithology of the study area. The result shows four to five distinct layers as shown in Table 2 consists of lateritic topsoil, fine sand, fine to medium grained and medium sand. The first layer is laterite with resistivity ranging from 350 Ωm in VES 4 to 1488 Ωm in VES 7 and thickness varying from 4.6 m in VES 14 to 1.7 m in VES 10. The second layer is fine sand with resistivity ranging from 72.9 Ωm in VES 4 to 434.7 Ωm in VES 14 and thickness varying from 4.6 m in VES 14 to 18.6 m in VES 3. The third layer is fine to medium sand with resistivity ranging from 151.8 Ωm in VES 3 to 3025.4 Ωm in VES 1 and thickness varying from 11.9 m in VES 16 to 46.6 m in VES 7. The fourth layer is medium to coarse sand with resistivity ranging from 379.1 Ωm in VES 6 to 4561.6 Ωm in VES 7. The thickness of this layer cannot be determined because electrode as the current electrode terminated in this layer. The aquiferous layer is in the third layer. Table 2 shows the aquifer resistivity, aquifer thickness and Dar Zarrouk parameters of the aquifer. The aquifer resistivity ranges from 244.4 Ωm in VES19 to 3025.4 Ωm in VES 1 with aquifer thickness varying from 6.0 m in VES 15 to 20.4 m in VES19. The transmissivity of the aquifer varies from 173 to 364 m^2/day. These values indicate that the aquifer transmit water very well. The conductivity varies from 0.0003283 VES 15 to 0.006588 Ω^{-1} VES 3. The longitudinal conductance varies from 0.002785 VES 15 to 0.01522 Ω^{-1}m in VES 3. Transverse resistivity 3506.53 VES 3 to 58633.8 Ω in VES 7.

Table 2: Dar-Zarrouk Parameters from iterated field data at site III

Location	Aquifer Resistivity ρ	Aquifer Thickness H	Conductivity $\sigma = \frac{1}{\rho}$ $(\Omega)^{-1}$	Longitudinal Conductance $S = \sigma \times h$	Transverse Resistivity $R = h\rho$	Transmissivity $T_r = kh$	Quality $k\sigma$
VES1	3025.4	13.7	0.0003305	0.00452	41447.98	137	0.003305
VES2	214.4	18.1	0.004664	0.08442	3880.64	181	0.04664
VES3	151.8	23.1	0.006588	0.1522	3506.58	231	0.06588
VES4	1975.7	18.0	0.0005061	0.009109	35562.6	180	0.005061
VES5	1253.0	14.9	0.0007891	0.01176	18669.7	149	0.007891
VES6	427.4	14.8	0.002340	0.03463	6325.52	148	0.02340
VES7	1258.0	46.6	0.0007949	0.03704	58622.8	466	0.007949
VES8	1359.3	11.1	0.0007357	0.008166	15088.2	111	0.007357
VES9	2244.7	15.8	0.0004455	0.007039	35466.26	158	0.00445
VES10	3045.7	12.7	0.0003283	0.004169	38680.39	127	0.003283
VES11	2190.4	15.7	0.0004565	0.007167	34389.28	157	0.004565
VES12	937.0	11.3	0.001067	0.01206	10588.1	113	0.01067
VES13	222.1	18.2	0.004502	0.08194	4042.22	187	0.04502
VES14	463.8	12.7	0.002156	0.02738	5890.26	127	0.02156
VES15	2154.5	6.0	0.0004641	0.002785	12927	60	0.004641
VES16	1240.0	11.9	0.0008065	0.009597	14.756	119	0.008065
VES17	2908.7	14.5	0.0003438	0.004985	42176.15	145	0.003438
VES18	450.1	13.7	0.002222	0.03044	6166.37	137	0.02222
VES19	244.4	20.4	0.004092	0.08348	4985.76	204	0.04092
VES20	1118.5	12.0	0.0008941	0.01073	13422	120	0.008941

The result of longitudinal conductance shows that the study area is not protected since majority of the protective capacity rating is poor (< 0.1) in all parts of the study area except VES 1which has weak protective capacity. The low value of the protective capacity is as a result of the absence of significant amount of clay as an overburden impermeable material in the study area thereby enhancing the percolation of contaminants into the aquifer.

The aquifer in the studied area is therefore prone to contamination from potential contaminant due to the fact that the water table is very low from the surface, it may take the contaminant plume a long time to get to the aquifer thereby making the groundwater safe for drinking and other domestic purposes. This signifies that the groundwater accumulates in this region of the study. One can describe hydraulic head (elevation) towards the well located within the study areas. Knowing the direction of groundwater flow is very important as it helps technician in citing boreholes where considerable quantity of water can be mined without drying. It is also important for locating septic tank for faeces (sock away) to avoid groundwater contamination.

A typical sounding curve for VES 1 at site 3 is shown in Figure 4 below.

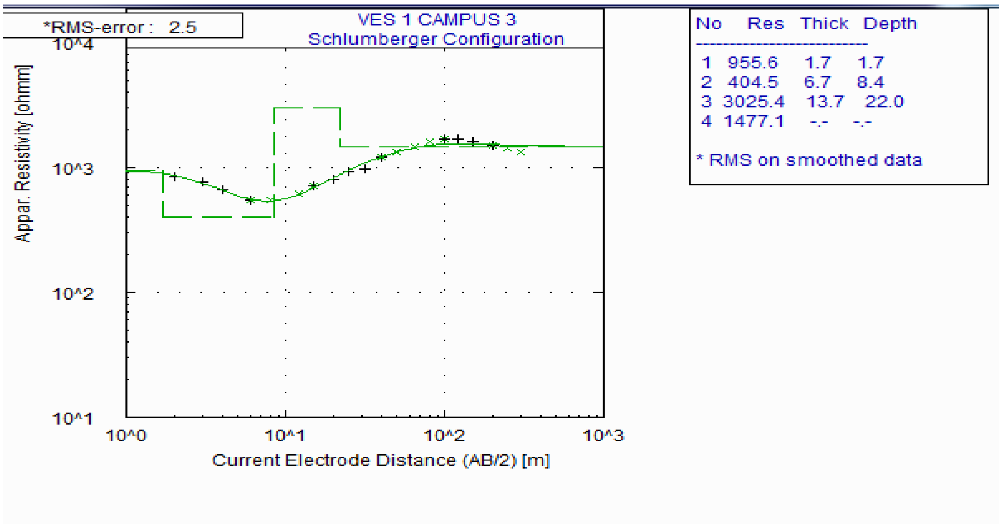


Figure 4. Typical Sounding Curve for VES 1 Site 3.

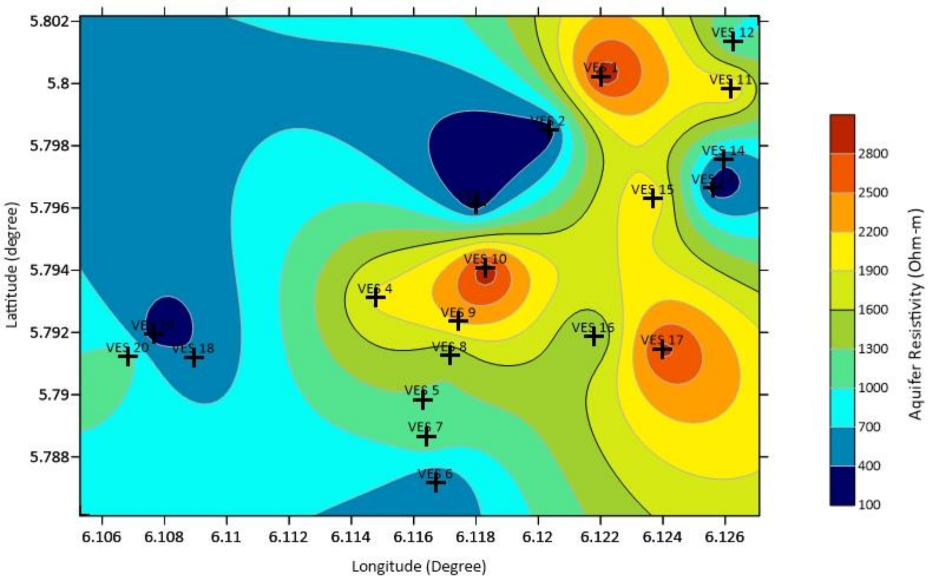


Figure 5: Aquifer Resistivity contour map of the study area.

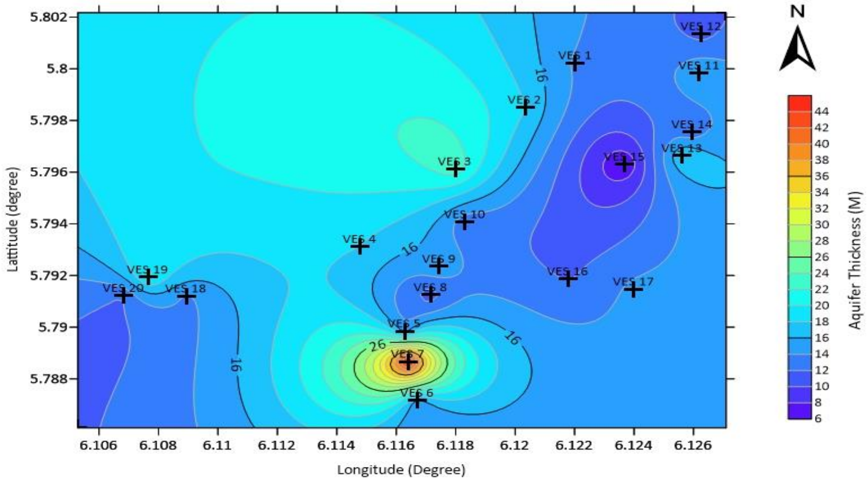


Figure 6: The Aquifer Thickness contour map of the study area.

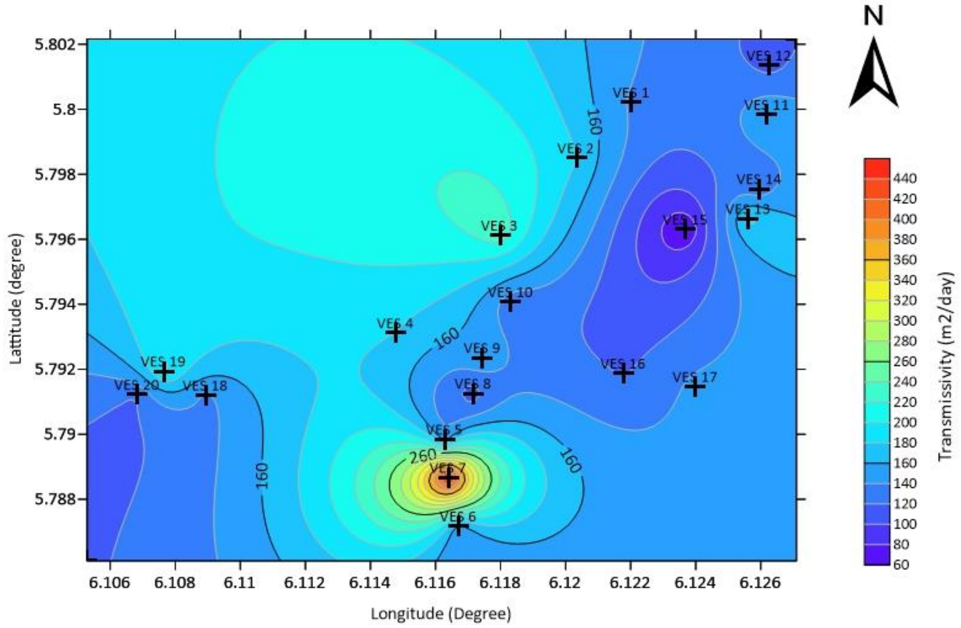


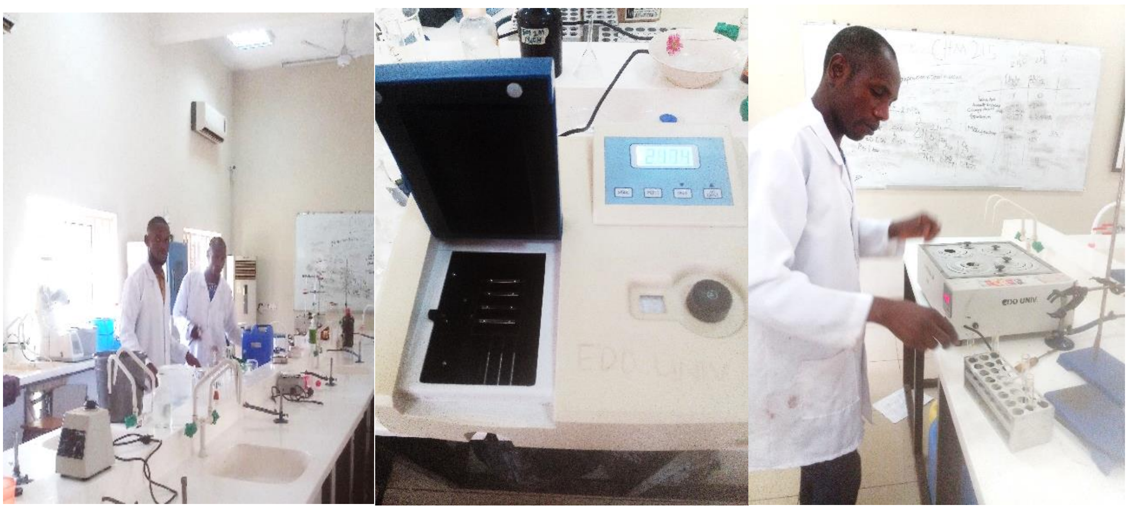
Figure 7: Aquifer Transmissivity contour map of the study area.

Table 3: Result of the Ground Water quality test

S/N	Parameters	Units	Nigeria Standard (Maximum Permitted Level)	Health Impact	Results		
					BH 1 (Delsu Site I)	**BH 2 (Delsu Site III)**	**BH 3 (Delsu Site III)**
1	Physical Analysis						
	Odour		Unobjectionable	None	Negative	Negative	Negative
	Turbidity	NTU	5.0	None	3.5	2.5	3.0
	PH		6.5 - 8.5	None	5.85	6.14	5.91
2	Chemical						

Analysis						
Total Dissolved Solids	Mg/l	500	None	200	50	10
Calcium	Mg/l	50.0		5.4	5.2	6.1
Magnesium	Mg/1	20.0	Consumer Acceptability	0.3	0.1	0.2
Total Hardness	Mg/l CaCo3	150	None	5.0	4.0	4.5
Calcium Hardness	Mg/l CaCo3	200	None	15.6	18.0	17.2
Magnesium Hardness	Mg/l $MgCO_3$	12		1.1	1.0	1.0
Manganese	Mg/1	0.2	Neurological Disorder	Nil	Nil	Nil
Chloride	Mg/l	200	None	38.2	22.5	28.3
Iron	Mg/1	0.05 - 0.3	None	Nil	Nil	Nil
Nitrate	Mg/1	50	Blue Baby Syndrome	1.27	1.00	0.49

NOTE: NTU Means NEPHELOMETRIC TURBIDITY UNIT



(a) Lab Section (b) Spectrophotometer (c) Lab Technician

Plate 2: Cross-Section of the geochemical analysis at the laboratory.

CONCLUSION

20 Schlumberger vertical electrical soundings (VES) were used in the geophysical research survey. The designation of an aquifer unit in the research area has been made possible by the survey's findings. In the study region, four (4) to five (5) unique geo-electric layers were identified, including the lateritic sand/topsoil, red lateritic sand, medium-coarse sand, coarse gravely sand, and gravely sand indicated in table 2. The productive aquifer unit in the area has been identified by survey results. According to computer study, the fourth layer, which is made up of medium-coarse sand grains, has a resistivity that ranges from 1190 ohm-m to 5276.2 ohm-m and a layer thickness that ranges from 110.5 m to 550.7 m. The depth to a sufficient aquifer or groundwater is roughly 120 metres drill depth. Where a groundwater search is necessary in the research region, it is advised to drill at a depth of at least 120 metres. An aquifer depth map was created as a result of the study, and it will be used as a reference for water drillers and decision-makers. The research area's subsurface soil type has been identified, and geophysical data on the groundwater has been provided. Water from boreholes meets the appropriate World Health Organisation (WHO) criteria for drinking water according to hydrogeochemical studies. Since the area's protective capacity is inadequate, periodic geochemical study research should be conducted there to determine when contaminants will reach the aquifer. In order to correlate the findings of the study, it is also advised that additional geophysical exploration techniques, such as seismic refraction, 2-D resistivity (dipole-dipole), ground penetrating radar (GPR), electromagnetic (EM), well logging, etc., be employed.

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