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Evaluation of the Aquifer Characteristics of Some Parts of Orsu, South-Eastern Nigeria.

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ABSTRACTThis study integrates surface direct current electrical resistivity method with pumping test results to determine various aquifer parameters. Twenty-eight Vertical Electrical Soundings (VES) data sets using the Schlumberger array were obtained from various parts of the study area, located within Latitude 5°48'N-5°56'N and Longitude 6°55'E – 7°02'E. A maximum current electrode spacing of 740m was used for data acquisition. Four of the soundings were carried out near existing boreholes. The sounding data were analyzed with the FORTRAN Resistivity 2D Inverse Computer Program to delineate the sub-surface layering. The results indicate that the aquifer thickness range from 30.5 to 143.5m. A quantitative interpretation of the sounding curves shows that some of the aquifers are shallow to semi-deep to deep, with depths ranging from 30.5 to 207m. Resistivity of the aquiferous layers varies from 1960Ωm to 37200Ωm. The high resistivity values associated with the aquifers in the area is possibly due to the presence of loose sand and sandy formation which corresponds to the local geology of most parts of the study area (Coastal Plain Sand) and the clayey sandstone and sandy clay-stone of the Ameki Formation. Hydraulic conductivity for the study area varies between 1.37m/day and 24.55m/day. Transmissivity values vary from 56.96m^2/day to 2174m^2/day. The transmissivity potential of the study area varies from moderate to high. The transmissivity values obtained are suitable for sustainable groundwater development. The results from the iso-resistivity depth probe show that there is no general continuous resistivity increase with depth, indicating the variable stratigraphic units in the area.

KEYWORDS: Aquifer parameters, hydraulic characteristics, transmissivity potential, Da-Zarrouk parameters, Vertical Electrical Sounding.

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I. INTRODUCTION

The importance of having access to fresh water supplies cannot be over-emphasized. Though the earth has abundant water resources, availability of fresh water for domestic and agricultural uses is not always guaranteed.The geology of an area determines the aquiferous zones where exploitable groundwater may occur (Domenico, 1992). Nigeria has an abundance of surface and groundwater resources. The water resources master plan for Nigeria which was prepared by the Japan International Co-operation Agency (JICA) in 2006 indicates an estimated surface water resources of 2.67 x 10^{11} m^3/year and groundwater storage of about 0.52 x 10^{11} m^3/year (Oteze, 2006). These figures greatly outweigh the country's total water demand of about 0.40 x 10^{11} m^3/year (Oteze, 2006).

Assessment and studies of groundwater resources are more tedious and expensive, in comparison to surface water resources. As resistivity is a fundamental electric property of rock materials closely related to their lithology, the determination of the subsurface distribution of resistivity from surface measurement can yield useful information on the structure or composition of buried formation. The electrical resistivity method is utilized in diverse ways for groundwater exploration (Zohdy, 1976; Frohlich and Urish, 2002). Computer modelled direct interpretation techniques are used to resolve the true thicknesses and resistivities of the aquiferous zones from surface resistivity measurements (Niwas and Singhal, 1981; Ekwe, et al. 2006).

Aquifer characterization is very useful in hydrological and hydrogeological studies. Fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity and aquifer depth are important parameters useful in describing subsurface hydrology. Much geophysical investigation of groundwater is directed towards the determination of the spatial distribution of the above-mentioned aquifer hydraulic parameters (Mendosa et al., 2003). Aquifer characteristics calculated from existing boreholes are usually correlated with surface resistivity measurements based on their relationship with pore space and heterogeneity (Rubin and Hubbard, 2005; De Lima et al., 2005; Niwas et al., 2006).

This study is targeted at evaluating the groundwater potential and aquifer characteristics of the area with the aid of the vertical electrical sounding and information obtained from pumping test data. The studyattempts to delineate the various lithologic units underlying the study area, determine the aquifer hydraulic characteristics of the area, determine the transmissivity potential of aquifers within the study area and provide iso-resistivity depth probes of the area.

The study is justified based on the uncertainties in the description of some hydraulic characteristics of aquifers in the area due to a limited number of studies combining surface resistivity measurements with pumping test data.

1.1 Location and surface hydrogeology of the Study Area

The study area lies between Longitude $6^{o}55^{'}$E – $7^{o}02^{'}$E and Latitude $5^{o}48^{'}$N-$5^{o}56^{'}$N, in the South-eastern part of Nigeria. It is located towards the Northern part of Imo State. The area is bounded to the North-West by Anambra State, to the East by Okigwe and to the South by Owerri.

The study area can rightly be described as a water shed. Two major rivers, Njaba and Orashi flow out of the area. The Niger River Basin drains only a small part of the West of Imo State. The principal tributary in the area is Orashi River flowing parallel to River Niger.

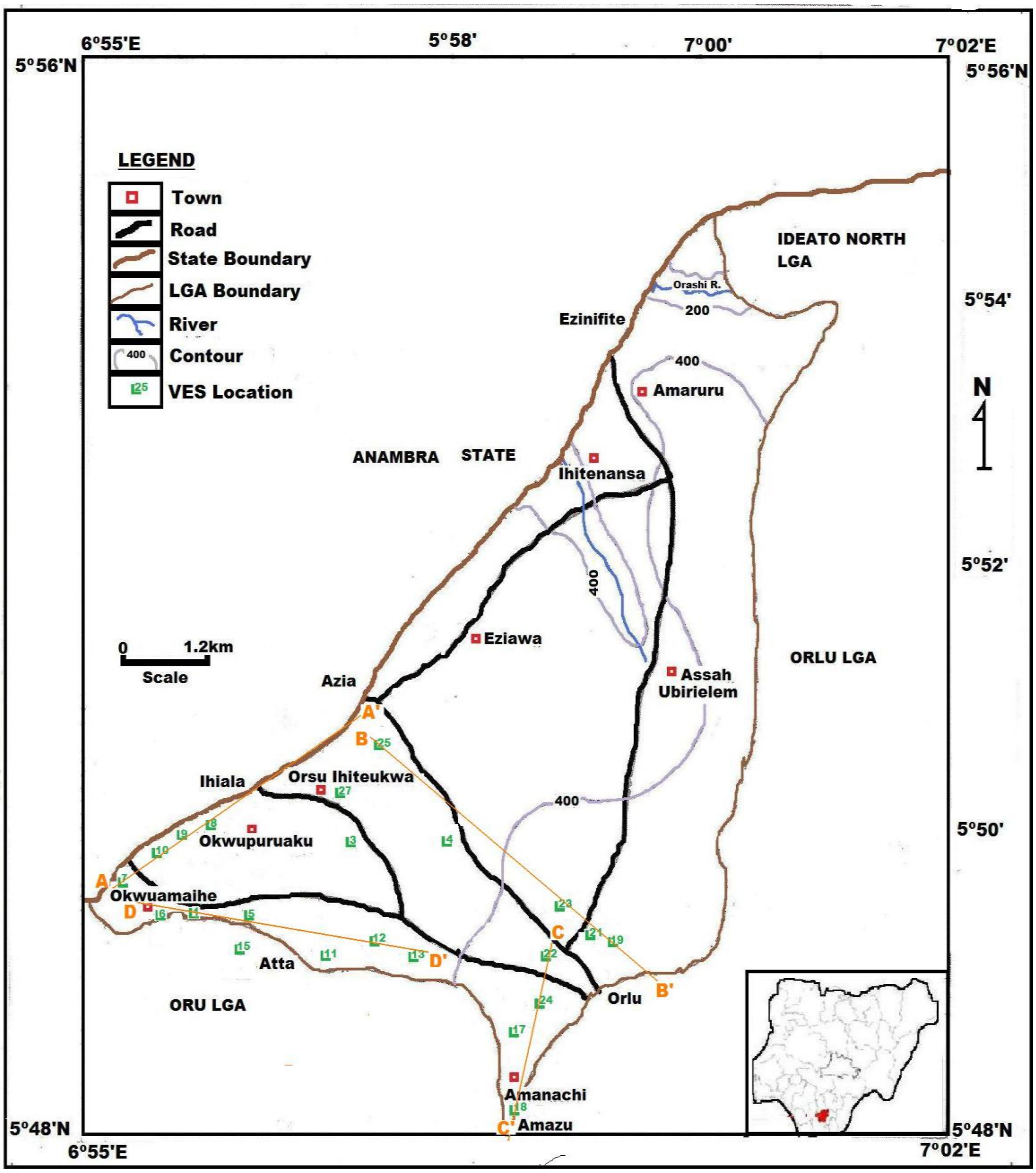

Fig 1. Location map of the study area showing the VES points

1.2 Geology of the Area

The study area comprises sediments belonging to the Benin and Ameki Formations. The Benin Formation consists of lenticular, unconsolidated and sandy sediments. It has been described as "Coastal Plain Sands". The Formation is continental in origin with sediments deposited during the Late Tertiary to Early Quaternary Period. The age of the Benin Formation is from Miocene-Recent and consists of friable sands with intercalation of shale and clay lenses (Onyeagocha, 1980). It also contains some isolated units of gravels, conglomerates, very coarse-grained sands and sandstone in Owerri area in South-eastern Nigeria. The Formation has a thickness ranging from 0 – 2100 meters. The sands and sandstones are coarse to fine and commonly granular in texture and can be partly unconsolidated. The sands are generally moderately sorted, poorly cemented and angular in shape (Mbonu et al, 1991).The sediments represent upper deltaic plain deposits. The sands may represent braided stream point bars and channel fills. The shales are few and thin and they may represent back swamp deposits. Having a very high run off,

the shales are the locus of several river systems; these rivers are fed by small seasonal tributaries from the shales as well as by the perennial river fed by springs that issue from the margins of sand bodies.
The Ameki Formation is of Eocene-Oligocene age and consists of grey clayey sandstone and sandy clay-stone. The Formation also consists of bluish calcerous silt with mottled clay, thin limestone and abundant calcerous shale.

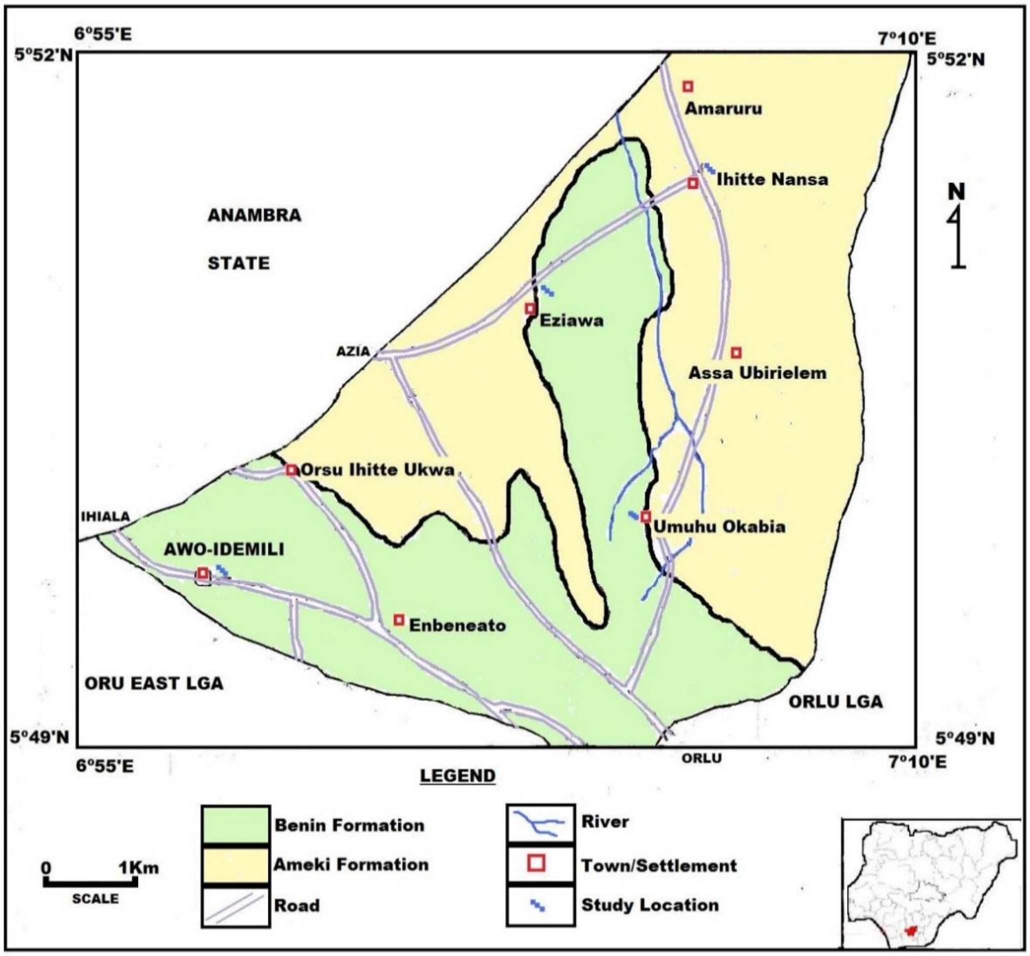

Figure 2. Geology map of the study area

II. METHOD OF STUDY

Geophysical data acquisition was carried out using the Vertical Electrical Sounding (VES) method. A total of 28 sounding results were obtained using the Schlumberger array with an electrode spacing of AB/2 of 370m. Four of these soundings were done near existing boreholes for correlation purposes. Field data was modelled and interpreted using FORTRAN Resistivity 2D Inverse Computer Program. The litho-logs of existing boreholes were used to correlate VES data while pumping test data was utilized to enhance the evaluation of the groundwater hydraulic characteristics.

III. RESULTS

The various aquifer characteristics within the study area are summarized in the table below.

Table 1. Summary of the aquifer characteristics of the study area

VES NO	Depth to water table (m)	Aquifer Thickness (m)	Apparent Resistivity (Ω-m)	Conductivity (S/m)	Transverse resistance (ohm-m²)	Longitudinal conductance (mho)	Kσ value	K values from wells	Hydraulic conductivity (m/day)	Transmissivity (m²/day)
1	40.3	59.7	2410	0.00041	143877	0.0248	0.003	4.34	7.32	437.004
2	207	49	2880	0.00035	141120	0.017			12.29	602
3	19.8	36.7	10100	0.0001	370670	0.0036			12.00	440.4
4	94	85	2430	0.00041	206550	0.035			6.34	539.02
5	57.5	38.4	2750	0.00036	105600	0.014			16.67	640.13
6	28.2	30.5	2390	0.00042	72895	0.0128	0.0036	3.89	8.57	261.43
7	87.9	54.1	2430	0.00041	131463	0.0223			10.24	554.2
8	58.8	90.2	2000	0.0005	180400	0.0451			12.00	1082.4
9	43.1	46.5	7320	0.00014	340380	0.0064			22.86	1062.86
10	94.4	88.6	9100	0.00011	806260	0.0097	0.0027	16.04	24.55	2174
11	93.3	55.7	3130	0.00032	174341	0.0178			9.06	504.78
12	115	65	3580	0.00028	232700	0.0182			3.57	232.14
13	125	69	2930	0.00034	202170	0.0235			4.12	284.12
14	140	68	2250	0.00044	153000	0.0302			1.82	123.64
15	36.2	76.8	37200	0.00003	2856960	0.0021			6.00	460.8
16	47.5	113.5	4230	0.00024	480105	0.0268			5.42	614.8
17	102	48	3120	0.00032	149760	0.0154			3.44	165
18	89.8	117.2	8000	0.00013	937600	0.0147	0.0017	11.97	13.08	1532.62
19	30.4	33.6	2350	0.000043	61500	0.0407			5.875	197.4
20	57.7	45.3	1870	0.00053	84711	0.0242			5.66	256.42
21	70.5	143.5	2380	0.00042	341530	0.0603			6.19	888.33
22	64.4	36.2	13800	0.00007	499560	0.0026			12.86	465.43
23	46.9	41.5	1960	0.00051	81340	0.0212			1.37	56.96
24	73.5	42.5	6050	0.00017	257125	0.007			2.35	100
25	55.7	61.3	2650	0.00038	162445	0.0231			2.37	145.18
26	135	94	8600	0.00012	808400	0.0109			3.33	313.33
27	40	101	9400	0.00011	949400	0.0107			3.27	330.55
28	64.5	59.5	11300	0.00009	672350	0.0053			3.44	204.94

IV. DISCUSSION

The depths to the water table across the study area were deduced from the sounding results by a quantitative interpretation of the sounding curves. The shallowest aquifer has a depth of 19.8m (St. John's Amaokwe, VES 3) while the deepest has a depth of 207m (Union Primary School, Awo, VES 2).Aquifer thickness ranges between 30.5m at Ubahaeze(VES 6) to 143.5m at Umuhu-Okabia. (VES 21). This variation is represented in Figure 3 below.

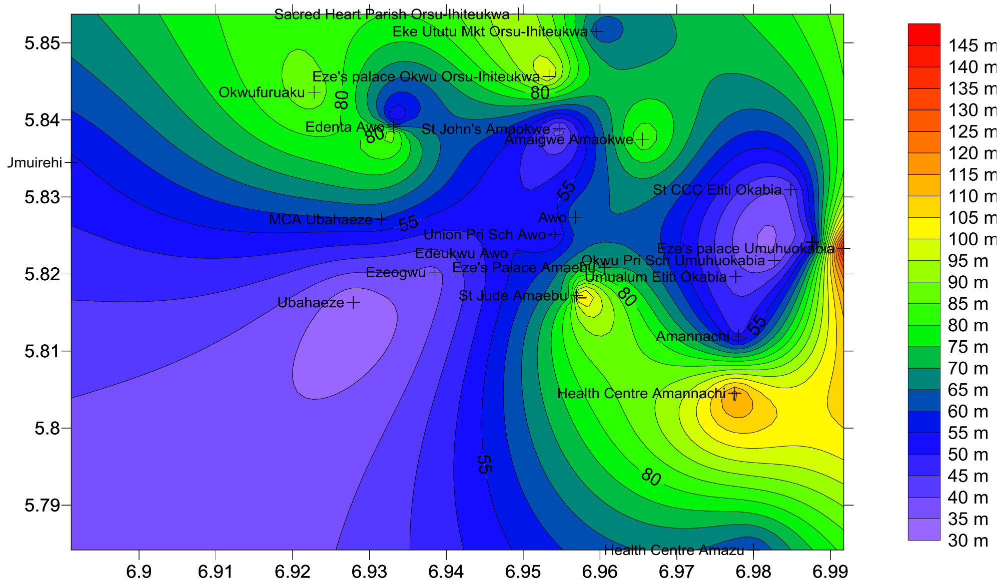

Figure 3. Contour map of aquifer thickness of the study area

There is a variation in the resistivity of the aquifers from 1960Ωm to 37200Ωm (Figure 4). The high resistivity values associated with the aquifers in the area is possibly due to the presence of loose sand, sandstone and sandy formation which corresponds to the local geology of most parts of the study area (Coastal Plain Sand) and the clayey sandstone and sandy clay-stone of the Ameki Formation.The aquifers around Amannachi and Amaebu have the highest values of apparent resistivity.

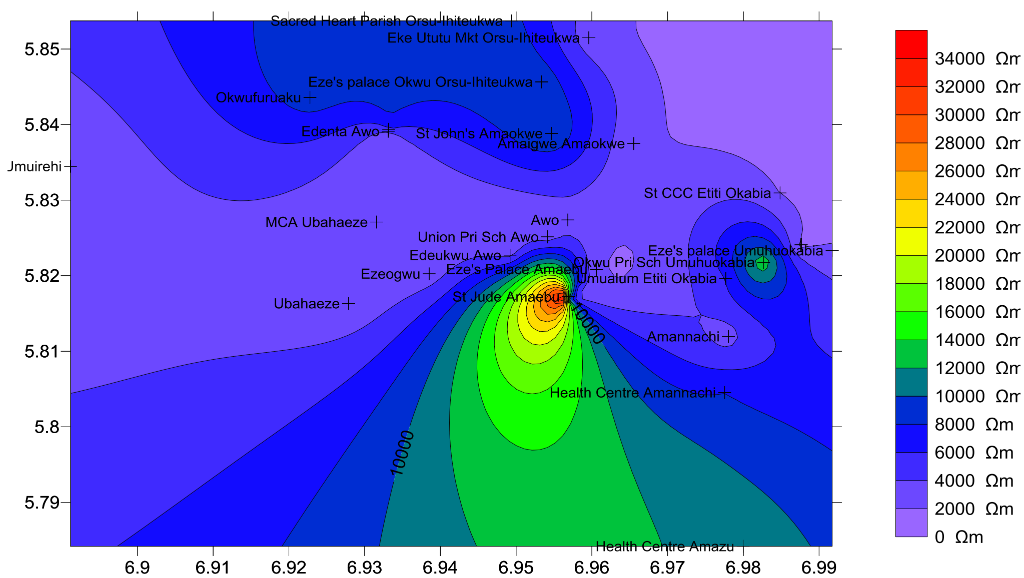

Figure 4. Contour map of the aquifer apparent resistivity of the study area.

Since the conductivity is the inverse of resistivity, it can be seen from Figure 5 that the aquifers around Amannachi, Amaebu (highest resistivity values) and Orsu-ihiteukwa, have the lowest values of conductivity.

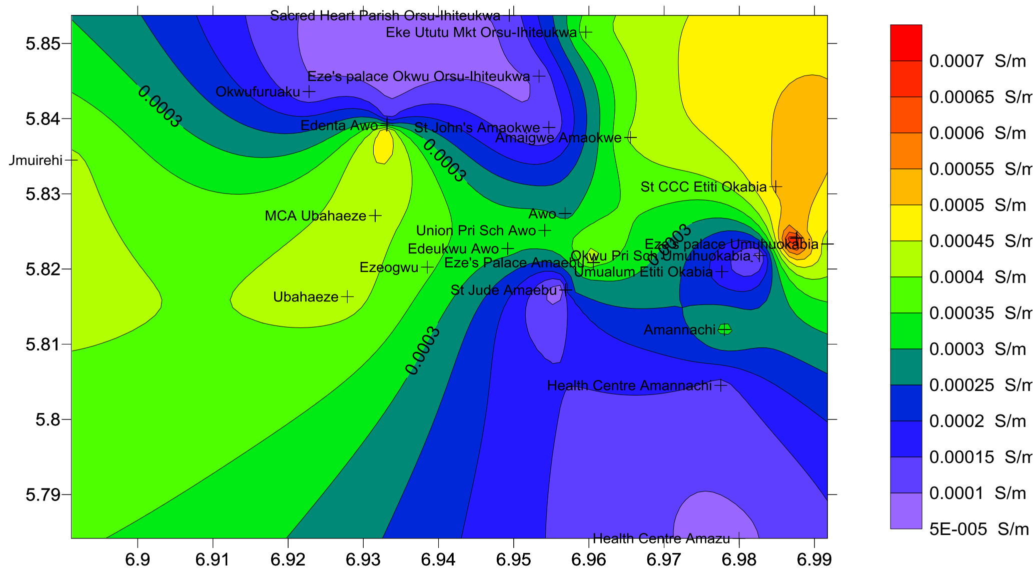

Figure 5. Contour map of the aquifer conductivity of the study area

The hydraulic characteristics of the aquifers within the study area were established using the concept of Dar-Zarrouk parameters (transverse unit resistance (R) and longitudinal conductance (C) in porous media. These hydraulic properties are usually controlled by the local geology of an area.

The following values of hydraulic conductivities and transmissivity were obtained for the aquifers in the study area: K_{mean}= 8.07m/day; K_{min}=1.37m/day; K_{max}= 24.55m/day;

T_{mean}= 523.95m^2/day; T_{min}= 56.96m^2/day; T_{max}= 2174m^2/day. The contour maps of the hydraulic conductivity and transmissivity are shown in Figures 6 and 7 respectively.

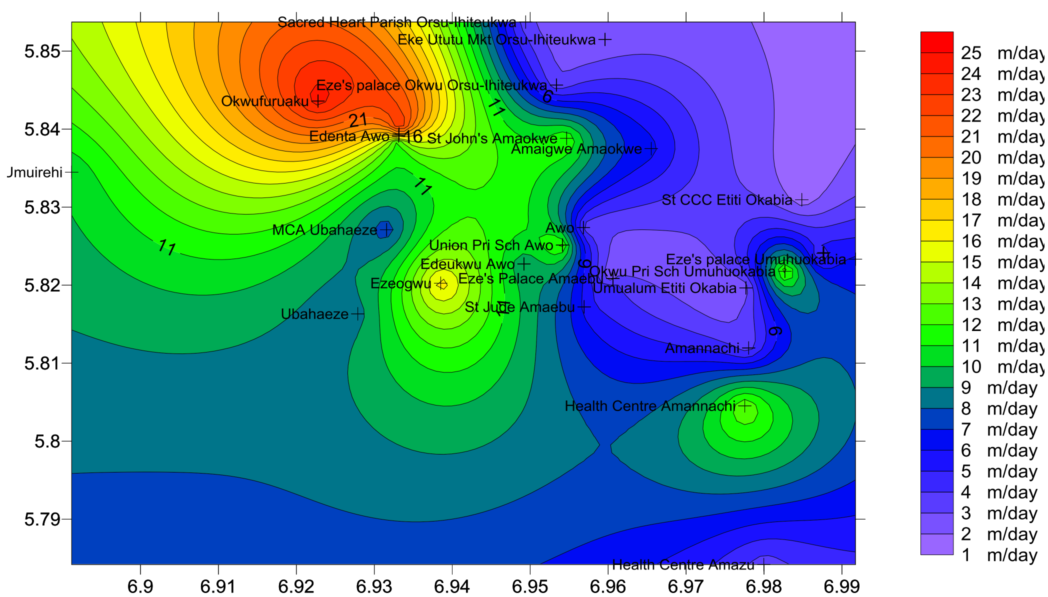

Figure 6. Contour map of the aquifer hydraulic conductivity of the study area.

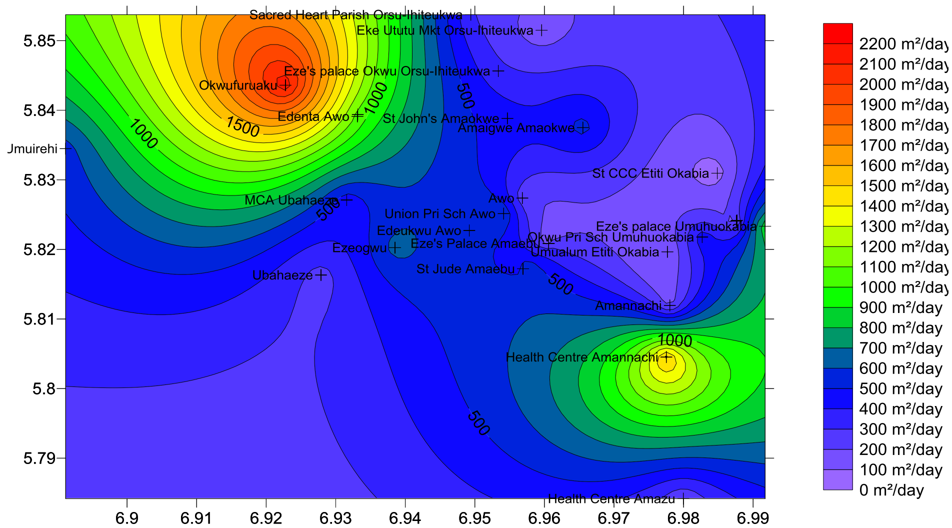

Figure 7: Contour map of aquifer transmissivity of the study area

The highest values of K and T obtained for the study are for VES 10 at Okwufuruaku. This indicates that this location has the greatest potential for productive aquifers because of its high transmissivity. Other areas with significantly high values of transmissivity include Edenta –Awo, Amannachi, Ubahaeze and parts of Orsu-Ihiteukwa. The lowest values of K and T were obtained at St. CCC EtitiOkabia(VES 23) This shows that this location has the lowest potential for productive aquifers because of its low transmissivity. High transmissivity values indicate a flat (narrower) cone of depression which suggests a shallow drawdown. Low transmissivity values indicate a steep (wider) cone of depression implying a deep drawdown.

The table below according to Gheorghe (1978) is a description of groundwater potential of an aquifer on the basis of transmissivity values.

Table 2.Gheorghe Standard for Transmissivity (T) (Gheorghe, 1978).

Transmissivity Range	Transmissivity Potential
Greater than 500m^2/day (5.79 x 10-3m^2/s)	High potential
Between 50 and 500 m^2/day (5.58 x 10^{-3}and 7.39 x 10^{-3}m^2/s)	Moderate potential
Between 5 and 50 m^2/day (9.06 x 10^{-3} and 5.50 x 10^{-3} m^2/s)	Low potential
Between 0.5 and 5m^2/day (5.01 x 10^{-3} and 5.58 x 10^{-3}m^2/s)	Very low potential
Below 0 .5m^2/day (5.01 x 10^{-3} m^2/s)	Negligible, flat

From the table, it can be seen that the aquifers in the study area are in two classes: those with moderate transmissivity potential and those with high transmissivity potential.

The values of the transverse resistance of the aquifers in the area are high. A geological formation reflecting a predominantly high transverse resistance value indicates that its resistivity is high or it has higher thickness withfavourable aquifer conditions.

The correlations between the VES results and the lithologs of some boreholes within the study area are shown below (Figures 8,9,10 and 11). The layering from the litho-logs has a strong correlation to the layering deduced from the VES results.

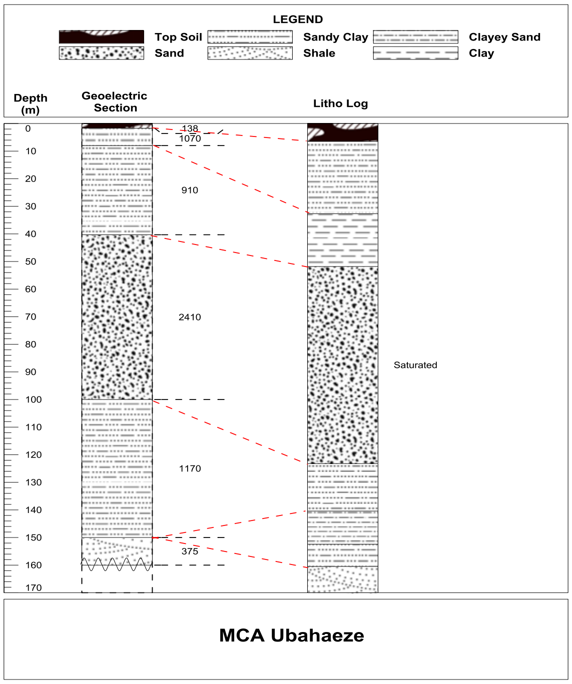

Figure 8. Correlation of the litho-log of borehole at MCA Ubahaeze with VES 6

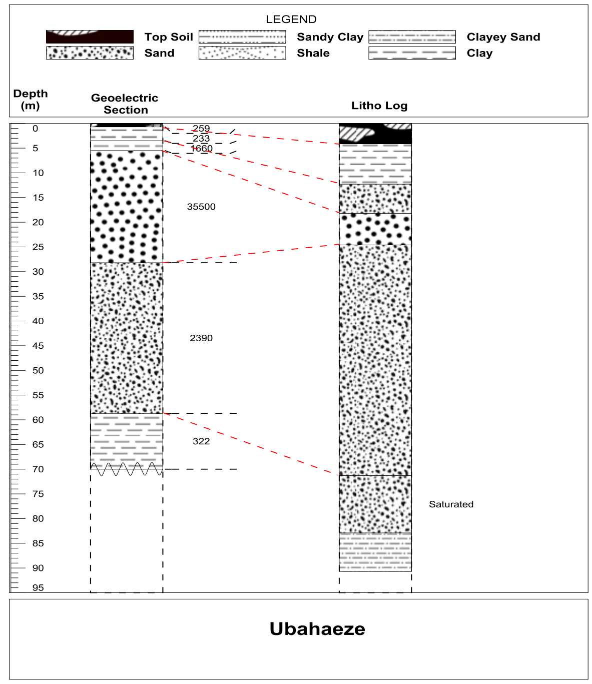

Figure 9. Correlation of the litho-log of borehole at Ubahaeze with VES 1

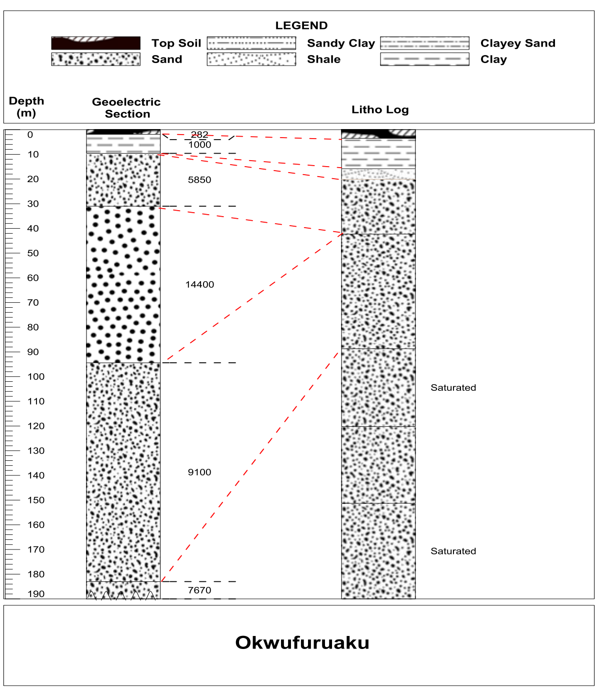

Figure 10. Correlation of the litho-log of borehole at Okwufuruaku with VES 10

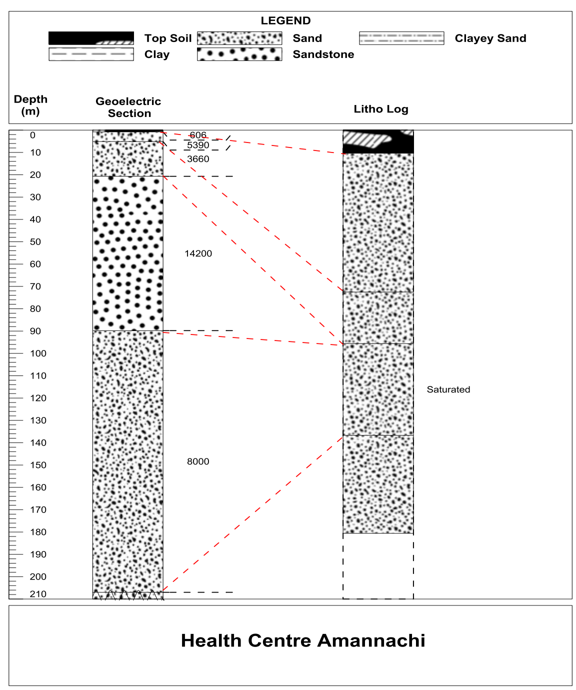

Figure 11. Correlation of the litho-log of borehole at Health Centre Amannachi withVES 18

The data of the geoelectric sounding was used for the analysis of the iso-resistivity depth probes of the area. Resistivity contour maps display the lateral variation in the surface geology of the area. The areas with lowresistivity values indicate the occurrence of relatively good conductors while those with high values indicate poor conductors. The values at AB/2=10m represent the top layer resistivity soil zone. In general, the resistivity values at this depth were low and could be as a result of overlying clayey formations in the area. There was a steep rise in the resistivity at the centre of the study area which may be due to the existence of a poor conductive sandy layer.

The top layer is normally represented by topsoil of low to moderate resistivity. The middle layer is represented by aquifers of moderate to high resistivity while the bottom layers represent hard rock (possibly sandstones) of very high resistivity approaching a maximum of about 14000m. The high resistivity values associated with the aquifers in the area is possibly due to the presence of loose sand and sandy formation which corresponds to the local geology of the most parts of the study area (Coastal Plain Sand) and the clayey sandstone and sandy clay-stone of the Ameki Formation. This therefore suggests that the sand groups (sand, sandstone, silty sand and clayey sandstone) in the area are probably saturated with freshwater bearing horizons.

The results from this depth probe show that there is no general continuous resistivity increase with depth. This indicates the variable stratigraphic units in the study area.

V. CONCLUSION

The results of the study have helped to delineate the aquiferous zones within the study area. The aquifer is thickest around Umuhu-Okabia (143.5m), and thinnest around Ubahaeze (30.5m).

Depth to aquifer ranges from 19.8m-207m. K_{mean},K_{min}andK_{max}valuesobtained are 8.07m/day, 1.37m/day and 24.55m/day respectively; while T_{mean}, T_{min} and T_{max}valuesobtained are given respectively as 523.95m^2/day, 56.96m^2/day and 2174m^2/day.

K_{max} and T_{max} were obtained at VES 10 (Okwufuruaku), reflecting the highest potential for productive aquifers. The lowest values of K and T were obtained at St. CCC EtitiOkabia (VES 23). Aquifers in the area generally show moderate-high transmissivity potential. The high resistivity values of the aquifer units are attributed to the presence of loose sand and sandy formations typical of the local geology of most parts of the study area. The values collaborate previous studies within the Benin and Ameki Formations by authors such as Ananaba et al. (1983); Ahiarakwem and Ejimadu (2002); and Ekwe at al. (2006).

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