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Application of Vertical Electrical Sounding (VES) For Groundwater Exploration in College of Education, Afaha Nsit and its Environs, Southern Nigeria

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Abstract: Surface geo-electrical survey using vertical electrical sounding (VES) method has been carried out in College of Education, Afaha Nsit and its environs in North-East Senatorial District of Akwa Ibom State in order to determine the aquifer characteristics and groundwater potential of the area. Fifteen vertical electrical sounding were carried out within the area of study with the SSP-ATS-MRP model of an IGLS (Integrated Geo-instruments and Services) resistivity meter employing schlumberger array configuration. The maximum current electrode separation was 400 and 600 in some cases. Interpretation of the VES data by partial curve matching technique aided by computer modelling using a computer inversion software (RES2DINV SOFTWARE VERSION 3.57.37) was used. The interpretation of the vertical electrical sounding (VES) data revealed three to five geoelectric units with depth to the aquiferous layers ranging from 46.3 m to 122.0 m and resistivity of the saturated layers varying between 616.6 and 1,111.9 ohm-m. Aquifer characteristics such as aquifer conductivity (σ), Transverse resistance (R), longitudinal conductance (S) and hydraulic conductivity (K) for all the VES points were computed. σ varies from 0.0001797 – 0.00145 mhos, R from 12,406.6 – 81,127.8 Ωm, S from 0.009 – 0.078 Ωm and K from 7.76 80.35 m/day. Computation of aquifer transmissivity values based on the results obtained showed a wide variation from 276.584 m2/day to 3,376.219 m2/day. The relationships and implications are discussed.

Key points: Aquifer characteristics, geoelectric layers, College of Education, Vertical Electrical Sounding (VES).

1. Introduction

Vertical electrical sounding method is one of the surface geoelectricla surveys used in prospecting for groundwater. Several geophysicists and researchers including Akpabio and Eyenaka (2008), Emenike (2001), Onwuemesi *et al.* (2006). Okorie *et al.* (2020), Igboekwe *et al.* (2012) and Anizoba *et al.* (2015) have reported its efficiency and effectiveness in prospecting for groundwater, fresh water/saline water boundary predication and contaminant plumb predication. However, this study is centered on the use of vertical electrical sounding in prospecting for groundwater in College of Education, Afaha Nsit and its environs.

The study area lies within latitude $4^0 48'46''$N and $7^0 52'45''$ E in North-East Senatorial District of Akwa Ibom State, Nigeria with an area extent of 144.6 sq.km (Figure 1).

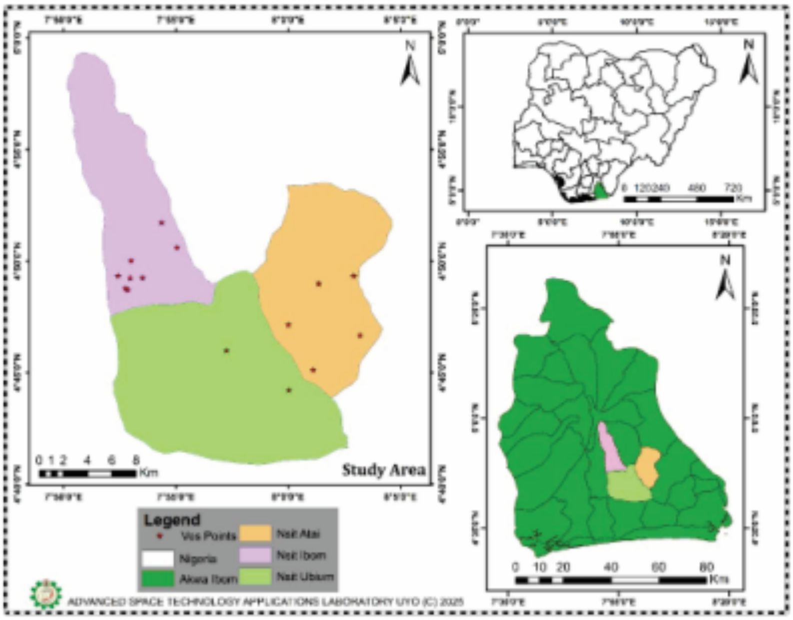


Figure 1: Location map of the study area showing the VES Stations

The study area covers some part of Nsit Atai, Nsit Ibom and Nsit Ubium Local Government Areas of Akwa Ibom State. It is good to note that, College of Education, Afaha Nsit and its environs has been of high economic activity in Nigeria and West African region and its attendance high population, currently the College is now running both Degree/Sandwich/Parttime programmes affiliated to the University of Uyo with a population of over 500,000 people and the basic amenities are over stretched. This population and yearly increase of admission have resulted in acute water increase in the campus. At the same time, it is also worrisome that existing boreholes are not functioning at their maximum yield in the study area.

Hence, the need for proper groundwater development and management in the area become imperative, since it is readily available though in varying quantities.

The research is aimed at determining depths to potential aquifers in the area and their aquifer parameters from vertical electrical soundings: Aquifer conductivity, transverse resistance, longitudinal conductance, hydraulic conductivity and finally aquifer transmissivity.

2. Geology of the Research Area

In terms of geology, according to Mbipom *et al.* (1996), the survey area falls within the coastal region denominated by the Benin formation which is also known as the coastal plain sands (CPS). The Benin formation which is underlain by the parallel Agbada formation covers over 80% of the study area. The Benin formation is entirely within the Genozoic Era (the white formation; yellow colour) especially the Tertiary (Paleogene & Neogene) and Quaternary period and also, especially in the uppermost layers (near the surface, Holocane deposit, green colour) as shown in Figure 2. The major aquifer formation, both confined and unconfined aquifers are encountered at varying depths and sometimes contain varying saline and clay groundwater (Esu and Adekon, 2011). The Benin formation is the uppermost layer in the Niger Delta Complex and the rocks are subdivided into three major formations: Benin, Akata and Agbada formations (Short and Stauble, 1967). The Benin formation consists predominantly of massive highly porous sand and gravels with locally thin shale and clay interbeds to form a multiaquifer system in the Delta (Akpabio and Eyenaka, 2008).

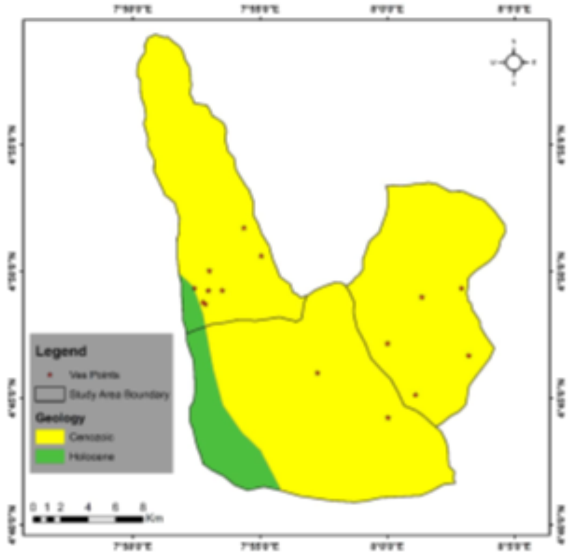


Figure 2: Geological map of the research area

3. Materials and Methods

3.1 Data Acquisition and Interpretation

Fifteen vertical electrical sounding (VES) were carried with the SSP-ATS-MRP model of an IGIS (Integrated Geo-Instruments and Services) resistivity meter using the schlumberger electrode configuration. The instrument measures the resistance of the subsurface earth structure sampled by the survey. Resistance of the earth subsurface measured by the instruments was used to calculate the apparent resistivity (ℓa) in ohm-meter (R) by the geometric factor (K). A log-log graph plot of apparent resistivity (ℓa) against current electrode distance (AB/2) was plotted for each VES station to generate a sounding curve using the conventional partial curve matching technique, in conjunction with auxiliary point diagrams (Oreuana and Mooney, 1966; Keller and Frischknecht, 1966), layer resistivity's and thickness with depths were obtained. Table 1 showed the GPS readings of locations, elevations and co-ordinates of each VES sounding points while Table 2 showed the summary of the VES interpretations.

Table 1: GPS Readings to show the locations, elevations and coordinates of each VES Sounding point

VES	STATION	ELEVATION (m)	LATITUDE	LONGITUDE
1	College of Education Campus	36	$04^{0}\ 48^{1}\ 43.1^{11}$N	$007^{0}\ 52^{1}\ 51.3^{11}$E
2	Afaha Nsit, Nsit Ibom	35	$04^{0}\ 48^{1}\ 47.1^{11}$N	$007^{0}\ 52^{1}\ 45.4^{11}$E
3	Afaha Ikot Ede, Nsit Ibom	35	$04^{0}\ 49^{1}\ 15.2^{11}$N	$007^{0}\ 52^{1}\ 58.0^{11}$E
4	Ikot Akpa Etang, Nsit Ibom	29	$04^{0}\ 50^{1}\ 01.9^{11}$N	$007^{0}\ 53^{1}\ 00.3^{11}$E
5	Mbiaso, Nsit Ibom	34	$04^{0}\ 49^{1}\ 15.4^{11}$	$007^{0}\ 53^{1}\ 30.9^{11}$E
6	St. Paul CNEC School, Afaha/Afia Nsit (Nsit Ubium)	45	$04^{0}\ 51^{1}\ 37.4^{11}$N	$007^{0}\ 55^{1}\ 02.9^{11}$E
7	Afaha Nsit, Nsit Ibom	30	$04^{0}\ 49^{1}\ 21.2^{11}$N	$007^{0}\ 52^{1}\ 25.3^{11}$E
8	Afaha Offiong, Nsit Ibom	50	$04^{0}\ 52^{1}\ 49.1^{11}$N	$007^{0}\ 55^{1}\ 04.9^{11}$E
9	Ikot Eyo, Nsit Ubium	35	$04^{0}\ 46^{1}\ 00.2^{11}$N	$007^{0}\ 57^{1}\ 15.4^{11}$E
10	Ikot Nkwot, Nsit Ubium	36	$04^{0}\ 44^{1}\ 13.8^{11}$N	$008^{0}\ 0^{1}\ 01.6^{11}$E
11	Ikot Ukpong, Nsit Atai	71	$04^{0}\ 47^{1}\ 09.5^{11}$N	$008^{0}\ 00^{1}\ 00.5^{11}$E
12	Ikot Nkpene, Nsit Atai	42	$04^{0}\ 48^{1}\ 59.7^{11}$N	$008^{0}\ 01^{1}\ 21.5^{11}$E
13	Odot I. Nsit Atai	48	$04^{0}\ 49^{1}\ 21.0^{11}$N	$008^{0}\ 02^{1}\ 55.1^{11}$E
14	Ikot Eket, Nsit Atai	33	$04^{0}\ 46^{1}\ 41.2^{11}$N	$008^{0}\ 03^{1}\ 12.0^{11}$E
15	Ibedo, Nsit Atai	39	$04^{0}\ 45^{1}\ 08.1^{11}$N	$008^{0}\ 01^{1}\ 06.5^{11}$E

Table 2: Geoelectric Parameters and Lithology delineation for the 15 (VES) Points

VES Station	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve type	RMS Error
1	1	2551.5	4.8	4.8	Sandy Soil	$\ell_1 < \ell_2 > \ell_3 > \ell_4 < \ell_5$	5.0
	2	4197.7	23.2	28.0	Rivers sand and gravel	KQA	
	3	1133.3	25.3	53.2	Sandstone		
	4	672.8	36.8	90.0	Loose sands		
	5	1824.5	-	-	Top soil		
2	1	232.0	2.4	2.4	Sandstone	$\ell_1 < \ell_2 < \ell_3 > \ell_4$	4.9
	2	916.8	11.8	14.1	Loose sands	AK	
	3	1550.6	39.1	53.2	Clay		
	4	88.4	-	-	Rivers sand and gravel		
3	1	687.4	2.2	2.2	Loose sands	$\ell_1 < \ell_2 > \ell_3 < \ell_4$	4.8
	2	1563.0	30.2	32.4	Sandstone	KH	
	3	820.4	75.2	107.6	Loose sands		
	4	1946.0	-	-	Rivers sand and gravel		
4	1	3158.4	1.0	1.0	Rivers sand and gravel	$\ell_1 < \ell_2 > \ell_3 < \ell_4$	4.4
	2	6703.2	10.0	11.0	Rivers sand and gravel	KH	
	3	786.7	72.1	83.1	Sandstone		
	4	1067.0	-	-	Loose sands		
5	1	309.1	0.5	0.5	Top soil	$\ell_1 < \ell_2 < \ell_3 > \ell_4 < \ell_5$	5.0
	2	587.9	11.8	12.3	Rivers sand and gravel	AKH	
	3	2958.9	31.9	44.2	Loose sands		
	4	456.0	33.4	77.6	Rivers sand and gravel		
	5	1247.7	-	-	Loose sands		
6	1	1394.6	2.3	2.3	Loose sands	$\ell_1 < \ell_2 > \ell_3 > \ell_4$	7.2
	2	1440.1	39.5	41.8	Loose sands	KK	
	3	151.0	19.3	61.2	Top soil		
	4	143.4	-	-	Top soil		
7	1	200.4	1.5	1.5	Top soil	$\ell_1 < \ell_2 > \ell_3 < \ell_4$	4.9
	2	7141.2	13.4	14.9	Sandstone	KH	
	3	455.2	62.7	77.6	Rivers sand and gravel		
	4	3071.9	-	-	Sandstone		
8	1	1119.0	10.6	10.6	Loose sands	$\ell_1 < \ell_2 > \ell_3 < \ell_4$	5.0

	2	3253.1	18.0	28.7	Loose sands	KH	
	3	696.1	59.9	88.6	Rivers sand and gravel		
	4	6454.9	-	-	Rivers sand and gravel		
9	1	930.6	3.0	3.0	Sandstone	$\ell_1<\ell_2>\ell_3<\ell_4$	5.1
	2	3637.5	16.0	19.0	Loose sands	KH	
	3	394.6	47.4	66.4	Rivers sand and gravels		
	4	4385.0	-	-	Rivers sand and gravels		
10	1	660.0	2.8	2.8	Sandstone	$\ell_1<\ell_2>\ell_3<\ell_4$	3.6
	2	1807.3	26.3	29.1	Loose sands	KH	
	3	520.2	70.9	100.0	Rivers sand and gravels		
	4	793.9	-	-	Sandstone		
11	1	1265.7	3.6	3.6	Loose sands	$\ell_1>\ell_2>\ell_3<\ell_4$	5.7
	2	708.1	42.6	46.2	Sandstone	QH	
	3	558.4	75.9	122.0	Rivers sand and gravels		
	4	965.1	-	-	Rivers sand and gravels		
12	1	704.4	0.3	0.3	Sandstone	$\ell_1<\ell_2>\ell_3<\ell_4$	5.3
	2	3980.5	23.1	23.4	Rivers sand and gravels	KH	
	3	201.3	71.4	94.8	Top soil		
	4	1127.4	-	-	Loose sands		
13	1	690.6	1.7	1.7	Rivers sand and gravels	$\ell_1<\ell_2>\ell_3$	4.6
	2	976.7	49.7	51.4	Rivers sand and gravels	K	
	3	182.6	-	-	Top soil		
14	1	1124.2	0.5	0.5	Loose sands	$\ell_1<\ell_2>\ell_3>\ell_4$	5.1
	2	3310.4	4.1	4.6	Rivers sand and gravels	KQ	
	3	1359.7	41.7	46.3	Rivers sand and gravels		
	4	424.9	-	-	Rivers sand and gravels		
15	1	1002.7	0.7	0.7	Loose sands	$\ell_1<\ell_2>\ell_3<\ell_4$	5.0
	2	1915.5	19.8	20.6	Loose sands	KH	
	3	471.8	71.1	91.7	Rivers sand and gravels		
	4	611.8	-	-	Rivers sand and gravel		

Typical field sounding curves and corresponding geologic logs presented as a function of layer thickness and resistivity are also shown (Figure 2a - 16a & 2b – 16b)

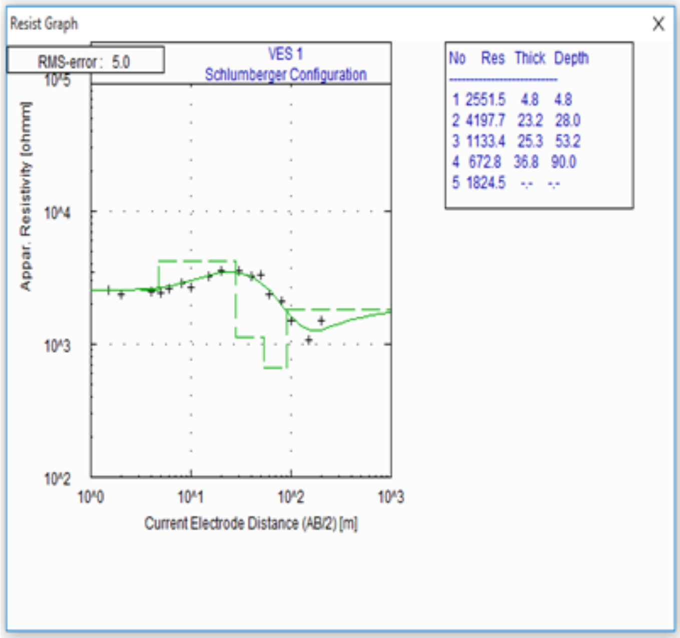


Figure 2a: Sounding Curve VES 1

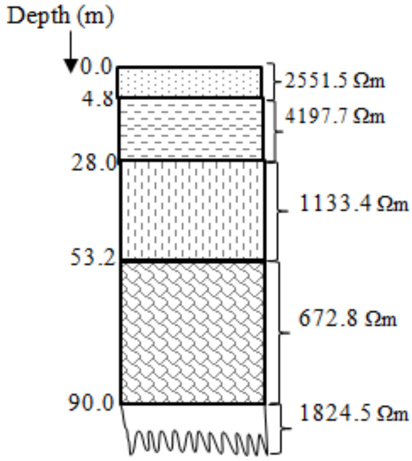


Figure 2b: Geological log for VES 1

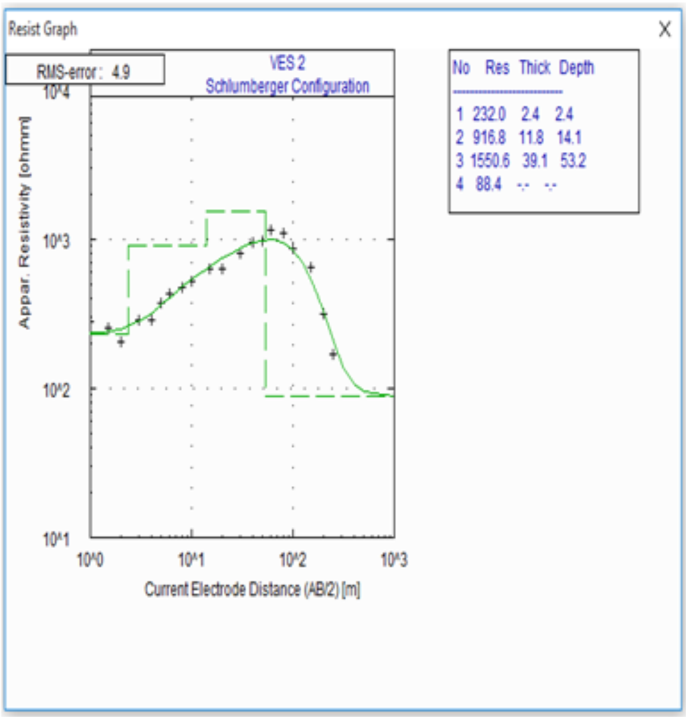


Figure 3a: Sounding Curve VES 2

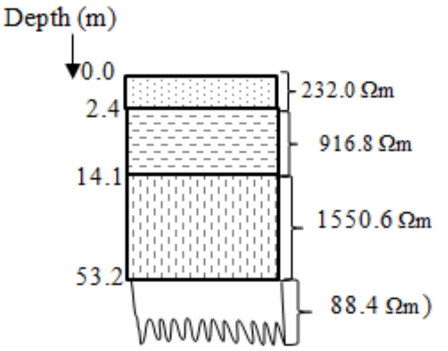


Figure 3b: Geological log for VES 2

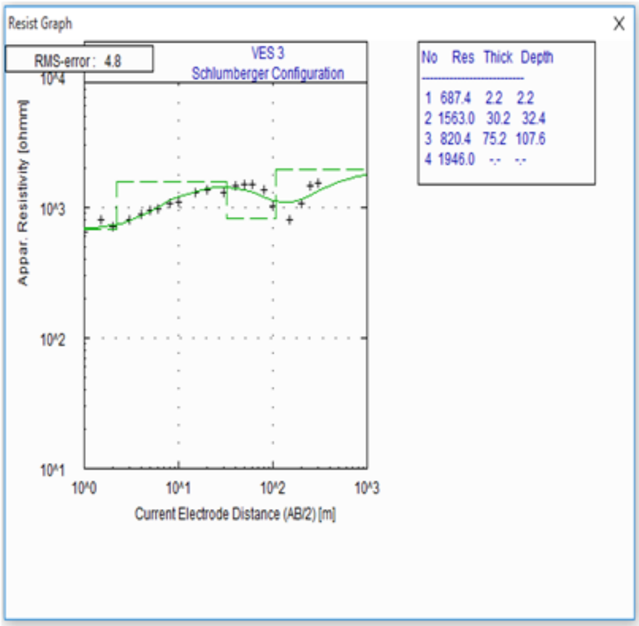


Figure 4a: Sounding Curve VES 3

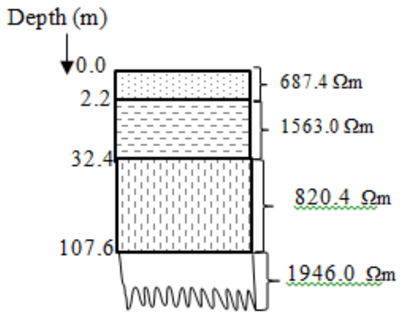


Figure 4b: Geological log for VES 3

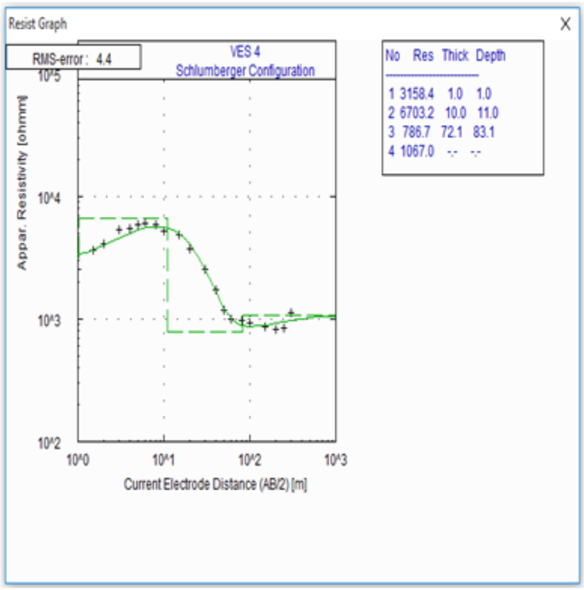


Figure 5a: Sounding Curve VES 4

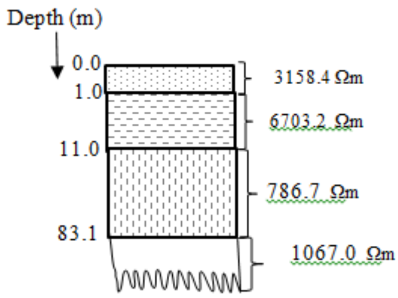


Figure 5b: Geological log for VES 4

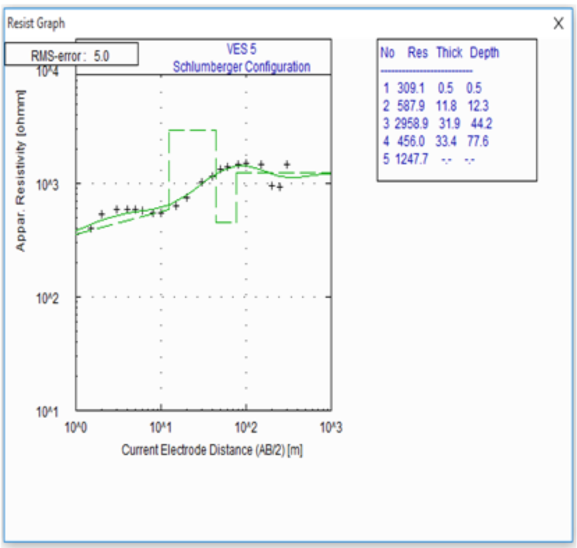


Figure 6a: Sounding Curve VES 5

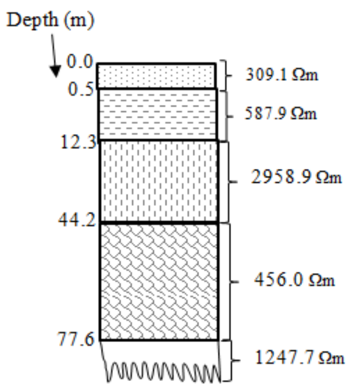


Figure 6b: Geological log for VES 5

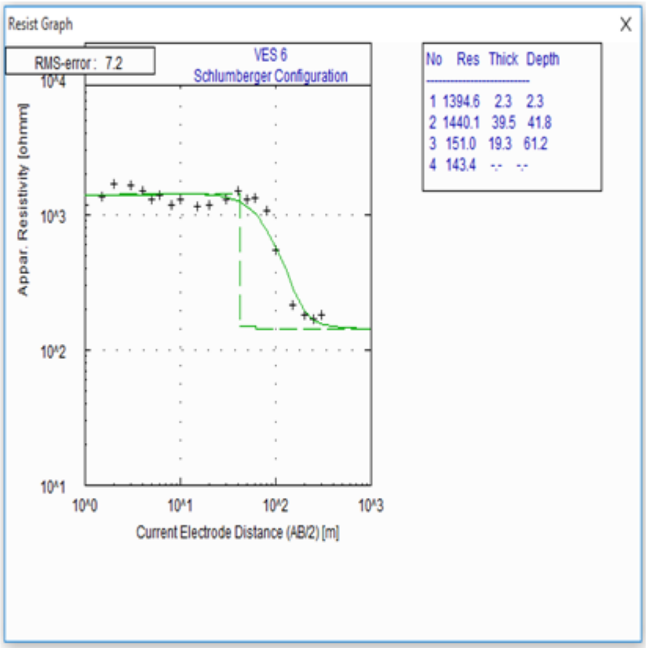


Figure 7a: Sounding Curve VES 6

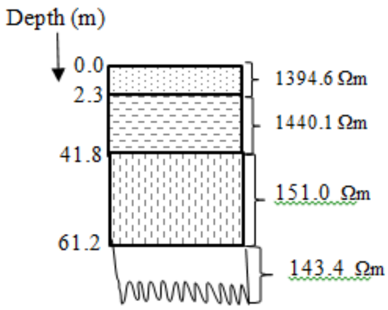


Figure 7b: Geological log for VES 6

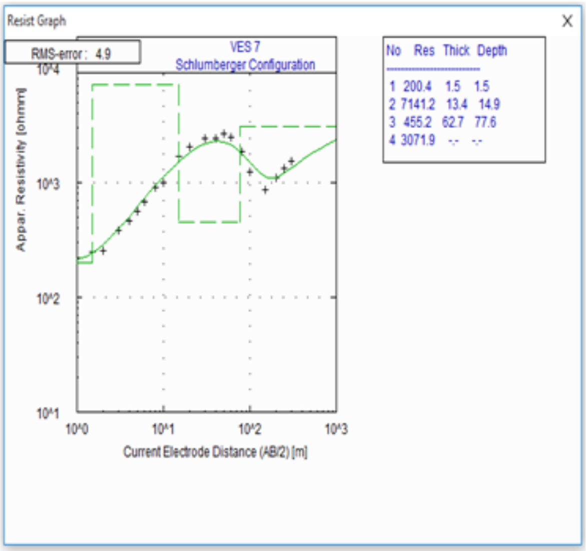


Figure 8a: Sounding Curve VES 7

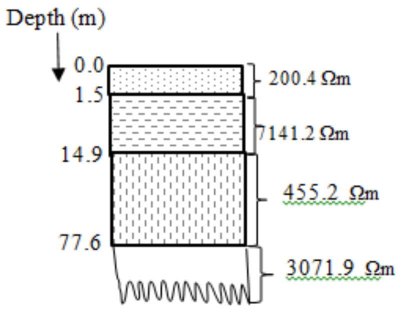
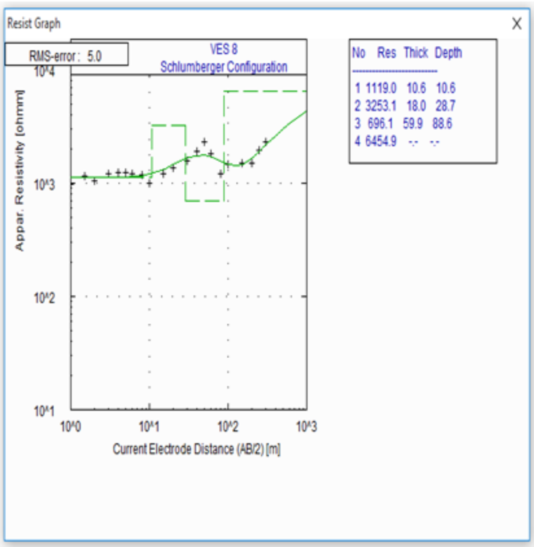


Figure 8b: Geological log for VES 7



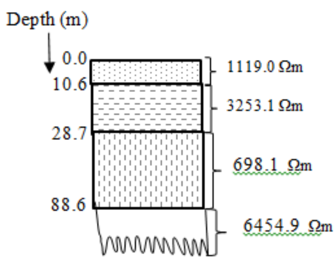


Figure 9b: Geological log for VES 8

Figure 9a: Sounding Curve VES 8

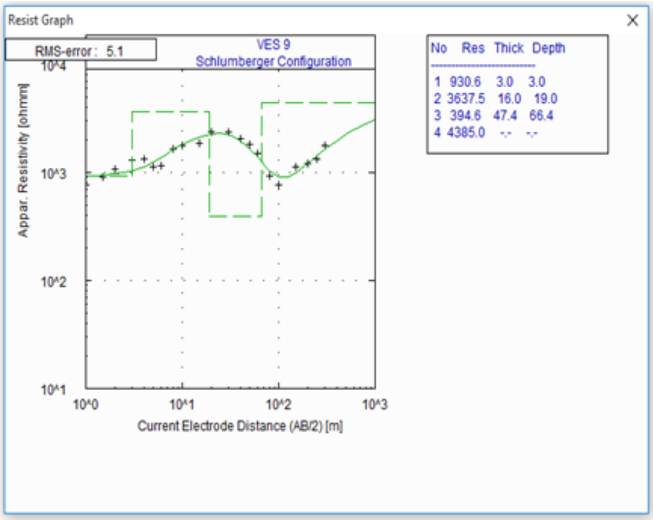


Figure 10a: Sounding Curve VES 9

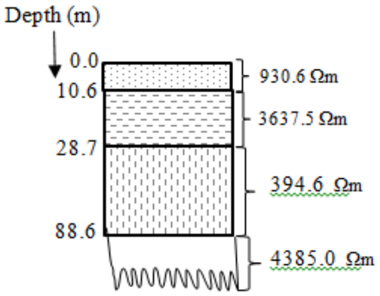


Figure 10b: Geological log for VES 9

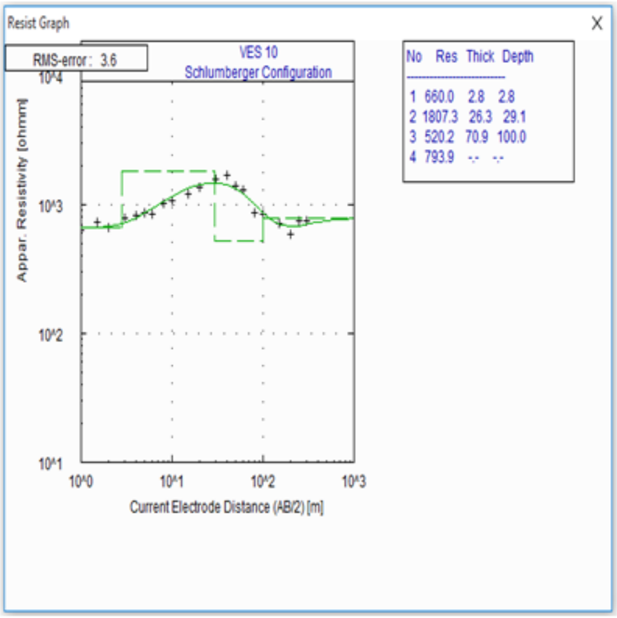


Figure 11a: Sounding Curve VES 10

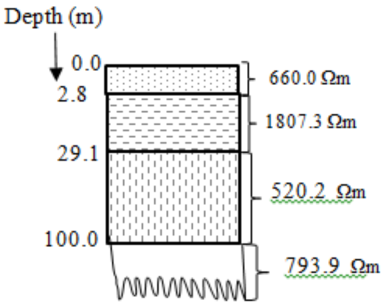


Figure 11b: Geological log for VES 10

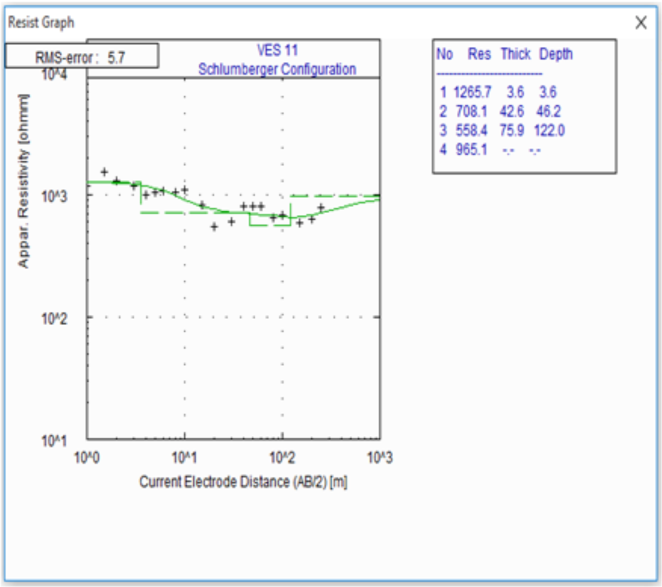


Figure 12a: Sounding Curve VES 11

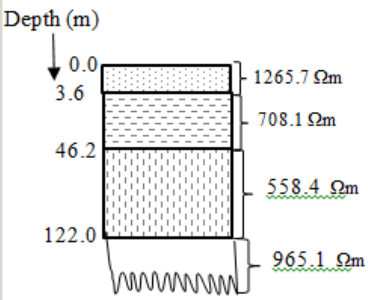


Figure 12b: Geological log for VES 11

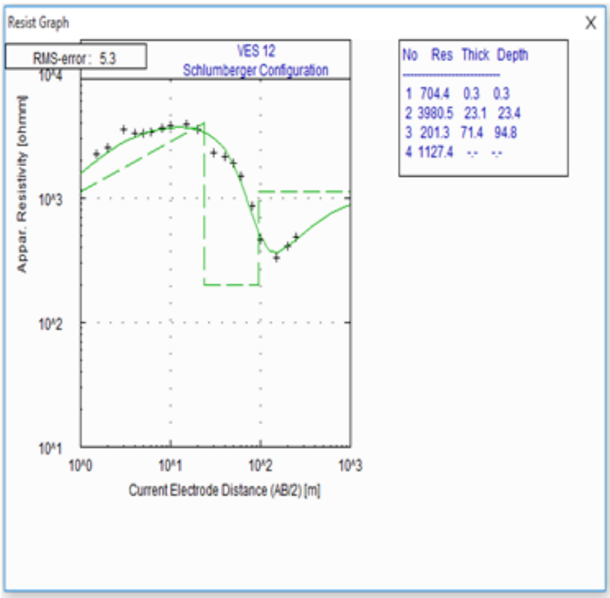


Figure 13a: Sounding Curve VES 12

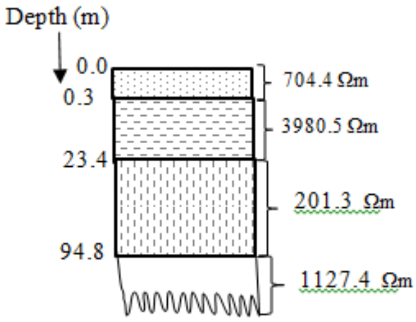


Figure 13b: Geological log for VES 12

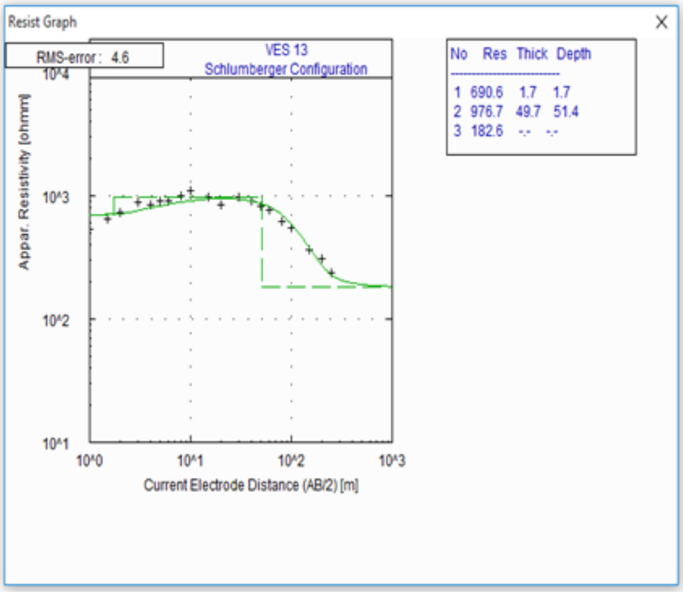


Figure 14a: Sounding Curve VES 13

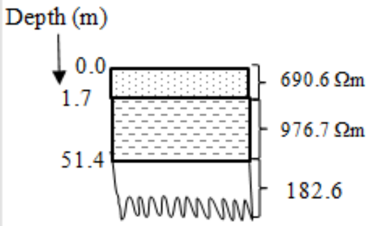


Figure 14b: Geological log for VES 13

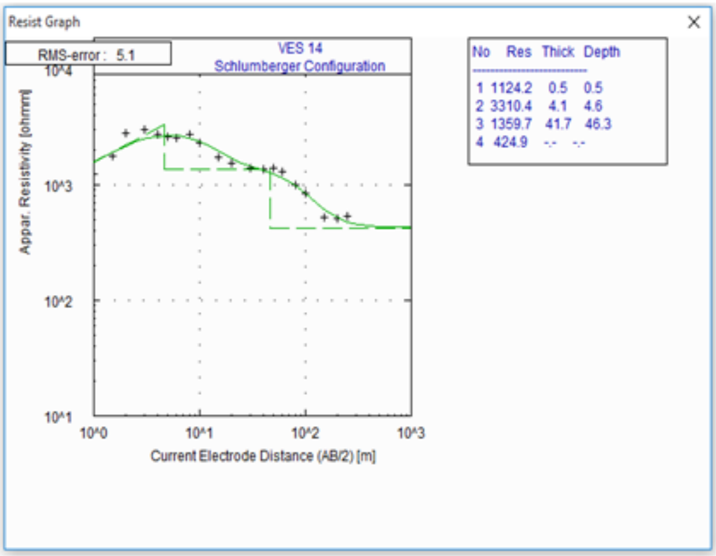


Figure 15a: Sounding Curve VES 14

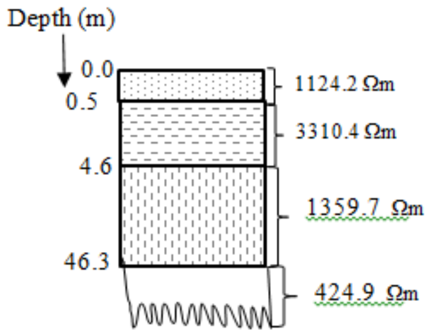


Figure 15b: Geological log for VES 14

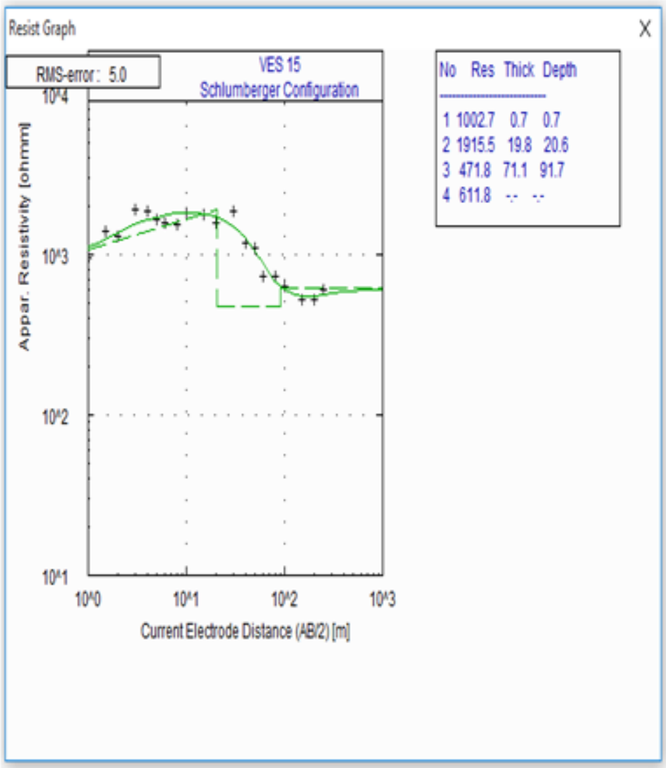


Figure 16a: Sounding Curve VES 15

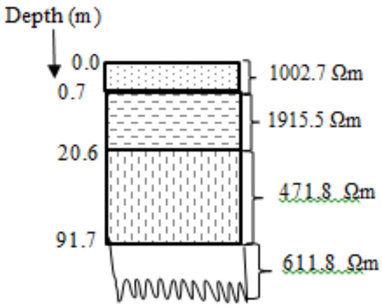


Figure 16b: Geological log for VES 15

3.2 Model Parameter for Determining Aquifer Characteristics

Niwas and Singhal (1981) have established an analytical relationship between aquifer transmissive T and transverse resistance (R) on one hand and between transmissivity and aquifer longitudinal conductance (S) in the other hand. The relationship is given by

$$T = K\sigma R = \frac{KS}{\sigma} = kh \text{ ---------------------- (1)}$$

Where K = hydraulic conductivity, σ = electrical conductivity and h = aquifer thickness

The transverse resistance, (R) if the ith layer having thickness hi and electrical conductance σi, were obtained from the VES interpretation results given by:

$$R = \frac{hi}{\sigma i} = hi\ell i \text{ -------------------------- (2)}$$

The longitudinal conductance S is given by

$$S = hi\sigma i = \frac{hi}{\ell i} \text{ ------------------------- (3)}$$

where hi and ℓi are the thickness and resistivity of the aquiferous layer for each VES $\sigma i = \frac{i}{\ell i}$ ----- ----------------------(4)

From the relations above, knowing the values of hydraulic conductivity (K) here assumed to be 20.82 m/day and with aquifer thickness here assumed to be 22.5, one can estimate the transmisivity and its variations from place to place (Table 3)

Table 3: Aquifer Parameters Calculated from VES Data

VES Stations	Aquifer Resistivity ℓ(Ω_m)	Aquifer Thickness h(m)	Aquifer Conductivity $\sigma = {}^{i}/_{\ell}$	Transverse Resistance R=h. ℓ(Ω_m)	Longitudinal conductance $S = \frac{h}{(\ell_1)}$ Ω_m^{-1}	Hydraulic conductivity K(m/day)	Transmissivity T=kh
1	2076.0	22.5	0.000482	46,710.0	0.011	20.82	468.45
2	697.0	17.8	0.00145	12,406.6	0.026	62.64	1,114.992
3	1254.2	35.9	0.0001797	45,025.6	0.029	7.76	276.584
4	2,928.8	27.7	0.000341	81,127.8	0.009	14.73	408.021
5	1,111.9	11.9	0.000899	13,231.6	0.010	38.84	462.196
6	782.3	61.1	0.00128	47,798.5	0.078	55.29	3,376.219
7	2614.7	25.9	0.000383	67,720.7	0.009	16.55	428.645
8	2880.8	29.5	0.000347	84,988.6	0.010	14.99	442.205
9	2336.9	22.1	0.000428	51,645.5	0.009	18.49	408.629
10	945.4	33.3	0.00186	31,481.8	0.035	80.35	2,675.655
11	874.3	40.7	0.00114	35,584.0	0.047	49.25	2,004.475
12	1503.4	31.6	0.000665	47,507.4	0.021	28.73	907.868
13	616.6	25.7	0.00162	15,846.6	0.042	69.98	1,798.486
14	1554.8	15.4	0.000643	23,943.5	0.009	27.78	427.812
15	1000.5	30.5	0.000910	30,515.3	0.031	39.31	1,198.955

Results and Discussion

Geo-electric parameters are interpreted from geophysical (electrical) resistivity survey data. Interpretations of vertical electrical data using RES2DINV software (Version 3.57.37) lead to the generation of geo-electrical layers. But before these, Table 1 showed the GPS reading showing locations, elevations and co-ordinates of each VES sounding point. The interpretation from these geo-electric layers enhance the identification and interpretation of layer parameters which includes numbers of layers and their apparent resistivities, thickness, depth, curve type and aquifer systems (lithology) Table 2.

About 15 curve types were identified in the study area (Table 2). Groundwater is known to accumulate in the interconnected pores spaces within the lithologic units. The shape of the VES curve (Figure 2a – 16a) depends on the thickness of each layer, the number of layers in the subsurface and the ratio of the resistivity of the layer. The geo-electric characteristics give the respective layer resistivity values and thickness. The section gives a maximum of 5 layers with varying and thickness across each VES point.

In general, there exists a common feature in the resistivity variation pattern of low-high-low in the area (Figure 4). The result shows a wide range of resistivity variation ranging from 88.4 to 7141.2 Ωm. One each of the fifteen sounding curves reflected the presence of five and three geoelectric layers each respectively while the remaining thirteen reflected the presence of four geoelectric layers. The curve types presented in this study are the KQA-type, AK –type, KH – type, AKH – type, KK-type, QH –type, K – type and KQ – type curves; with the KH – curve types being the majority of the curve types in the study area (Table 2).

Interpretation of VES data suggest that VES 2 have very low resistivity in fourth layer (88.4 Ωm) at an indefinable thickness and depth while VES 7 have a very high resistivity in the second layer (7,141.2 Ωm) with a thickness of 13.4m and depth of 14.9 m respectively. This indicates that at high resistivity values, there is likelihood of the layer to be saturated with loose sand, sandy soil, top soil and rivers sand and gravel (Figure 3)

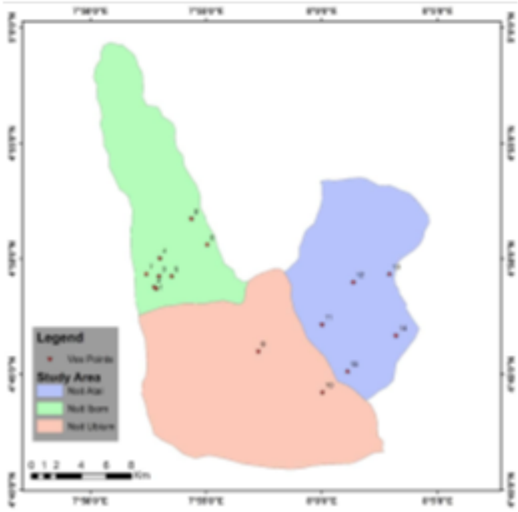


Figure 3: VES points and Local Government Areas

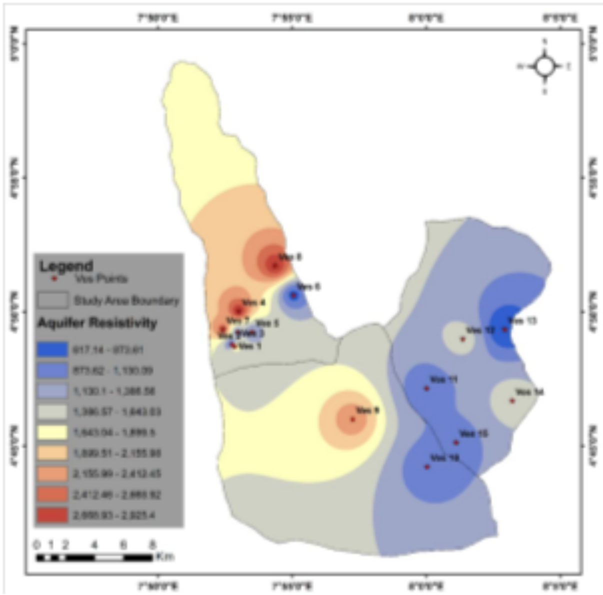


Figure 4: Map of aquifer resistivity in the study area

The aquifer transmissivity varies remarkable from 276.584 – 3,376.219 m^2/day (Table 3). VES locations with high thickness have higher transmissivity (e.g. VES 6, 61.1 m thick). The lowest transmissivity values are found at VES 3 and VES 9 respectively; their thickness are correspondingly low. These results are not out of place since transmissivity is a function of aquifer thickness. VES 1, 3, 4, 5, 7, 8, 9 and 14 have above average resistivities with their longitudinal conductances are correspondingly low. Though their transmissivities are average (468.45; 276.584; 408.021; 462.196; 428.645; 442,205; 408.629 and 427.812 m^2/day) the thin layers also confirms their unsuitability for a productive venture. VES 2, 6, 10, 11, 12, 13 and 15 has transmissivities between 907.868 m^2/day to 3,376.219 m^2/day. VES 6 has high transmissivity of 3,376.219 m^2/day (Figure 5) with a high hydraulic conductivity (55.29 m/day) showed in Table 3.

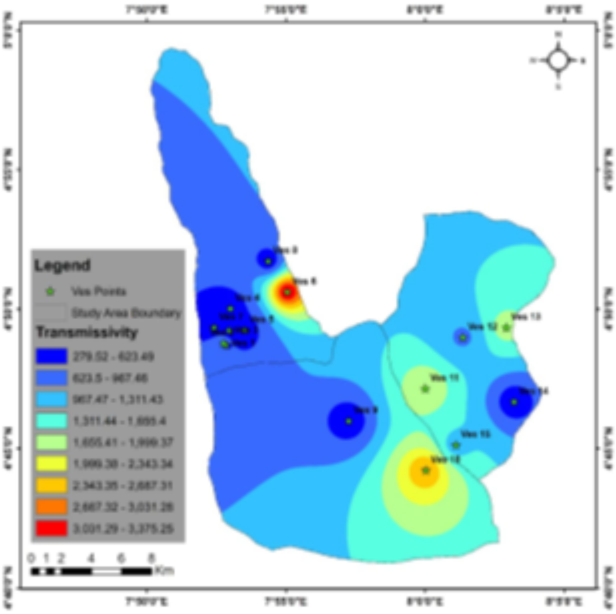


Figure 5: Map of transmissivity in the study area

The distribution of hydraulic conductivity values across the study area (Figure 6) shows that the area in the vicinity of VES 4, 9 and 14 are underlain by resistive aquifer materials (2,928.8 Ωm, thickness 27.7 m; 2,336.9 Ωm, thickness 22.1m and 1554.8 Ωm, thickness 15.4 m). This is so because the hydraulic conductivity is very low. These are obviously not viable area for groundwater prospecting (Figure 6).

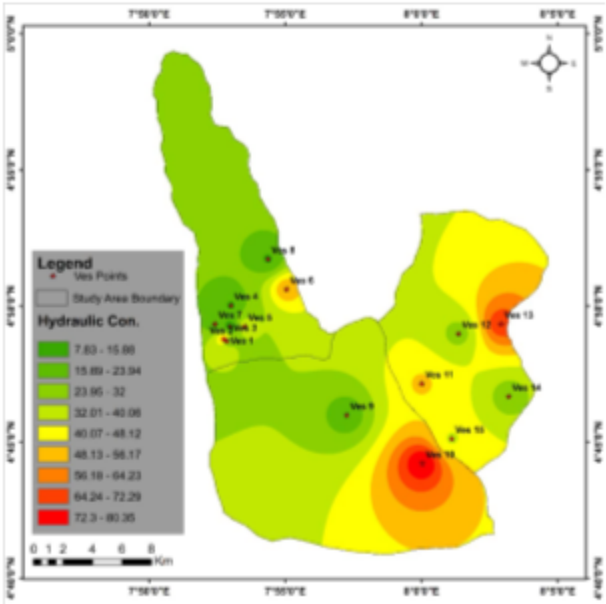


Figure 6: Map of hydraulic conductivity in the study area

The most prolific VES location for exploration are around VES 6 and VES 10, the hydraulic conductivity is the highest, the thickness is correspondingly high.

The results of this study have led to the determination of transmissivity and hence aquifer within the study area. The aquifer varies in thickness from place to place from low values of 11.9 m at VES 5. Depths to the aquifer range from 0.3 m (VES 12) to 107.6 m) (VES 3).

The electrical characteristics and high transmissivity recorded in most parts of the area is not inconsistent with the coastal plain sands consisting of fine-medium -coarse grain sands.

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