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Geoelectric Investigation of the Hydraulic Properties of the Aquiferous Zones for Evaluation of Groundwater Potentials in the Complex Geological Area of Imo State, Nigeria

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ABSTRACT

Okigwe district is in the complex geological environment of Imo State and lies between latitude 5°30-5°57/N and longitude 7°04-7°26/E. It covers a land area of about 1,824 km^2. Water is becoming scarce in the area owing to increasing demand and deteriorating quality due to pollution. This is compounded by the gradual increase in the rate of industrial and commercial activities and the cases of borehole failure in some parts of the area. This study therefore aimed at delineating sites for productive boreholes. To achieve this, 120 Vertical Electrical Soundings (VES) were sited within the study area. The ABEM terrameter was used to acquire data using the Schlumberger electrode array and a maximum current electrode spread of 900 m. Twelve of the VES Stations were sited near existing boreholes to enhance interpretation. The resistivity of the aquiferous zones varied from 33.1 Ωm obtained in the Northern part to 32600 Ωm recorded in the Southern area. The aquifer thickness is low in the Northern part but high in the Southern part reaching a maximum of 104.4 m recorded at Otoko. Using an average transmissivity of 1032.0848 m^2 day^{-1} determined from pumping test, a mean conductance value of 91.222 m day^{-1} was obtained for the area. Hydraulic conductivity varied from 9.8854-115.9646 m day^{-1} while transmissivity ranged from 992.04-10263.65 m^3 day^{-1}. With these results and the distribution of storativity and specific capacity values, the Southern and Northeastern parts of the district are promising for sitting boreholes with high yield expectation.

Key words: Groundwater potential, resistivity, transmissivity, hydraulic conductivity, storativity

INTRODUCTION

The Imo State Government has carried out some water projects in the area in which huge sums of money were invested. The Okigwe regional water scheme sited in Onuimo Local Government Area is still not functional in terms of supplying potable water from Imo River channel. There are many failed boreholes in the area in places like Uturu Isukwunato (in old Okigwe District), Umunakanu Ehime and some other areas around Okigwe as the geology of these areas is predominantly clay and shale. Areas around Avutu fall within the transition zone of Benin Formation to Bende Ameki group, Amuzu Ihube in Okigwe falls within the portion of Ajali Sandstones where the clay and shale members are predominant. The complex geological setting of the area especially around the northern part may have accounted for the failure of boreholes. Hence, proper geophysical survey of the study area is required.

MATERIALS AND METHODS

Geology of the study area: Okigwe District is in Imo State of Nigeria. The District is made up of six Local government Areas; Isiala Mbano, Ihitte Uboma, Ehime Mbano, Onuimo, Obowo and Okigwe. The area lies between latitude 5°30-5°57'N and longitude 7°04-7°26'E (Fig. 1) covering a land area of about 1,824 km^2. There is a good network of roads within the area. The major roads include the Umuahia-Enugu express road that passes through Ezinachi, Okigwe and Ihube. The major roads that link the various Local Government Areas include the tarred and untarred roads.

The study area is a complex geological environment in Imo State. The following stratigraphic units underlie the area: the Benin Formation, the Ogwashi - Asaba Formation, the Bende-Ameki Formation, Imo Shale Formation, Nsukka Formation and Ajali Formation (Akaolisa and Selemo, 2009; Nwosu *et al.*, 2010). The Benin Formation is overlain by lateritic overburden and underlain by the Ogwashi - Asaba Formation which is in turn underlain by the Ameki Formation of Eocene to Oligocene age (Mbonu *et al.*, 1991). The Benin Formation consists of coarse-grained gravelly sandstones with minor intercalations of shales and clay. The sand units which are mostly coarse grained, pebbly and poorly sorted contain lenses of fine grained sands (Onyeaguocha, 1980; Short and Stauble, 1976). The Southern part of the study area covering Obowo, Southern part of Ehime Mbano and Isiala Mbano fall within this formation.

The Ogwashi-Asaba Formation is made up of variable succession of clays, sands and grits with seams of lignite. It also forms part of the study area. The Ameki Formation consists of greenish-grey clayey sandstones, shales and mudstones with interbedded limestones. This Formation in turn overlies the impervious lmo Shale group characterized by lateral and vertical variations in lithology. The lmo Shale of Paleocene age is laid down during the transgressive period that followed the Cretaceous. It is underlain in succession by Nsukka Formation, Ajali Sandstones and Nkporo Shales.

Field measurement procedure: A total of 120 Vertical Electrical Soundings (VES) were carried out in the study area (Fig. 1) using the Schlumberger electrode configuration and a maximum current electrode spacing of 900 m. Twelve of the VES stations were sited near existing boreholes to enhance interpretation. The ABEM Terrameter (SAS) 300 B was used to acquire data. It has a liquid crystal digital read-out and an automatic signal averaging microprocessor. Four stainless non polarizable electrode were used, two current electrodes and two potential electrodes. A freshly charged 12 V DC battery was used to supply current. The current electrode spacing was increased symmetrically about the station point, keeping the potential electrode constant until it became necessary to increase the potential electrode as the recorded signal diminished. The apparent resistivity values computed were plotted against half of the current electrode spacing (L/2) on a log-log graph scale. The sounding curves obtained were subjected to conventional partial curve matching using the Rijks Waterstaat (1975) master curves to obtain the initial model parameters (resistivities and thickness) for computer aided interpretation. The software package used is the Schlumberger automatic analysis version 0.92 (Henker, 1985).

THEORETICAL BASIS OF THE STUDY

The two principal quantities used to determine a geoelectric layer are the resistivity p_i and thickness h_i where i = the position of the layer (Zhody, 1965). Other parameters include longitudinal conductance, transverse resistance and coefficient of anisotropy all of which are derived from the layer resistivity and thickness.

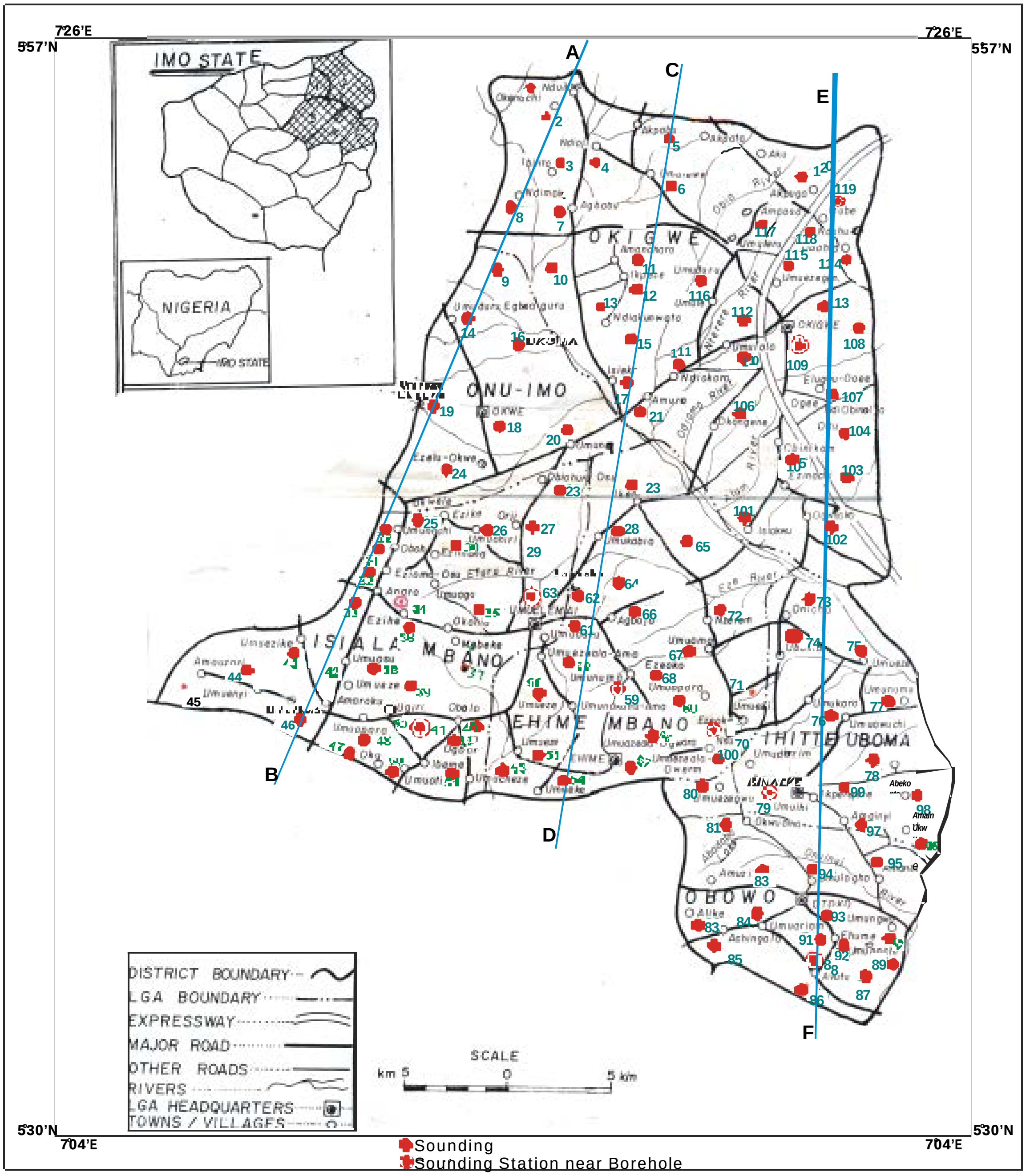

Fig. 1: Map of study area showing sounding stations and interpretative geolectirc cross-section (IGCS) traverse

Given a column of unit square cross sectional area cut out of group of layers of infinite extent, the total transverse unit resistance R is given as:

$$R = \sum_{i=1}^{n} h_i p_i \qquad i = 1,2,3,n \tag{1}$$

The total longitudinal unit conductance:

$$S = \sum_{i=1}^{n} \frac{h_i}{p_i} \qquad i = 1, 2, 3, n \tag{2}$$

where, p_i and h_i are the resistivities and thickness of the *ith* layer. The average longitudinal resistivity:

$$p_i = \frac{H}{S} \tag{3}$$

Where:

$$H = \sum_{i=1}^{n} h_i \qquad i = 1, 2, 3, ... n \tag{4}$$

and the average transverse resistivity:

$$p_t = \frac{R}{H}$$

The coefficient of anisotropy is the square root of the ratio of p_t to p_L.

The longitudinal conductance S_i can also be represented by:

$$S_t = \sigma_I h_i \tag{5}$$

where, σ_i is the layer conductivity which is analogous to the layer transmissivity, T_{ri} used in groundwater hydrology (Mbonu *et al.*, 1991), given by:

$$T_{ri} = K_I h_i \tag{6}$$

where, K_i is the hydraulic conductivity of the ith layer of thickness h_i. The parameters R and S are called the Dar Zarouk parameters which have been proved to be very powerful in enhancing the interpretation of groundwater surveys (Zhody, 1965).

The relationship between aquifer transmissivity T_r and transverse resistance R and that between T_r and S have been derived analytically by Niwas and Singhal (1981) as follows:

$$T_r = K\sigma$$

$$R = \frac{KS}{\sigma} \tag{7}$$

In areas where the geologic setting and water quality do not vary greatly the product Kσ remains fairly constant (Niwas and Singhal, 1981). Hence, if the values of K from the existing boreholes and σ from the sounding interpretation around the borehole are available, it is possible to estimate the transmissivity and its variation from place to place from the determinations of R or S for the aquifer.

Fetter (2007) relation for obtaining storativity from pumping test data can be written as:

$$S_t = \frac{T_r tu}{360r^2} \tag{8}$$

where, u is determined from well function:

r = Radial distance from the pumping well to the observation well
T_r = Aquifer transmissivity

Chatterjee (2005) relations for specific capacity of wells can be modified by appropriate substitution as:

$$S_C = 0.85\ kh$$

K = Hydraulic conductivity
h = Screen length

RESULTS AND DISCUSSION

The survey revealed multi geoelectric layers. There is marked variation in resistivity with depth across the entire study area. The geoelectric section compared with the borehole lithology gave the resistivity of the probable aquifer, the depth to aquifer, the aquifer thickness as well as aquifer depth which varied across the area. The aquiferous zones occur most in the fourth and the fifth geoelectric layers. Typical modeled curve, the geoelectric section and lithology are shown in Fig. 2 for VES 32 near Anara borehole in the South and for VES 119 near Ihube Okigwe borehole in the Northern part of the area (Fig. 3). The curves are a combination of H- type and K-type (Ekine, 2010) and HKH-type and KQH-type (Oseji *et al.*, 2005).

The hydraulic properties determined from the boreholes are displayed in Table 1. Parameters 1-6 are determined on the basis of pumping test while 7-15 were determined on the basis of VES results. Although, the computation was based on the screened portions of the aquifer, the close agreement between parameters 2 and 15 for Madona II borehole attest to the reliability of the VES results. The table compares aquifer characteristics determine from pumping test data with those obtained from VES results. Transmissivity and specific capacity values are least for Umunumo boreholes with magnitude of 25.4950, 21.6707 m^3 day^{-1}, respectively. This area falls within the Bende Ameki Formation. The Formation is aquiferous but groundwater exploitation is sometimes difficult due to high percentage of shale (Nwosu *et al.*, 2010). However, the transmissivity values determined from VES results (parameter 14) are fairly uniform and relatively high for the boreholes sampled.

Table 2 is the summary of aquifer characteristics obtained from VES 101-120. Low aquifer resistivity value of 667 Ωm was recorded for VES 120 near Akpugo. The aquifer is relatively thin in the Northern part but thick in the Southern part aquifer thickness of 9.4 m is recorded for VES 116 near Umuduru while the highest thickness of 104.4 m is obtained in the Southern part of the district.

The transmissivity values obtained for the study area varied from 992.04 m^2 day^{-1} (VES 120) obtained in the Northern area (Table 2) to 10263.65 m^2 day^{-1} obtained in the Southern part (VES 89). Generally transmissivity values increase southwards.

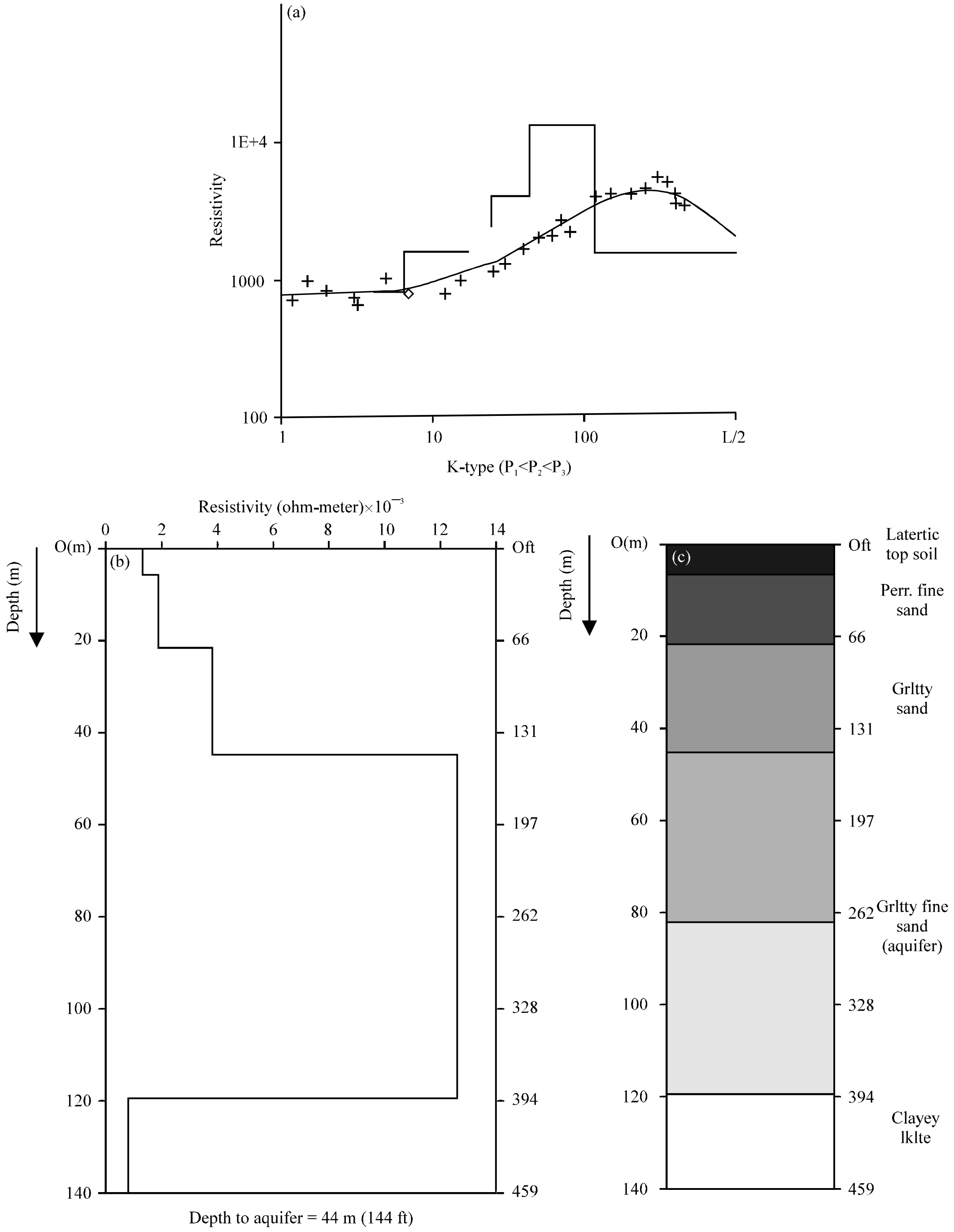

Fig. 2(a-c): Model curve, geoelectric section and lithology of VES 32 near Anara Borehole (a) Model curve, (b) Geoelectric section and (c) Lithology

The storativity values range from 1.59×10^{-4} observed in the Northern part of the Study area around VES 118-7.80×10^{-3} recorded in the Southern part at VES 98. The trend in the variation of transmissivity and storativity values is consistent with the geology of the area. The Southern part where the higher values of transmissivity and storativity are obtained, fall within the coastal

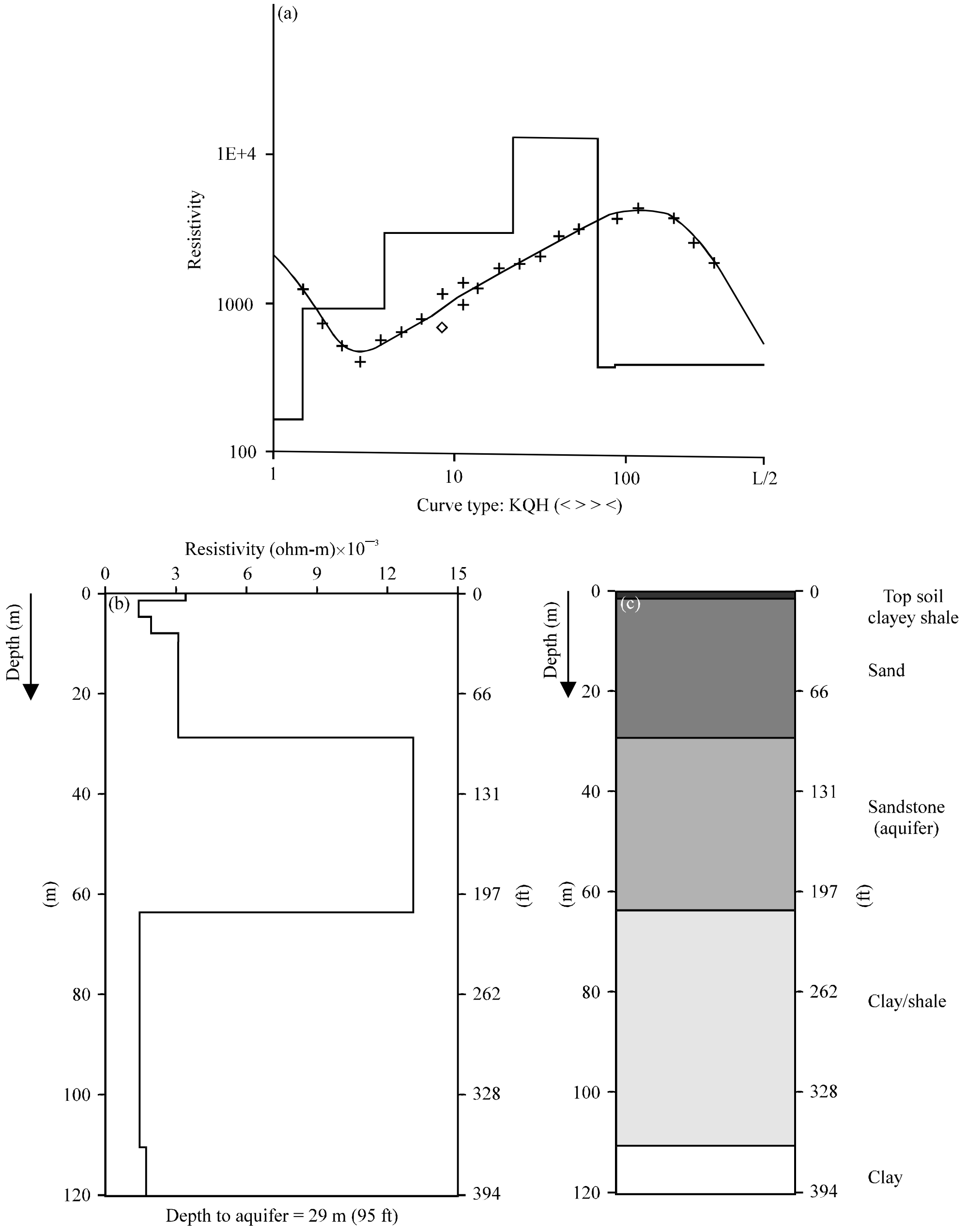

Fig. 3(a-c): Model curve, geoelectric section and lithology of VES 119 near lhube Okigwe Borehole (a) Model curve, (b) Geoelectric section and (c) Lithology

plain sands (Benin Formation) which is made up of alternating layers of sands, sandstones and loams of clays (Nwankwo *et al*., 2011). As the sandy components form more than 90% of the sequence of layers, permeability, transmissivity and storage coefficients are high. The high transmissivity values recorded in the South and Southwestern area covering Isiala Mbano, Ehime Mbano, Ihitte Uboma and Obowo where higher values of aquifer thickness are observed agrees with the expected result as transmissivity is a function of aquifer thickness. There is little the top

Table 1: Aquifer characteristics calculated for some boreholes located in the study area

Parameters	AVUTU BH	ANARA BH	UMUNUMO 2 BH	AMARAKU 2 BH	MADONINA 2 IHITTE UBOMA BH	NSU BH	UGIRI BH	MBANO HOSP. UMUELEMAI BH	ISIWEKE BH	OKIGWE BH
Screen length (m)	21.34	15.24	15.24	6.10	21.95	17.68	15.24	9.75	12.19	5.39
Average filed hudraulic conductivity k (m day^{-1})	22.5957	-	1.6729	115.3321	21.9952	-	22.158	61.333	393.463	-
Transmissivity (m^2 day^{-1})	482.1922	-	25.4950	703.5285	482.7946	-	136.272	597.997	4796.341	-
Storativity	0.000257	-	0.000210	0.000375	0.000226	-	0.00073	0.0000319	0.02558	-
Specific storage	0.00012	-	0.000014	0.000061	0.000010	-	0.00005	0.000033	0.000210	-
Specific capacity (m^2 day^{-1})	409.8634	-	21.6707	577.997	410.3754	-	287.035	508.297	4076.867	-
Resistivity of aquifer (Ωm)	5810	13400	12600	15000	16200	2430	6080	14800	4368	13950
Aquifer thickness h (m)	24.80	18.20	16.00	35.50	38.20	23.6	24.50	71.70	18.40	16.40
Conductivity σ (Ω^{-1} m^{-1})	0.000172	0.000746	0.000079	0.000067	0.00062	0.00412	0.00164	0.000068	0.000229	0.000072
Longitudinal conductance S	0.0043	0.0014	0.0013	0.0024	0.0024	0.0097	0.0040	0.0048	0.0042	0.0012
Transverse resistance	1440.88	1243880	201600	532500	618840	57348	148960	1061160	80371.20	228780
Kσ value	0.007158	0.042304	0.005096	0.001948	0.001675	0.018018	0.006909	0.000979	0.012845	0.004531
K/σ	241955.23	76106.01	816522.78	433,907.46	435,772.58	106,146.60	619,498.53	211,683.82	244,611.35	874,055.56
Transmissivity of aquiferous zone Tr (m^2 day^{-1})	1031.382	10317.141	1027.337	1037.245	1036.625	1033.282	1029.112	1038.691	1032.366	1036.626
Hydraulic conductivity	41.6163	56.7080	64.5053	29.0728	27.0179	43.7324	42.1259	14.3945	56.0916	62.9320

Table 2: Summary of aquifer characteristics for all the sounding stations showing depth to water table

Sr. No.	Resistivity of aquifer (Ωm)	Depth to water table (m)	Thickness (m)	Conductivity σ (Ω^{-1} m^{-1})	Transverse resistance R (Ωm)	Longitudican conductance S (m Ω^{-1})	Hydraulic conductivity K (m day^{-1})	Transmissivity Tr (m^2 day^{-1})	Conductivity product Kσ	Storativity	Specific capacity (m^3 day^{-1})
101	2168	99.8	12.6	0.000461	27316.80	0.005812	81.9115	1031.51	0.037761	6.20×10^{-4}	877.272
102	11200	100.0	16.0	0.000089	179200.00	0.001429	64.5053	1028.78	0.005741	7.89×10^{-4}	877.272
103	16000	113.0	15.6	0.000063	249600.00	0.000975	66.1593	1040.34	0.004168	7.69×10^{-4}	877.272
104	18920	72.9	13.8	0.000053	261096.00	0.000729	74.9788	1034.93	0.003964	6.80×10^{-4}	877.273
105	21000	77.7	20.3	0.000048	426300.00	0.000967	50.8416	1040.34	0.002440	1.00×10^{-4}	877.272
106	18600	86.8	16.2	0.000054	301320.00	0.000871	63.7089	1036.63	0.003440	7.99×10^{-4}	877.272
107	18500	141.1	17.1	0.000054	316350.00	0.00924	60.3558	1031.05	0.003259	8.43×10^{-4}	877.271
108	1500	96.2	21.8	0.000067	327000.00	0.001533	47.3433	1037.25	0.003172	1.07×10^{-4}	877.271
109	13950	91.6	16.4	0.000072	228780.00	0.0001756	62.9320	1036.63	0.004531	8.09×10^{-4}	877.272
110	12090	96.3	9.3	0.000083	112437.00	0.000769	1109769	1035.67	0.009211	4.58×10^{-4}	877.272
111	18000	100.8	14.2	0.000056	255600.00	0.000789	72.6820	1040.34	0.004070	7.00×10^{-4}	877.272
112	21890	97.7	12.3	0.000046	269247.00	0.000562	83.9093	1039.25	0.003860	6.06×10^{-4}	877.272
113	17210	108.0	120	0.000058	206520.00	0.00693	86.0071	1030.21	0.004989	5.92×10^{-4}	877.272
114	16150	82.7	13.6	0.000062	219640.00	0.000842	75.8886	1033.43	0.004705	6.70×10^{-4}	877.272
115	15600	91.1	8.9	0.000064	138849.00	0.030571	115.9646	1030.43	0.007422	4.39×10^{-4}	877.272
116	23100	30.0	9.4	0.000043	217140.00	0.000407	109.7963	1025.17	0.004721	4.63×10^{-4}	877.272
117	1470	71.0	15.0	0.000068	22344.00	0.010340	67.9003	1031.67	0.046172	7.49×10^{-4}	877.272
118	13950	47.9	32.3	0.000072	450585.00	0.002315	31.9531	1036.63	0.002301	1.59×10^{-4}	877.272
119	13100	28.9	33.7	0.000076	441470.00	0.257552	30.6257	1027.54	0.003276	1.66×10^{-4}	877.273
120	667	50.1	38.8	0.001499	24879.00	0.058171	26.6001	992.04	0.039874	1.91×10^{-4}	877.268

layers are generally not continuous and show large variations in layer resistivity. These layers correspond to the brown to reddish lateritic overburden interspersed with sandy soils, sandy clay with humus observed around Onuimo area (VES 14, 19, 29) along AB (Fig. 4) and VES 6,11,12 along CD (Fig. 5). Part of the top layers have been greatly weathered which gave rise to high resistivity as observed around Ndioji (VES 2) and Uboma (VES 74). The deeper layers are more

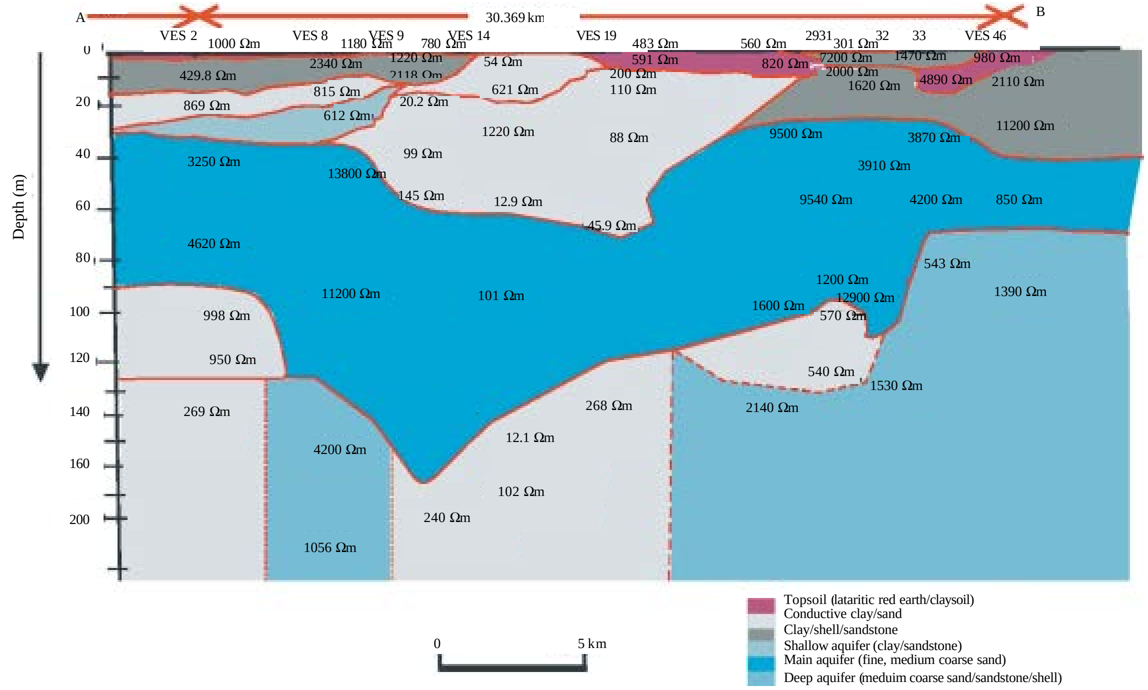

Fig. 4: Interpretative geoelectric cross-section (IGCS) along profile AB

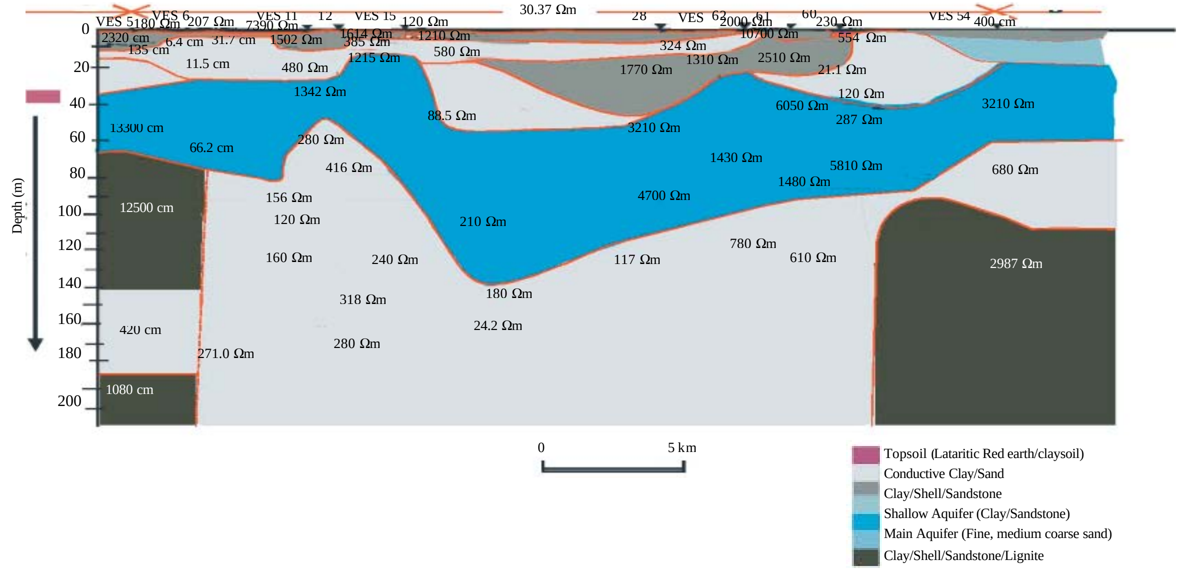

Fig. 5: Interpretative geoelectric cross-section (IGCS) along profile CD

continuous than the shallow layers. The second and third layers are composed of red lateritic soil, coarse to medium sand and clay. The fourth layer consists of fine medium coarse sands, sandstone and sandy shale. This layer constitute the major aquifers zone. The cross sections reveal the presence of shallow and deep aquifers. Along profile AB, the resistivity of the aquifer varied from 101 Ωm observed around Umuduru Egbeaguru (VES 14) to 13800 Ωm at Ndimoko (VES 8). The aquifer thickness varies from 4.2 m around VES 11-104.4 m around VES 95 where it is thickest.

The aquiferous layer is underlain by conductive layer composed of clays and/lignite and shale. In some locations the aquifer extends deeper into this layer as observed in VES 86 and 88 around Avutu (Fig. 5). The geoelectric cross-section also reveals the presence of confined aquifer around Onuimo (Fig. 6). This agrees with the geology of the area as the aquifer occurs between impervious clay layers. Oseji *et al.* (2005) used this technique successfully to investigate the aquifer characteristics and groundwater potential in Kwale, Delta State, Nigeria. Table 3 summarizes the range of values of some hydraulic properties computed for the study area, their location and their implications.

Table 3: Summary of the range of variation of hydraulic properties for the study area and their implications

Aquifer characteristics	Range of values	Implication
Conductivity	0.000031 (VES 93)-0.01000 (VES 21)	Northern part is more conductive
Transverse resistance	288 (VES 59)-230,968,80.00 (VES 95)	Southern part more resistive
Longitudinal conductance	0.000024 (VES 3)-1.421308 (VES 24)	Indicates the presence of low resistive (higher conductance) aquifer material and high resistive (low conductance)
aquifer material		
Hydraulic conductivity	9.8847 (VES 95)-115.9646 (VES 29 and 115)	Indicates variations in the flow rate of the aquifer
Transmissivity	992.04 (VES 120)-10263.65 (VES 89)	Amount of water transmitted by the thickness of
saturated		
		aquifer is more in the southern part
Conductivity product	0.00648 (VES 93)-0914046 (VES 7)	Indicates possible variation in water quality and geologic
setting		
Storativity	1.59×10^{-4} (VES 118)-7.80×10^{-3} (VES 98)	More water is stored in the southern part of the area

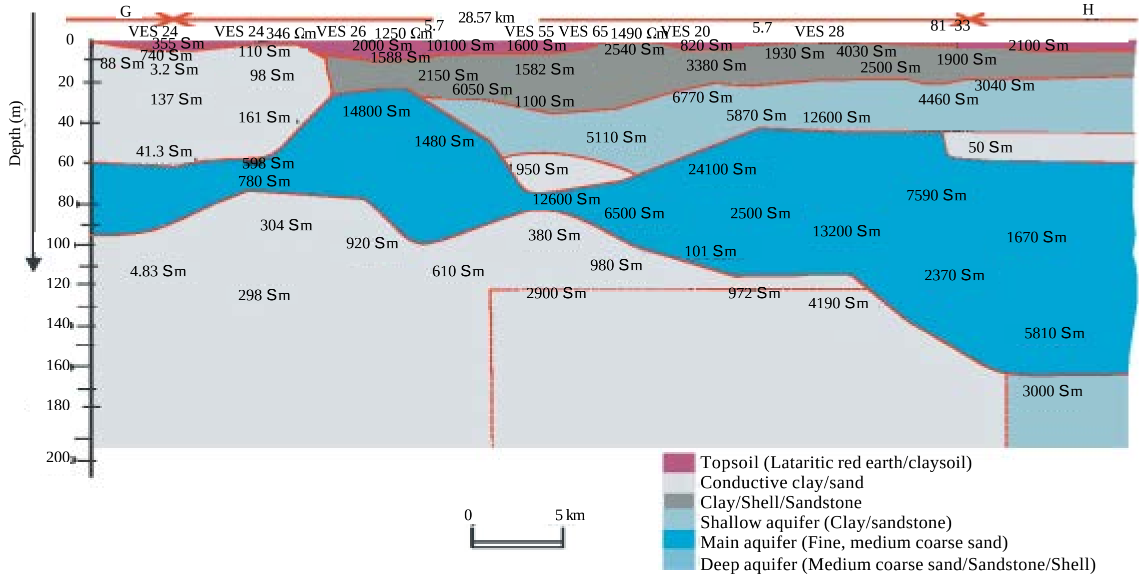

Fig. 6: Igeolectric cross-section (IGCS) along profile line GH

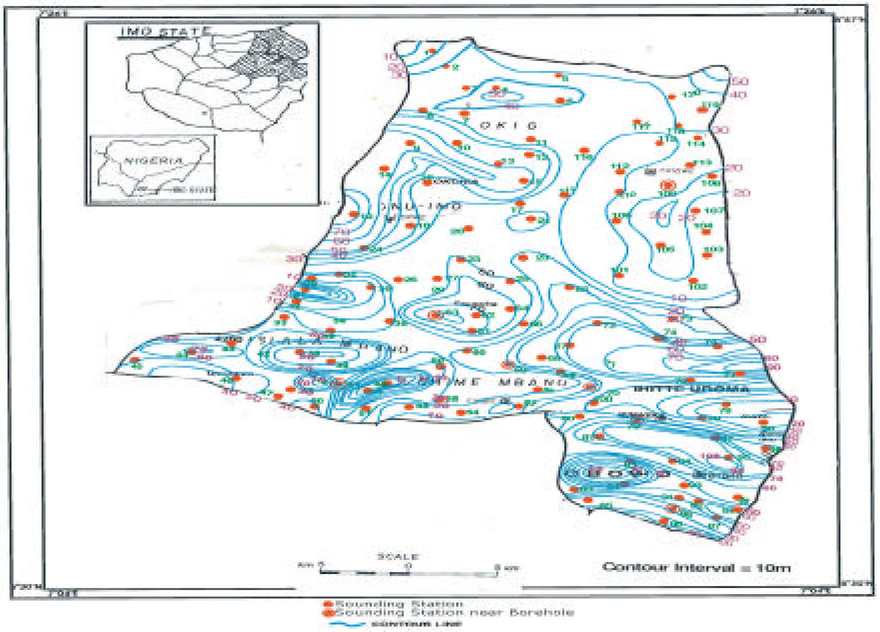

Fig. 7: Isopach map of the aquiferous zones in the study area

Isopach map of the aquiferous zone: The Isopach map of the major aquiferous zone constructed from the VES results (Fig. 7) shows that the aquifer thickness varies across the entire area. There are isolated closures suggesting discontinuities in the aquifer systems. The aquifer is thin in the northern part of the area covering Okigwe and parts of Onuimo areas with values of about 9 m recorded at VES 115 and 116 located at Umueze and Umule, respectively. The aquifer thickness increases down the Southern part of the study area. The highest value of aquifer thickness of 104.4 m is recorded at VES 95 located at Amanzo, in Obowo in the South-South part of the district.

Generally, the aquifer is thick enough in the Southeast, Southwest and South-South parts of the study area for drilling productive boreholes.

Layer resistivity contour map of the aquiferous zone: The layer resistivity contour map of the major aquiferous zone constructed for the area (Fig. 8) shows marked resistivity variations across the district. The low aquifer resistivity values ranging from 16-2382 Ωm recorded around the Northern part covering part of Okigwe and Onuimo Local Government Areas in the Central and Northwestern parts is consistent with the nature of the depositional environment. The area is underlain by clay, clay-shale members. Separating this zone from higher resistivity aquifer horizon in the North-eastern part having resistivity values ranging from 11200 Ωm at Ogwuoko (VES 102) to 23160 Ωm observed at Umuduru (VES 116) is resistivity value of about 5000 Ωm. The boundary coincides with the channels of Nterere, Odioma and Alum Rivers that flow into the Imo River. Demarcating these two zones also from the Southern high resistivity aquifer system is also resistivity value of about 5000 Ωm, coinciding with the channels of Efuru and Eze rivers that drain the area.

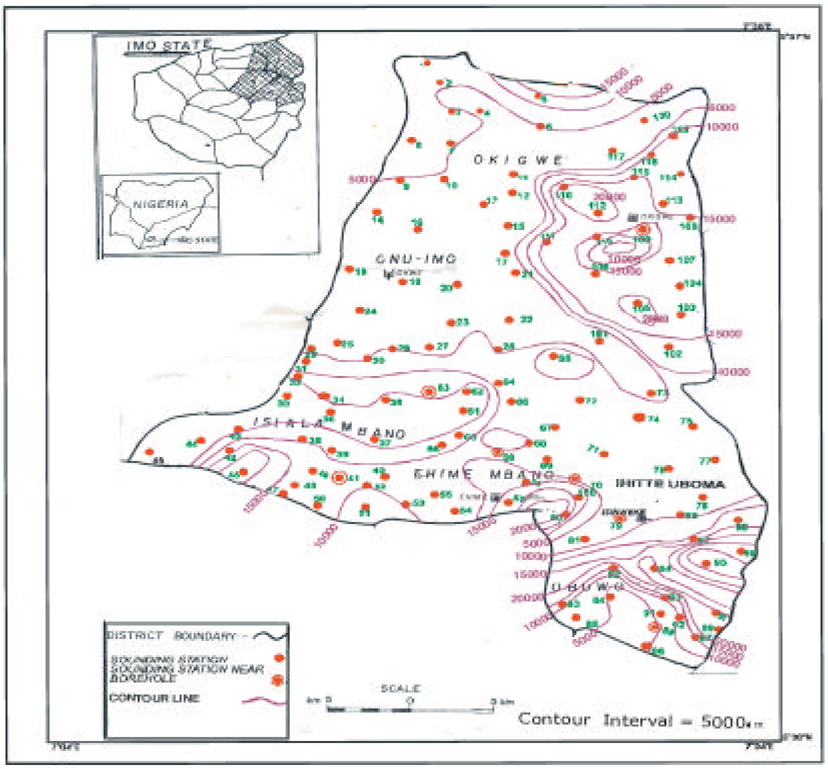

Fig. 8: Layer resistivity contour map of the aquifers zone

The sharp variations in resistivity observed in the South-South zone covering Obowo L.G.A. could be attributed to the inhomogeneous nature of the thick aquifers in the region and the water quality within the aquifer. Ekine and Iheonunekwu (2007) obtained similar result in Mbaitoli area of Imo State which is in the same geological environment with the Southern part of the study area.

Groundwater potential evaluation: Evaluation of groundwater potential of an area can be based on the characteristic aquifer geoelectrical parameters obtained from VES interpretation results and borehole hydrogeological information (Olorunfemi *et al.*, 1999; Ekwe *et al.*, 2006). Based on the groundwater yield of the boreholes determined from pumping test data, aquifer geometry, longitudinal conductance, transmissivity as well as storativity values, groundwater potential map of the study area was produced (Fig. 9).

The aquifer system in Zone A in the Southern part has the highest yield; 8292 m^3 day^{-1} recorded at Isinweke (VES 79), 4364 m^3 day^{-1} recorded at (VES 88), 1746 m^3 day^{-1} recorded at (VES 41) and 5237 m^3 day^{-1} observed at Umuelemai. These clearly indicate that the southern part of the district is the most prolific in terms of groundwater exploitation and thus the most promising in sitting productive boreholes. This zone correspond to the area of high aquifer transmissivity and thickness. In terms of longitudinal conductance this area is underlain by thick and high conductance aquifer materials and thus are good prospects for drilling boreholes. This area also recorded the highest value of storativity. These results are consistent with the observations made by Ekwe *et al.* (2006) around Obowo in a similar study of Imo River basin aquifers. The study covered Umuahia and part of the South-South part of Okigwe district.

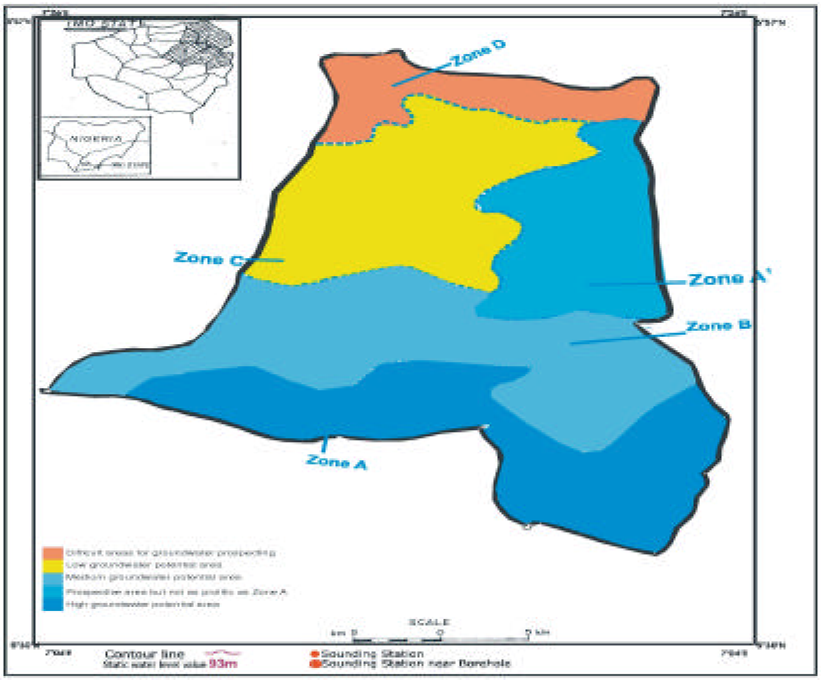

Fig. 9: Groundwater potential map of the study area

The Northeastern part of Okigwe (Zone A[1]) can be classified as Zone A based on the Kä and longitudinal conductance values as well as the transmissivity values. However, the groundwater yield of borehole located at Okigwe gives a value of 327 m^3 day^{-1} which is much lower than that in the zone located in the southern part of the study area. This variation could result from the complex nature of the depositional environment as there is marked difference in the transverse resistance values, aquifer thickness being lower coupled with the lower values for storativity observed in this North-eastern part of Okigwe (Zone A[1]). Hence, this area is not as prolific in terms of groundwater exploitation as that in the southern part of the district. Zone B is the next promising for groundwater exploitation or medium groundwater potential. Zone C is the low groundwater potential area while part D is a difficult area for groundwater exploitation.

CONCLUSION

This study has succeeded in evaluating the groundwater potential of the complex geological area of Imo State and mapped the aquiferous zone. It has also delineated sites for productive boreholes from VES results. The Southern and Northeastern parts of the district are more promising for siting borehole with high yield expectations than the North Western part as there is no well defined sand body that constitute aquifer there. The occurrence of aquifer in this area is linked to the presence of fracture in the shale members.

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REFERENCES

Akaolisa, C.C.Z. and A.O.I. Selemo, 2009. A study of the sand and Gravel deposit around the permanent site of the Federal University of technology, Owerri using the vertical electrical sounding (VES) techniques. Niger. J. Phys., 21: 81-88.

Chatterjee, A.K., 2005. Water Supply, Waste Disposal and Environmental Engineering. 7th Edn., Khanna Publishers, Delhi, India, pp: 59-82.

Ekine, A.S. and E.N. Iheonunekwu, 2007. Geoelectric survey for groundwater in mbaitoli local government area, Imo state Nigeria. Sci. Afr., 6: 39-48.

Ekine, A.S., 2010. Fundamentals of Applied Geophysics. Pearl Publishers, Nigeria, pp: 35-36.

Ekwe, A.C., N.N. Onu and K.M. Onuoha, 2006. Estimation of aquifer hydraulic characteristics from electrical sounding data: The case of middle imo river basin aquifers, south-eastern Nigeria. J. Spatial Hydrol., 6: 121-131.

Fetter, C.W., 2007. Applied Hydrogeology. 2nd Edn., C.B.S. Publishers and Distributors, New Delhi, India, pp: 161-550.

Henker, C.J., 1985. Schlumberger Automatic Analysis Software. Version 0.92, University of Amsterdam, Nederlands.

Mbonu, P.D.C., J.O. Ebeniro, C.O. Ofoegbu and A.S. Ekine, 1991. Geoelectric sounding for the determination of aquifer characteristics in parts of the Umuahia area of Nigeria. Geophysics, 56: 284-291.

Niwas, S. and D.C. Singhal, 1981. Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. J. Hydrol., 50: 393-399.

Nwankwo, C., L. Nwosu and G. Emujakporue, 2011. Determination of dar zarouk parameters for the assessment of groundwater resources potential: Case study of Imo state, South Eastern Nigeria. J. Econ. Sustainab. Dev., 2: 57-71.

Nwosu, L.I., C.N. Nwankwo and A.S. Ekine, 2010. An SP survey of groundwater and correlation with resistivity survey results in parts of Mbano area of Imo State, Nigeria. Arch. Applied Sci. Res., 2: 45-55.

Olorunfemi, M.O., J.S. Ojo and O.M. Akintunde, 1999. Hydro-geophysical evaluation of the groundwater potentials of the Akure Metropolis, Southestern Nigeria. J. Mining Geol., 35: 207-228.

Onyeaguocha, A.C., 1980. Petrogrphy and depositional environment of the Benin formation. J. Mining Geol., 17: 147-151.

Oseji, J.O., E.A. Atakpo and E.C. Okolie, 2005. Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta state, Nigeria. J. Applied Sci. Environ. Mgt., 9: 157-160.

Short, K.C. and J.A. Staeuble, 1967. Outline of Geology of Niger Delta. AAPG Bull., 6: 761-799.

Waterstaat, R., 1975. Standard Graphs for Resistivity Prospecting. Swets and Zeithinger, The Netherlands.

Zhody, A.A.R., 1965. The auxiliary point method of electrical sounding interpretation and its relationship to the Zarouk parameters. Geophysics, 30: 644-660.