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RESEARCH ARTICLE

DETERMINATION OF LITHOLOGICAL INFLUENCE ON HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY USING VES DATA IN PARTS OF RIVERS STATE, NIGERIA

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ABSTRACT

Vertical Electrical Sounding (VES) was used to determine lithological influence on hydraulic conductivity and transmissivity in parts of Rivers State, Nigeria. A total of 10 Vertical Electrical Sounding were conducted at ten locations. The VES data were collected using ABEM terrameter SAS 300B and processed using Win-Resist Software and Microsoft Excel Sheet. The influence of the lithology on the Hydraulic conductivity and transmissivity were analyzed based on the Hydraulic Parameters derived from Dar–Zarrouck parameters. Result from the Vertical Electrical Sounding revealed a four to six geo-electric layers. The aquifer resistivity ranges from 39.40Ωm to 17290.7Ωm. Results of the Hydraulic conductivity shows range of 0.005 to 2.538cm/s with the highest value dominating in the cetral part of the study area suggesting large grain sands that can permeate groundwater flow while the transmissivity ranges from 0.22587cm/s^2 to 132.487 cm/s^2 with average of 19.1587cm/s^2. Area with high transmissivity is identified with high groundwater potential permeable with groundwater flow is seen in the central part of the study area with range of 110 to 135 cm/s^2 indicating a thick aquifer sand. Result from the nearby borehole in correlation with the VES point showed an agreement with the VES data at Ogale and Eagle Island location. The result of the study can be applied in ground water resources management, hydrological studies and provides valuable information for town planner.

KEYWORDS

Aquifer, Conductivity, Grain size, Transmissivity, Electrical resistivity, Lithology

1. INTRODUCTION

Hydraulic conductivity is very important when the determination of how fast water moves through the soil pores. It is a function of the texture, grain size and distribution, density, as well as the macrostructure of the soil (Ahamefula et al., 2013). For most engineering problems involving seepage and drainage of soils, Darcy's Law is valid according to (Asfahani, 2007). The conventional method for determining aquifer parameters is a pumping test, which is expensive and yields results appropriate only to a small region of the aquifer. These methods are expensive and time-consuming especially when a large set of data is required because to hydraulic parameters of geologic formations vary over relatively small spatial scales (Ezeh, 2011). It is difficult to accurately characterize subsurface aquifer properties using just the information obtained from widely spaced boreholes, (Ekwe et al., 2010).

A more complete and accurate characterization of the subsurface shall be achieved by using an integrated exploration approach in which geophysical data are jointly interpreted. Although various geophysical techniques currently been applied to explore and asses water resources, the DC electrical resistivity method still proves the most efficient and cost effective method in groundwater studies. This is due to the closer relationship between the electrical conductivity and some hydrogeological properties of the aquifer (Okonkwo and Ezeh, 2013).

The resolution of flow and transport problems in aquifers depends on information about the hydraulic parameters, which influence the occurrence and movement of groundwater. Considered the most important parameter in hydrogeological studies, hydraulic conductivity (K) indicates the ability of aquifers to conduct water. The amount of water transmitted horizontally throughout the aquifer thickness (h) equals transmissivity (T), generically represented as the product between K and h. However, despite the importance for groundwater assessment and management, information about K and T values are scarce due to limitations in field data acquisitionOkiongboand Chiojioke (2014).

2. GEOLOGY AND LOCATION OF THE STUDY AREA

2.1 Geology of the study area

Rivers State and its environs forms part of Niger–Delta Complex with the usual Benin formation and low land zones of south- eastern Nigeria. The Niger Delta covers most areas of Rivers state including Port Harcourt local government Area. It is made up of extensive river line area all the way through which the River Niger links the Atlantic, divided into several distribution which empty in the sea. The deltaic plains consists of sands that are not consolidated, and the sizes of grains ranges from coarse to medium forming lenticular layers with intercalation of peaty matter and lenses of soft, silt clay and shales. Gravelly layers that make up to about 10m in thickness have been recorded. The uppermost sediments are aerated, made up sandstones that are not consolidated and have an, extremely unpredictable thickness all over the zone. Benin formation that is sandy and are well connected to allow easily passage of water, the lying on top of the laterite earth and unconsolidated top of the formation coupled with the shale beneath that makes up the Bende–Ameki and

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Ogwashi–Asaba series provide the conditions that hydrologicallyfavours the formation of aquifer in the locality (Amechi, 1996).

2.2 Location of the study area

The study area comprises of selected areas within Rivers State and its environs, the base map of the VES points show the areas where the survey were carried out as shown in figure 1. There were no criteria for site selection, it was chosen randomly.

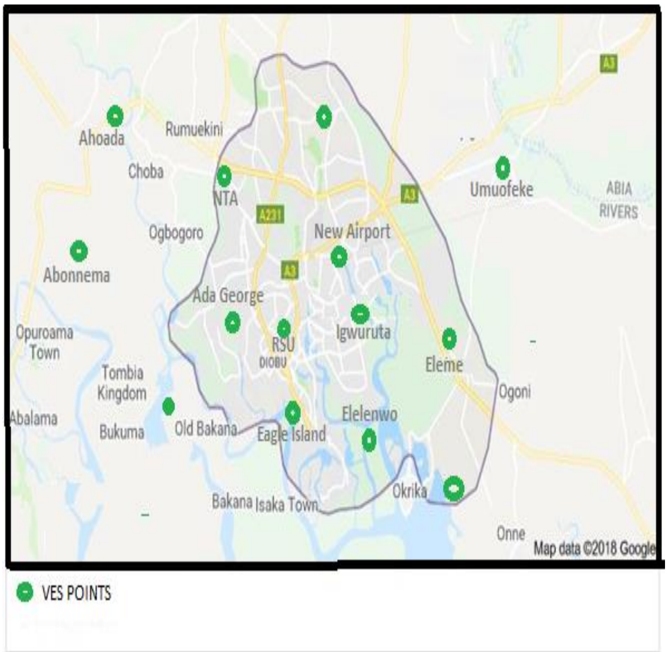

Figure 1: Base Map of the Study Area

3. Materials and Methods

3.1 Materials

Five borehole logs and tenvertical electrical sounding data were used for this study, the materials used for the vertical electrical sounding consist of Abemterremater SAS 300B, four pair of Electrode, measuring tapes, brass Hammer, four reels of cables, four interconnected wires, 12 volts battery, field data sheet and Global positioning system for taking the coordinates of the survey site. For the Geoelectric logging, ABEM Terrameter SAS 300B log 200 along with one current and one potential electrode was used to measure the electrical resistance and the spontaneous potential of the geological material along the open borehole wall.

3.2 Methods

The Schlumberger techniques of Vertical Electrical Sounding (VES) method is the method employed in this study. This was carried out with a resistance meter that gives the value of ground resistance R directly, the four electrodes, inline but not at the same distance is push into the ground to a depth about 0.4m in such a way as to guarantee close electrical contact with the ground. The value of the apparent resistivity, ρ_a obtained by:

$$\rho_a = \pi \frac{(AB/2)^2 - (MN/2)^2}{(MN)} \times R_a \qquad [1]$$

where $\frac{AB}{2}$ *is* the current electrode spacing

$\frac{MN}{2}$ is the potential electrode spacing

And R_a is resistance

For the down hole logging, three down hole log parameters (short and long normal resistivity and spontaneous potential) were determine by connecting the Abemterrameter 300B to the Abemtetrameter SAS log 300B and lowering the sonde into a drilled uncased borehole situated within the study area in order to characterize the rock samples and their influence on hydraulic conductivity and the transmissivity of the area.

3.2.1 Field Procedure

The immediate aim of geo-electric prospecting is to institute the electrical resistivity distributions of the subsurface rock formation from which subsurface depth and structures in the area of interest can be deduced. In this work, direct current was passed into the ground from the Abemterrameter signal averaging system 300 B by means of a pair of current electrode and the resulting potential difference is measured between two properly placed electrodes with respect to the current electrodes. A typical layout of the field procedure is shown in figure 3.1.A and B represent the positive and negative electrode through which the current in injected into the ground (earth) while M and N represent the electrode pair across which the potential difference caused by the injected current is measured. O indicates the centre of the configuration sounding points. The procedure is expanding electrodes A and B in a symmetrical distance from centre O, while MN was kept fixed. For each reading, the current passed into the ground via AB generated a potential difference between M and N. The magnitude of the potential difference is a measure of the ground between the electrodes; MN was then increased as a result of expansion of AB value. The resistance values were recorded on the field data sheet. For the well logging, the potential terminal of the Abemterrameter was connected to the voltage electrode and the current return connected to the current electrode as well. The current return electrode is placed at most 75m away from the borehole point while the electrode was placed away from the borehole point before the probe before lowering the sonde of the logger into the mud filled uncased borehole and measuring and recording the values of the geological parameters against the depth. The Abemterrameter SAS 300B log 200 was used to measure the electrical resistivity and the spontaneous potential of the opened borehole wall.

3.2.2 Field Data interpretation

The apparent resistivity (ρ_a) value plotted as a function of the current electrode spacing (AB/2) resulted in field curves for each VES location. The classification of the real resistivity ($\rho_{a\,aquifer}$,Ωm) and ($h_{aquifer}$, m) of the aquifer from the field curves was achieved by inversion of the field data, elaboration of the geoelectric models and verification of the geoelectric models ability to represent saturated formation. The VES data was elaborated on the geoelectric models using WinResist geophysical software which is software to solve regularization of nonlinear inversion problem by Tikhonov's approach. The result of the VES was interpreted using the Winresist software to determine the aquifer depth and to estimate the hydraulic conductivity and transmissivity while the well log data was interpreted on a log-log graph of Microsoft excel in order to generate thelithologic section.

4. Results and Discussion

4.1 Results

4.1.1 Vertical Electrical Sounding (VES) Data Presentation

The results of the Vertical Electrical Sounding (VES) of the study area are presented in Tables 1 to 10 which show the values of potential electrode spacing, current electrode spacing, resistivity and geometric factor and figures 2 to 11 which show the VES curves and models.

4.1.2 Aquifer and Hydraulic Parameter Evaluation

Table 11 shows the aquifer and hydraulic parameters evaluated for the study area.

4.1.3 Geoelectric Layer Parameter Evaluation

Table 12 shows the geoelectric layer parameter evaluated for the study area.

Table 1: VES of Enerst Cole

AB/2 (m)	MN/2(m)	K	RHO (Ωm)
1	0.3	5.236	1.5708
1.5	0.3	11.7809	3.53427
2	0.3	20.944	6.2832
2.5	0.3	31.7249	9.51747
4	0.5	50.2655	25.13275
5	0.5	78.5398	39.2699
7	0.5	76.969	38.4845
8	1	100.531	100.531
10	1	157.08	157.0796
12	1	226.195	226.1947
15	1.5	235.619	353.4291
20	1.5	251.327	376.9911
25	2.5	392.699	981.74775
30	2.5	565.487	1413.7168
40	5	502.655	2513.274
50	5	785.398	3926.991
70	10	769.69	7696.902
80	10	1005.31	10053.096
100	10	1590.8	15907.963

Table 2: VES of New Airport

AB/2 (m)	MN/2(m)	K	RHO (Ωm)
1	0.3	5.236	1.5708
1.5	0.3	11.7809	3.53427
2	0.3	20.944	6.2832
2.5	0.3	31.7249	9.51747
4	0.5	50.2655	25.13275
5	0.5	78.5398	39.2699
7	0.5	76.969	38.4845
8	1	100.531	100.531
10	1	157.0796	157.0796
12	1	226	226.1947
15	1.5	235.6194	353.4291
20	1.5	251.3274	376.9911
25	2.5	392.6991	981.74775
30	2.5	565.4867	1413.71675
40	5	502.6548	2513.274
50	5	785.3982	3926.991
70	10	769.6902	7696.902
80	10	1005.3096	10053.096
100	10	1590.7963	15907.963
120	15	1507.9645	22619.4675
150	15	2356.1945	35342.9175

Table 3: VES of Elechi

AB/2 (m)	MN/2(m)	K	RHO (Ωm)
1	0.3	5.236	1.5708
1.5	0.3	11.7809	3.53427
2	0.3	20.944	6.2832
2.5	0.3	31.7249	9.51747
4	0.5	50.2655	25.13275
5	0.5	78.5398	39.2699
7	0.5	76.969	38.4845
8	1	100.531	100.531
10	1	157.0796	157.0796
12	1	226	226.1947
15	1.5	235.6194	353.4291
20	1.5	251.3274	376.9911
25	2.5	392.6991	981.74775
30	2.5	565.4867	1413.71675
40	5	502.6548	2513.274
50	5	785.3982	3926.991

Table 4: VES of OgaleEleme

AB/2 (m)	MN/2(m)	K	RHO (Ωm)
1	0.3	5.236	1.5708
1.5	0.3	11.7809	3.53427
2	0.3	20.944	6.2832
2.5	0.3	31.7249	9.51747
4	0.5	50.2655	25.13275
5	0.5	78.5398	39.2699
7	0.5	76.969	38.4845
8	1	100.531	100.531
10	1	157.0796	157.0796
12	1	226	226.1947
15	1.5	235.6194	353.4291
20	1.5	251.3274	376.9911
25	2.5	392.6991	981.74775
30	2.5	565.4867	1413.7168
40	5	502.6548	2513.274
50	5	785.3982	3926.991
70	10	769.6902	7696.902
80	10	1005.3096	10053.096
100	10	1590.7963	15907.963
120	15	1507.9645	22619.468

Table 5: VES of Ahoada			
AB/2(m)	**MN/2(m)**	**K**	**RHO(Ωm)**
1	0.3	5.236	97.80848
1.5	0.3	1.7809	19.696754
2	0.3	20.944	155.61392
2.5	0.3	31.7249	183.36992
4	0.5	50.2655	248.81423
5	0.5	78.5398	278.03089
7	0.5	76.969	128.53823
8	1	100.531	260.37529
10	1	157.0796	273.00434
12	1	226.1947	245.64744
15	1.5	235.6194	298.7654
20	1.5	251.3274	213.12564
25	2.5	392.6691	406.41252
30	2.5	565.4867	451.25839
40	5	502.6548	259.87253
50	5	785.3982	589.04865
70	10	769.6902	625.75813
80	10	1005.3096	586.0955
100	10	1590.7963	620.41056
120	15	1507.9645	674.06013
150	15	2356.1945	631.46013
200	15	4188.7902	816.81409

Table 6: VES of Aggrey Road			
AB/2(m)	**MN(m)**	**K**	**RHO(Ωm)**
1	0.6	5.236	3.1416
1.5	0.6	11.7809	7.06854
2	0.6	20.944	12.5664
2.5	0.6	32.7249	19.63494
3.2	1	32.1699	32.1699
4	1	50.2655	50.2655
5	1	78.5398	78.5398
6	1	113.0973	113.0973
7	2	76.969	153.938
8	2	100.531	201.062
10	2	157.0796	314.1592
12	2	226.1947	452.3894
12	3	150.7964	452.3892
15	3	235.6194	706.8582
20	3	418.879	1256.637
20	5	251.3274	1256.637
25	5	392.6991	1963.4955
30	5	565.4367	2827.1835
30	10	282.7433	2827.433
40	10	502.6548	5026.548
50	10	785.3982	7853.982
50	15	523.5988	7853.982
60	15	753.9822	11309.733
70	15	1026.2536	15393.804
70	20	769.6902	15393.804
80	20	1005.3096	20106.192
100	20	1570.7963	31415.926
120	20	2261.9467	45238.934

Table 7: VES of IPO 3			
AB/2 (m)	**MN/2(m)**	**K**	**RHO (Ωm)**
1	0.6	5.236	54.40204
1.5	0.6	11.7809	79.992311
2	0.6	20.944	91.1064
2.5	0.6	32.7249	85.739238
3.2	1	32.1699	72.703974
4	1	50.2655	74.8453295
5	1	78.5398	81.2101532
6	1	113.0973	79.0550127
7	2	76.969	91.131296
8	2	100.531	77.207808
10	2	157.0796	64.8738748
12	2	226.1947	60.1677902
12	3	150.7964	81.430056
15	3	235.6194	81.7599318
20	3	418.879	73.303825
20	5	251.3274	85.7026434
25	5	392.6991	105.636058
30	5	565.4367	98.9514225
30	10	282.7433	74.3614879
40	10	502.6548	77.911494
50	10	785.3982	81.6814128
50	15	523.5988	92.6769876
60	15	753.9822	135.716796
70	15	1026.2536	164.200576
70	20	769.6902	240.913033
80	20	1005.3096	207.093778
100	20	1570.7963	183.311928
120	20	2261.9467	341.553952
120	30	1507.7963	274.418927
150	30	2356.1945	325.154841
200	30	4188.7902	531.976355
200	50	2513.2741	535.327383
250	50	3926.9908	691.150381
300	70	5654.8668	1006.56629
300	70	4039.1906	848.230026

Table 8: VES of Umuidike			
AB/2(m)	**MN(m)**	**K**	**RHO(Ωm)**
1	0.6	5.236	27.27956
1.5	0.6	11.7809	219.006931
2	0.6	20.944	975.9904
2.5	0.6	32.7249	471.893058
3.2	1	32.1699	691.65285
4	1	50.2655	1115.8941
5	1	78.5398	1528.38451
6	1	113.0973	1904.55853
7	2	76.969	1386.21169
8	2	100.531	1440.60923
10	2	157.0796	1630.48625
12	2	226.1947	1671.57883
12	3	150.7964	1155.10042
15	3	235.6194	765.76305
20	3	418.879	815.138534
20	5	251.3274	779.11494
25	5	392.6991	2882.41139
30	5	565.4367	4647.88967
30	10	282.7433	2567.30916
40	10	502.6548	2518.30055
50	10	785.3982	5434.95554
50	15	523.5988	2366.66658
60	15	753.9822	3287.36239
70	15	1026.2536	4022.91411
70	20	769.6902	3378.93998
80	20	1005.3096	3699.53933
100	20	1570.7963	9770.35299
120	20	2261.9467	389.054832
120	30	1507.7963	60.311852
150	30	2356.1945	3793.47315
200	30	4188.7902	22535.6913
200	50	2513.2741	17190.7948

Table 9: VES of Elelenwo			
AB/2(m)	MN/2(m)	K	RHO (Ωm)
1	0.3	5.236	137.1
1.5	0.3	11.7809	1648.2
2	0.3	20.944	2032.9
2.5	0.3	32.7249	2361.9
3.2	0.5	32.1699	2697
4	0.5	50.2655	3090.2
5	0.5	78.5398	3224.7
6	0.5	113.0973	3275.9
7	1	76.969	3338.9
8	1	100.531	3342.5
10	1	157.0796	3247.2
12	1	226.1947	3078.4
12	1.5	150.7964	2985.4
15	1.5	235.6194	3035.9
20	1.5	418.879	2969.3
20	2.5	251.3274	3010.1
25	2.5	392.6991	3070.5
30	2.5	565.4367	3185.9
30	5	282.7433	3218.1
40	5	502.6548	3223
50	5	785.3982	3130.5
50	7.5	523.5988	2930.9
60	7.5	753.9822	2953.8
70	7.5	1026.2536	2647.1
70	10	769.6902	2634.7
80	10	1005.3096	2500.3
100	10	1570.7963	2294.4
120	10	2261.9467	1996.4
120	15	1507.7963	1841.3
150	15	2356.1945	1448
200	15	4188.7902	1410.7
200	25	2513.2741	983.6
250	25	3926.9908	999.3
450	30	5654.8668	251.3
500	30	4039.1906	107.9

Table 10: VES of Industrial Road			
AB/2 (m)	MN/2(m)	K	RHO (Ωm)
1	0.6	5.236	3.1416
1.5	0.6	11.7809	7.06854
2	0.6	20.944	12.5664
2.5	0.6	32.7249	19.63494
3.2	1	32.1699	32.1699
4	1	50.2655	50.2655
5	1	78.5398	78.5398
6	1	113.0973	113.0973
7	2	76.969	153.938
8	2	100.531	201.062
10	2	157.0796	314.1592
12	2	226.1947	452.3894
12	3	150.7964	452.3892
15	3	235.6194	706.8582
20	3	418.879	1256.637
20	5	251.3274	1256.637
25	5	392.6991	1963.4955
30	5	565.4367	2827.1835
30	10	282.7433	2827.433
40	10	502.6548	5026.548
50	10	785.3982	7853.982
50	15	523.5988	7853.982
60	15	753.9822	11309.733
70	15	1026.2536	15393.804
70	20	769.6902	15393.804
80	20	1005.3096	20106.192
100	20	1570.7963	31415.926
120	20	2261.9467	45238.934
120	30	1507.7963	45233.889
150	30	2356.1945	70685.835
200	30	4188.7902	125663.706
200	50	2513.2741	125663.705
250	50	3926.9908	196349.54
300	60	5654.8668	339292.008
300	60	4039.1906	242351.436
350	70	5497.7871	384845.097

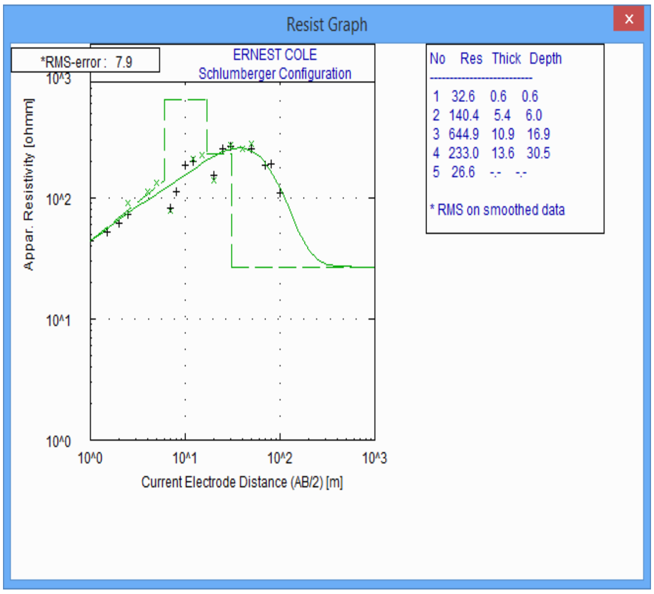

Figure 2: Ernest Cole VEScurve and Model

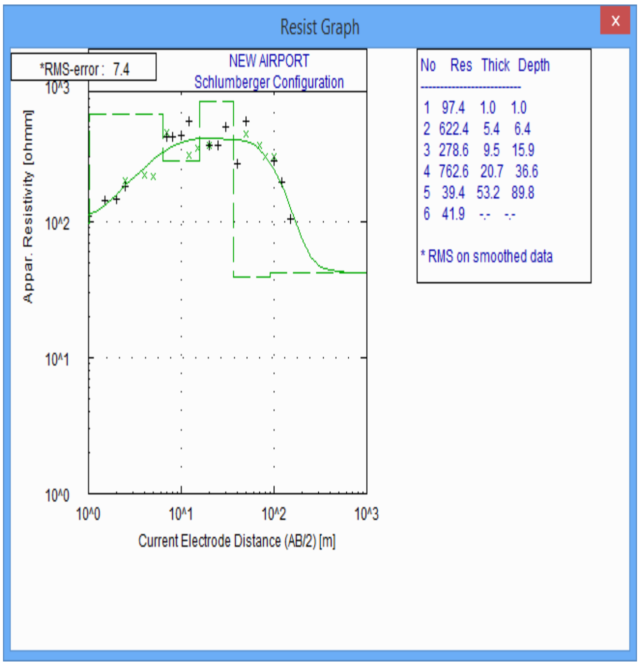

Figure 3: New Airport VEScurve and Model

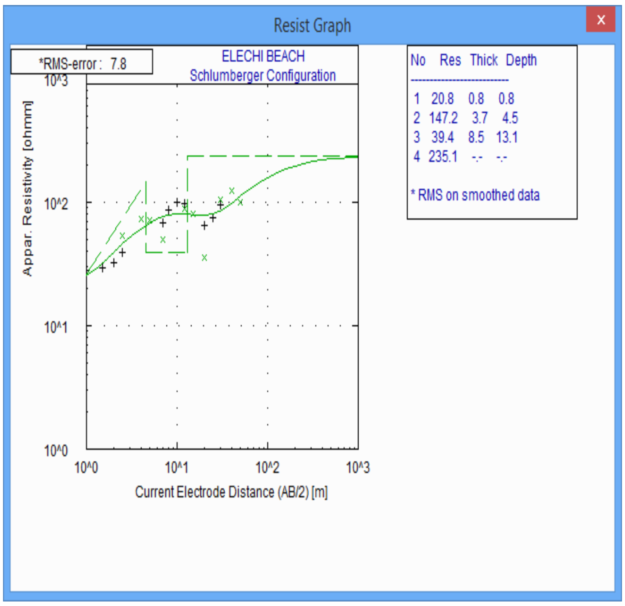

Figure 4: Elechi Beach VES curve and Model

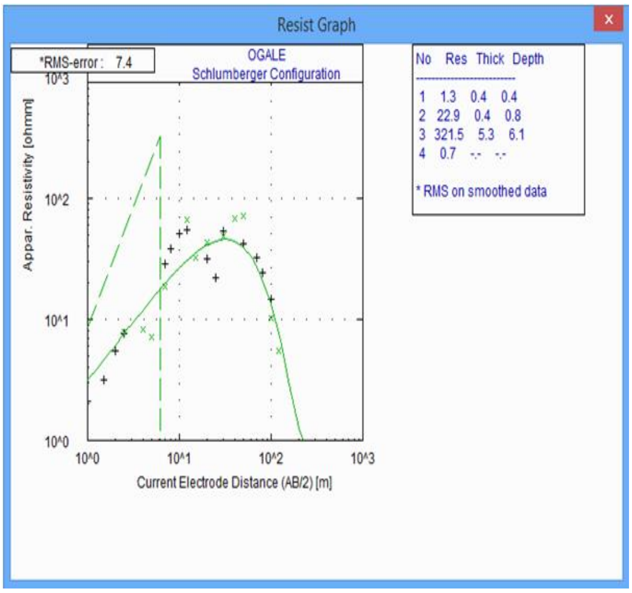

Figure 5: Ogale Eleme VES curve and Model

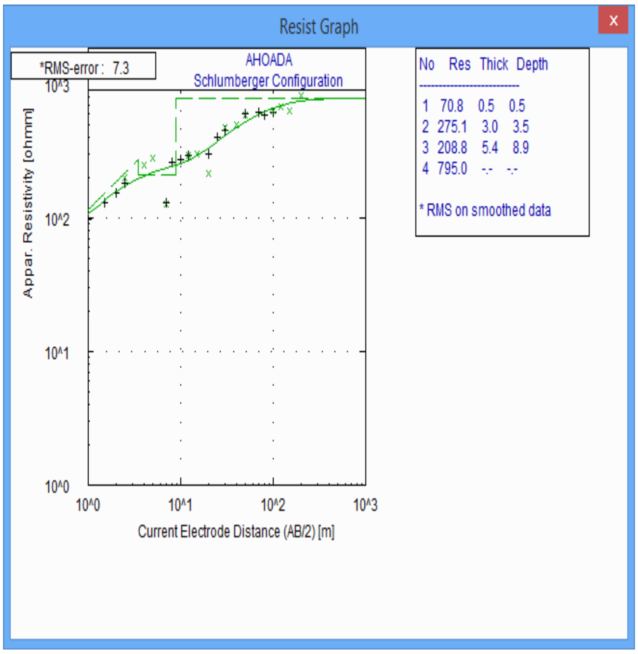

Figure 6: Ahoada VES curve and Model

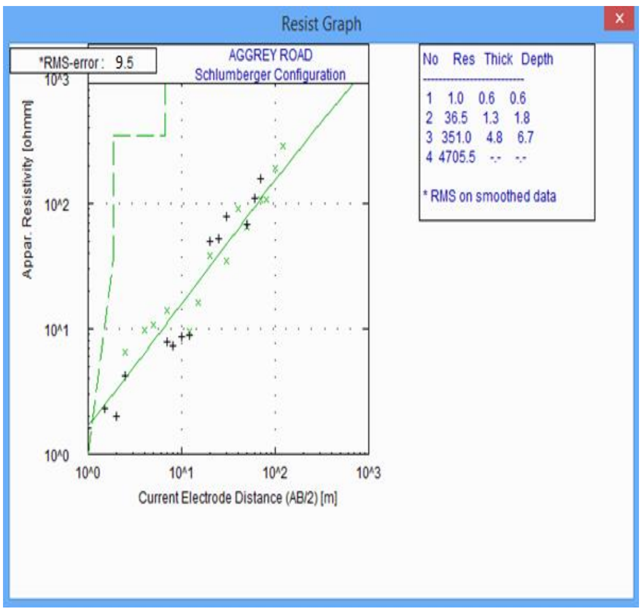

Figure 7: Aggrey Road VES curve and Model

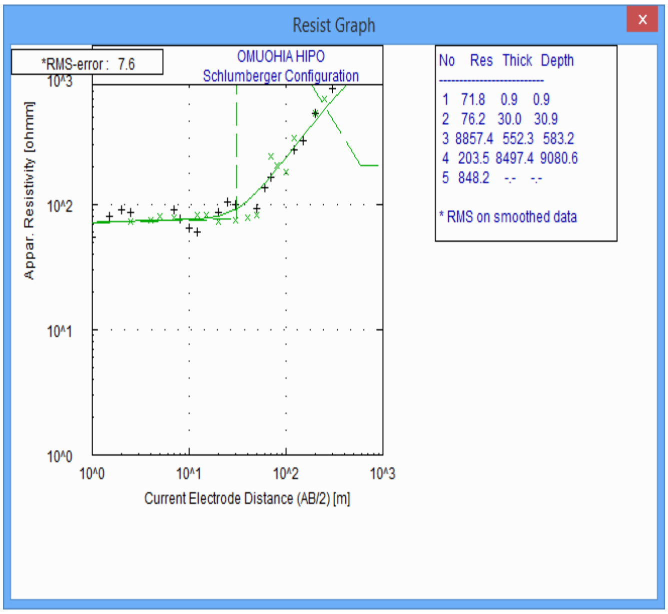

Figure 8: Ipo 3 VES curve and Model

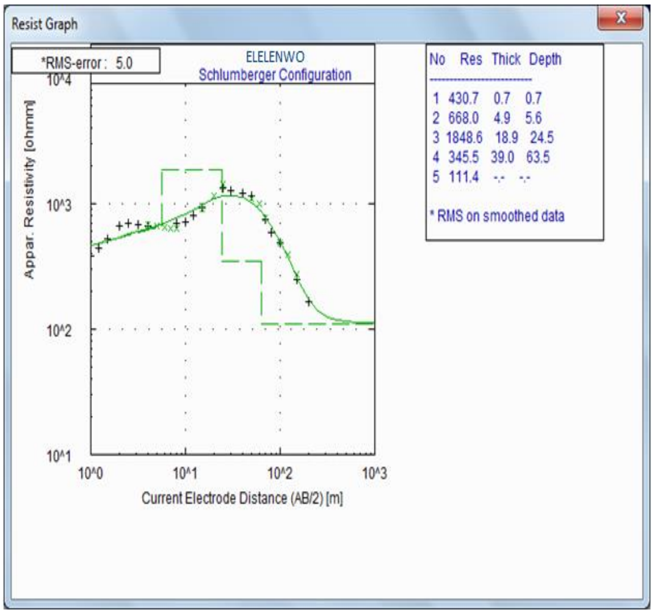

Figure 10: Elelenwo VES curve and Model

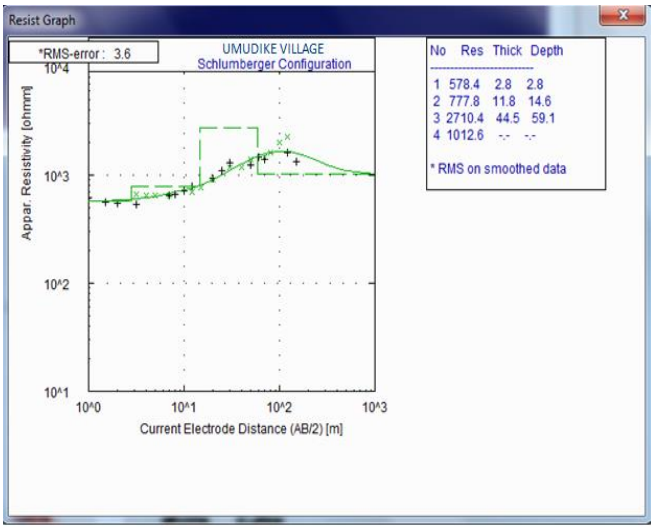

Figure 9: Umuodike VES curve and Model

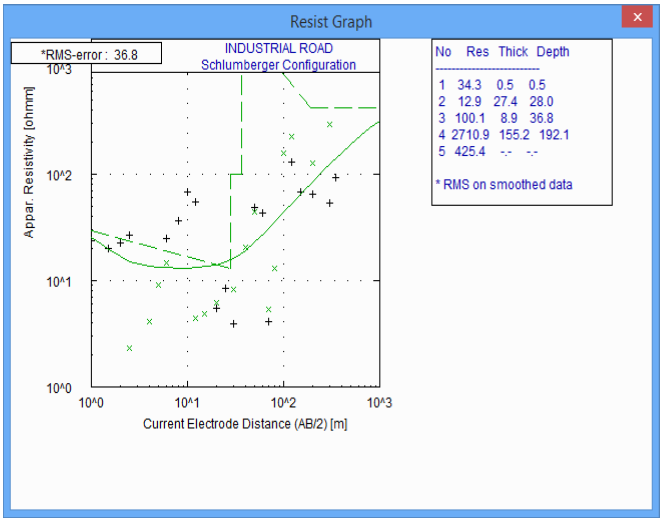

Figure 11: Industrial Road VES curve and Model

Table 11: Aquifer and Hydraulic Parameters

Station	Depth(m)	Thickness(m)	Aquifer Resistivity(Ωm)	S=h/ρ	T=hρ	σ=1/ρ	T=σh	Northing	Easting	Elevation(m)	No. Layers	Curve Type
Enerst Cole	30.5	13.6	233	0.05837	3168.8	0.00429	0.0584	280057	528829	60	5	AKQ
New airport	89.8	52.2	39.4	1.32487	2056.7	0.02538	1.3249	273182	554591	75	6	KHKH
Elechi Beach	23.4	19.2	625	0.03072	12000	0.0016	0.0307	287892	577455	16	4	HK
Ogale	20	13.9	40	0.3475	556	0.025	0.3475	292126	529504	21	4	AK
Ahoada west	53	44.1	795	0.05547	35060	0.00126	0.0555	237968	558779	22	4	HK
Aggrey Road	80	73.3	4705.5	0.01558	344913	0.00021	0.0156	280805	526749	38	4	AA
Ipo 3	30.9	30	76.2	0.3937	2286	0.01312	0.3937	274412	558059	76	5	AKQ
Umuodike	59.1	44.5	2710.4	0.01642	120613	0.00037	0.0164	287286	565586	53	4	AA
Elelenwo	63.5	39	345.5	0.11288	13475	0.00289	0.1129	281868	533437	70	5	AKQ
Industrial Rd	192.1	155.2	2710.9	0.05725	420732	0.00037	0.0573	279585	527934	37	5	HAK

Table 12: Geo-eletric layer parameters from Geoelectric Sounding interpretation and models

VES LOCATION	Electrical Resistivity(Ωm)						Thickness(m)					RMS (%)
	ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	h1	h2	h3	h4	h5	
Enerst Cole	32.6	14.4	644.3	233	26.6		0.6	5.4	10.4	13.6		7.9
New airport	97.4	622.4	278.6	762.6	39.4	419	1	5.4	9.5	20.7	53.2	7.4
Elechi Beach	20.8	147.2	39.4	235.1			0.8	3.7	8.5			7.8
Ogale	1.3	22.4	3215	0.7			0.4	0.4	5.3			7.4
Ahoada west	70.8	275.1	208.8	795			0.5	3	5.4			7.3
Aggrey Road	1	36.5	351	4705.5			0.5	1.3	4.8			9.5
Ipo 3	71.8	76.2	885	7.4	203.5	848.2	0.9	30	552.3	848		7.6
Mudike	578.4	777.8	2719.4	1012.6			2.8	11.8	44.5			3.6
Elelenwo	430.7	668	1833.5	3455	111.4		0.7	4.9	18.9	39		5
Industrial Road	34.3	12.9	100.1	2710.9	425.4		0.5	27.4	8.9	155.2		36.8

4.2 Discussion

4.2.1 Aquifer Resistivity of the Study Area

Aquifer resistivity plays a key role during investigation of potential aquifers, and it is pertinent to show the distribution of Aquifer resistivity of the area of study so as to guide on where future wells can be sited. The Aquifer resistivity values and the spatial locations of the surveyed area were plotted using Surfer13 software to generate a contour showing the distribution of resistivity within the area of interest (Figure 12). The region with the highest apparent resistivity values corresponds to the area coloured red, while the regions with yellow colour corresponds to areas that has the lowest resistivity values. The regions with highest resistivity values indicate areas where good ground water are accumulated, while areas with very low resistivity values might not favour good underground water accumulation. The areas coloured with red shade in parts of North-West the study area which corresponds to the highest resistivity value of 130,000Ωm to 170,000Ωmcorresponds to area with conglomerate materials that can enhance good ground water flow, while the others parts with green and yellow colour represents parts of the study area with moderately and low aquifer resistivity zones with ranging resistivity values of 3,000Ωm -13,000Ωm and 40Ωm -3,000Ωm respectively.

4.2.3 Aquifer Thickness of the Study Area

Aquifers may occur at various depths. Those closer to the surface are not only more likely to be used for water supply and irrigation, but are also more likely to be topped up by the local rainfall. Over-exploitation can lead to the exceeding of the practical sustained yield; i.e., more water is taken out than can be replenished.

Aquifer thickness is one of the most important parameters when trying to locate a site for potential well, apart fromresistivity values. Figure 13 is the Aquifer Thickness map generated from the study area from Table 11. It shows the distributed thickness of Aquifers within the study area. The North-West parts of the map are dominated by Aquifer thickness within 10m – 40m. These areas are shallow wells and they can easily been seen from the map as areas coloured with yellow. Also aquifers thickness within Parts of the South-West and part of the central part are dominated by aquifers with thickness ranging from 40 – 130m, aquifers with the maximum thickness (Red) of within 130 to 160m are observed towards few areas in the North- Western part of the Study area.

4.2.4 Longitudinal Conductance of the Study Area

When exploring for site with a very high groundwater potential, longitudinal conductance (S) is one of the geo-electric parameters that must be sought for. High values of Longitudinal Conductance are generally a sign of relatively thick sequence and should be given the highest priority during groundwater site location.

The Longitudinal conductance(S), obtained from the geo-electric layer parameters (Table 12), can also be used to determine the overburden protective capacity of aquifers within the area of study. The generated longitudinal conductance map (Figure 14) was computed using equation 4 for all the VES locations. The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underling aquifer (Abiola et al., 2009).

The values of longitudinal conductance(S) obtained from the study area, range 0.00579 to 1.32487 Ω-1 (Table4.2). The data from the vertical electrical sounding were used to generate the longitudinal conductance map (Figure 14) using SURFER 13 Contouring Toolkits. From the map, the study area has a very low longitudinal conductance values which was represented with a red colour. It implies that the possibility of getting underground water within the survey areas is slim.

4.2.5 Transverse Resistance

Figure 15 shows the transverse resistance contour map of the study area used to identify the aquifer protective capacity of the study area. The figure shows that the transverse resistance has range of 556Ωm^2 to 824,766Ωm^2. Area with low transverse resistance value of 556 Ωm^2 to 150,000Ωm^2 (yellow) indicates areas that are associated with low resistivity formation such as clayed soil. Portion of the map with high transverse resistance value (Red shade) with value range of 654,000Ωm^2

to 800,000Ωm^2 corresponds to high resistivity formation in the subsurface.

4.2.6 Hydraulic Conductivity

The calculated hydraulic conductivity is shown in Table 12 with the contour maps shown in figure 16. From the table and the map, the hydraulic conductivity ranges from 0.005 cm/s to 2.538 cm/s. From the hydraulic conductivity map in figure 16, the shaded portion coloured red indicate areas with high hydraulic conductivity. This occurs partly at the central part and the southern parts of the study area. Area with high Hydraulic conductivity in the map depicts areas with large grain coarse sand that can act like a good aquifer zone. Area with low hydraulic conductivity with value between 0.005 to 0.5cm/s which occurs at the southern part of the study area (Yellow)indicates areas with low groundwater flow due to its small grain size.

4.2.7 Transmissivity of the study Area

The transmissivity values of the study area and its variations within the geologic formation is calculated as shown in table 11 and its interpreted using table 2.1 (Offodile, 1983) for the aquifer characterisation.

Figure 17 reveals the transmissivity map of the study area. The value ranges from 0.22587 cm/s^2 to 132.487cm/s^{2}with an average of 19.5187cm/s^2, From the contour map, the transmissivity values increases at the central part (Red) with high values range of 110cm/s^{2}to 135cm/s^2 . Areas with low transmissivity value are prominent at the North, South, and Western part of the study area (Yellow). Ares with high transmissivity values area identified as areas of high groundwater potential and aquifer materials which area highly permeable to groundwater movement are seen in the central part of the study area (red) with value range of 110 to 135 cm/s^2 Hence, area with high transmissivity can be attributed to having thick auriferous sand.

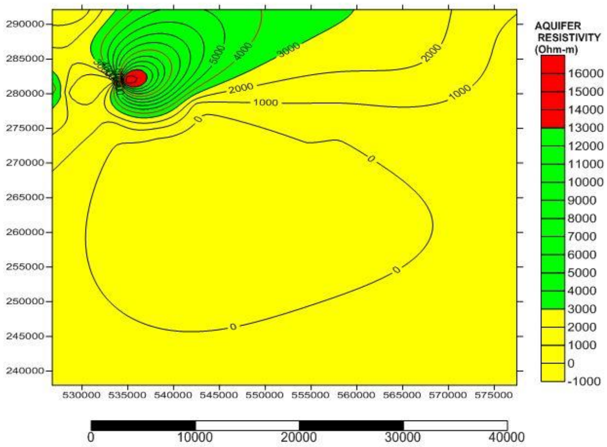

Figure 12: Aquifer Resistivity Map

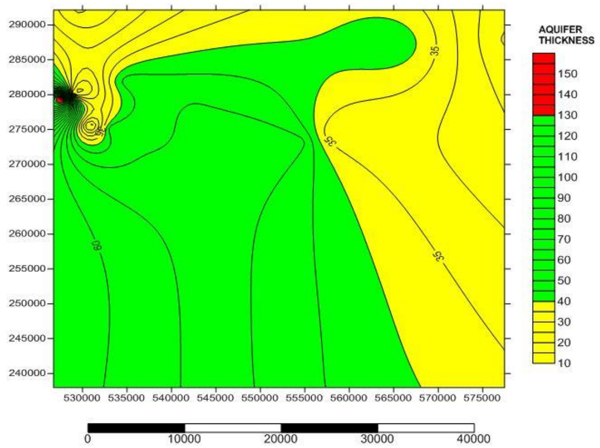

Figure 13: Aquifer Thickness Map

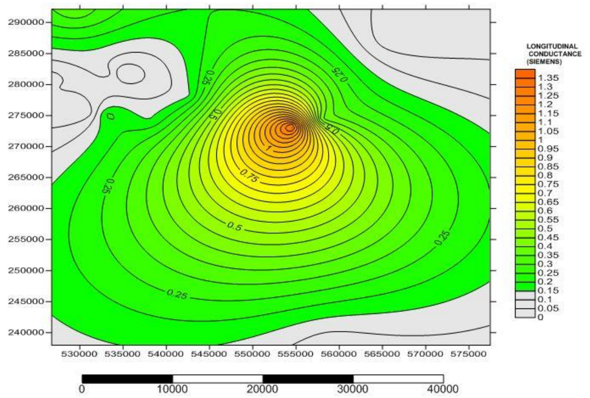

Figure 14: Longitudinal Conductance Map

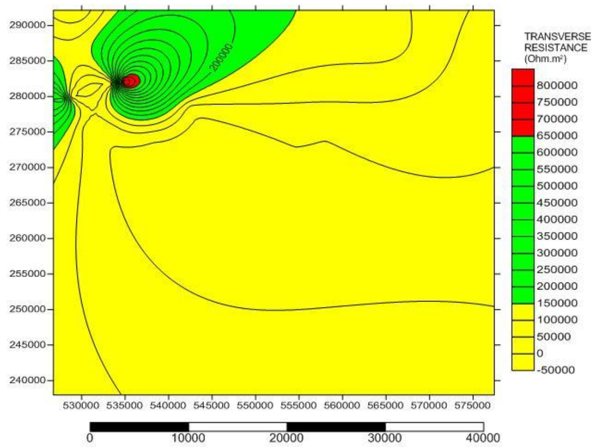

Figure 15: Transverse Resistance

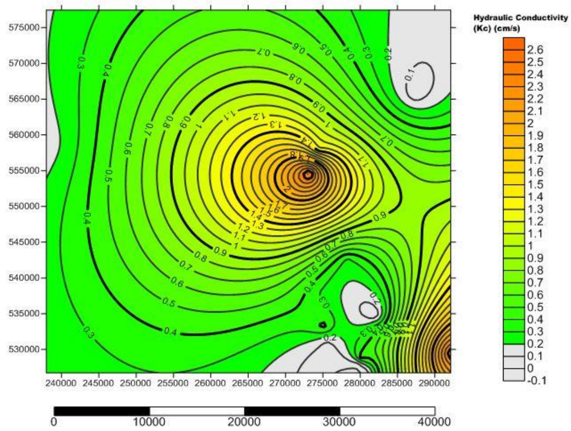

Figure 16: Hydraulic Conductivity Map

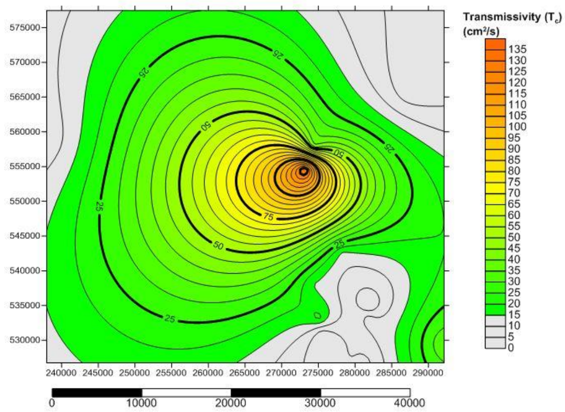

Figure 17: Transmissivity Map

5. Conclusion

Based on the interpreted results of Vertical Electrical Sounding conducted in the area, three to seven subsurface geo-electrical layers could be revealed. With a view to depict the survey results in a realistic and effective way, various contour maps have been arranged, viz., aquifer resistivity contour, and aquifer thickness contour for different thickness ranges, longitudinal conductance contour.It was noticed that the porosity decrease with the direction of decreases in the grain size and conductivity (South, South-West and North-East region), due to the absent of gravel layer there.

The variability of the resistivity and hydraulic conductivity, were resulted from the lithology changing in the aquifer (gravel, sand, clay) which can affect the active porosity, changing the salinity and increasing clay ration in the aquifer. Transmissivity for the aquifer were calculated and varied between $0.22587 cm/s^2$-$132.487 cm/s^2$, while the value of hydraulic conductivity varied between 0.05cm/s to 2.538cm/s. These variations were due to:

1. Increasing and decreasing of saturated thickness: transverse resistivity was normal proportional with thickness, hydraulic conductivity, and Transmissivity.
2. Lithological mixture: Aquifer resistivity was proportional to the transverse resistivity and changing active porosity, which effect on hydraulic conductivity.
3. Clay ratio: increasing clay ratio leads to decrease the hydraulic conductivity value and transmissivity of the study area.
4. They are both proportional with Transmissivity and hydraulic conductivity.

6. Recommendation

In view of the findings from the research work, the following recommendations are made:

I. Resistivity survey and geophysical well logging should be done in the study area prior to drilling and casing to enhance best screen section for optimal aquifer yield.

II. Other method of hydraulic and transmissivity test such as pumping test should be carried out within the study area to validate the vertical electrical sounding (VES) result.

III. Boreholes within the study area should be sited where the hydraulic conductivity and transmissivity is high to adequate groundwater supply.

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References

Ahamefula, U. U, Benard, I .O., Boniface, C. E., Nkechi, E .E., and Harold, C. O. (2013). Estimation of subsurface hydrological parameters around Akwuke, Enugu,Nigeria using surface resistivity measurements. Journal Of Geophysics And Engineering, 10.

Amechi, B. U. (1996). Geo-electric investigations for groundwater in parts of Etche Local Government Area of Rivers State.

Asfahani, J. (2007). Geoelectrical investigation for characterizing the hydrogeological conditions in semi-arid region in Khanasser valley, Syria. Journal of Arid Environments, 68(1), 31-52.

Ekwe, A. C, Nnodu, I. N, Ugwumbah, K. I, and Onwuka, O .S. (2010). Estimation of aquifer hydraulic characteristics of low permeability formation from geosounding data: A case study of Oduma Town, Enugu state. Journal of Earth Science., 4(1), 19- 26.

Ezeh, C. (2011). Geoelectrical studies for estimating aquifer hydraulic properties in Enugu State, Nigeria. Internal Journal of Physical Science. 6(14), 3319-3329.

Joel, E . S, Olasehinde, P . I, De, D . K, Omeje, M. and Adewoyin, O .O. (2016). Estimation of Aquifer Transmissivity from Geophysical Data. A case Study of Covenant University and Environs, Southwestern Nigeria. Sci. Int (Lahore), 3379-3385.

Okiongbo, K . and Chiojioke, S . O. (2014). The use of Geoelectrics in the Study of a shallow Quaternary Alluvial Aquifer in Yenagoa, Southern Nigeria. Global Journal of Pure and Applied Sciences, 20, 117.

Okonkwo, A. C and Ezeh, C. C. (2013). Aquifer hydraulics and delineation of groundwater quality zones using Electrical resistivity method at Oduma and environs in Enugu state,South-East Nigeria. Journal of Geology and Mining., 3(1), 31 - 39.