ORIGINAL RESEARCH PAPER

Physics

Volume : 6 | Issue : 11 | November 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

GROUNDWATER PROSPECT FOR SITING PRODUCTIVE WATER BOREHOLE USING TRANSMISSIVITY VALUES DETERMINED FROM PUMPING TEST AND SURFACE GEOELECTRIC SOUNDING DATA IN PARTS OF THE SEDIMENTARY AREA OF SOUTHEASTERN NIGERIA.

KEYWORDS transmissivity, aquiferous zones, resistivity, pumping test data, hydraulic conductivity.

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ABSTRACT *Transmissivity values were determined from pumping test and surface geoelectric sounding data in Okigwe geopolitical zone of Imo state, Nigeria. Eleven out of the fifteen boreholes drilled in the area, which have drawdown values were used to determine the parameters. The Schlumberger electrode array with a maximum electrode spacing of 900m were used to carry out 120 vertical electrical soundings (VES) across the study area. Relating the geoelectric resistivity data to the borehole hydrogeological information for the area led to delineation of probable aquiferous zones. The aquifer thickness increases towards the southern part to a maximum value of 104m obtained at Amonze in Obowo Local Government Area. Using an average transmissivity of 1030.085m^2/day determined from the pumping test data, a mean conductance value of 19.222m/day was obtained for the area. The transmissivity values vary from 992m^2/day to 1038m^2/day while the hydraulic conductivity values range from 9.885 to 115.965m/day. Based on the result of the study, and the diagnostic hydraulic and electrical conductivity product (k) values, zones of sites for productive boreholes were delineated. The southern and northeastern parts of the study area are more promising for siting boreholes with high yield expectations. These areas have high transmissivity and aquifer thickness values.*

INTRODUCTION:

The study area is Okigwe geopolitical zone in Imo State of Nigeria. The area lies between Latitudes 5°30'N and 5°57'N of the Equator and Longitudes 7°04'E and 7°26'E of the Greenwich Meridian (Fig.1) covering an area of about 1824 km^2. The study area is made up of six Local Government Areas namely, Isiala Mbano, Ihitte Uboma, Ehime Mbano, Onuimo, Obowo and Okigwe.

Water is an important element of the natural environment but is becoming increasingly scarce owing to increasing demand and deteriorating quality due to pollution (Ayoade and Oyebande, 1978, Nwachukwu, 2011). Adequate water supply is essential to public health and wellbeing as well as agricultural and industrial activities. The rapid increase in the rate of industrial and commercial activities in the study area has placed higher demand for potable water. Surface water and groundwater are the two main sources of water in the study area. Surface water is usually polluted as a result of decaying organic matter. Clay and silt largely found in parts of the district especially around Amuro, Okwe and Okigwe town are carried by surface run-off into the streams and rivers. Thus river and stream water frequently showed discolouration by organic matter and high turbidity due to suspended solids. On the other

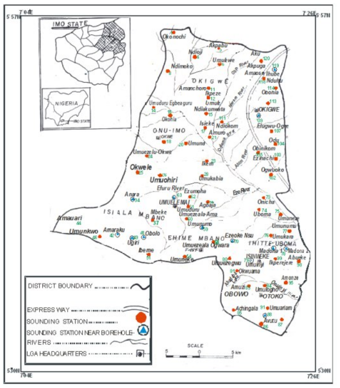

Fig. 1 Map of study showing some of the sound stations

hand, groundwater is relatively free from pollution as it undergoes tremendous physical treatment on its way from ground surface to the aquifer. Physical processes such as filtration takes place during infiltration. Also only few organisms survive at the depth of water table in the earth (Njoku, 1991). Hence, groundwater is considered the major source of potable water to meet the water needs of the people (Egwebe and Ifedili, 2006).

Certain aquifer characteristics are useful in assessing the water resources potential of a place. These parameters include the hydraulic conductivity and transmissivity. The determination of these aquifer characteristics is best done on the basis of data obtained from pumping wells (Mbonu et al., 1990; Ekine and Iheonunekwu, 2007). They can also be determined from surface geoelectric sounding results. These parameters are needed to execute proper water planning and management and also in determining the natural flow of water through an aquifer and its response to fluid extraction (Ekwe et al., 2006; Oseji *et al.*, 2005 and Odoh *et al.*, 2009).

Records available in Imo State water development agency (IWADA) show that there are failed water borehole projects in the area. These areas include Anara and Ihube. The failure could be linked to the nature of geological setting and inadequate or lack of geophysical information to guide during drilling. Proper geophysical investigation is therefore required to delineate sites for productive boreholes in the zone.

In the present study, the objectives are to define the aquifer geometry of the study area; to correlate some aquifer characteristics determined from pumping test analysis with those obtained from results of surface geoelectric soundings; establish the variation of some hydraulic and electrical properties of the aquiferous zones and therefore delineate sites for productive boreholes in the area.

Geology and Hydrogeology of the Study Area

The geology of the district (Fig. 2) reveals the following stratigraphic units; the Benin Formation, the Ogwashi - Asaba Formation, the Bende - Ameki Formation, Imo Shale

Volume : 6 | Issue : 11 | November 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

Formation, Nsukka Formation and Ajali Formation (IWADA, 2002; Akaolisa and Selemo, 2009). 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., 1990). The Benin Formation consists of coarse - grained gravelly sandstones with minor intercalations of shales and clay. The sand units are mostly coarse to fine grained, pebbly and poorly sorted (Onyeagocha, 1980; Short and Stauble, 1967). 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 Bende-Ameki Formation consists of greenish - grey clayey sandstones, shales and mudstones with interbedded limestones. This Formation in turn overlies the impervious Imo Shale Group.

The Ajali Formation consists of thick friable, poorly sorted sandstones typically white in colour but sometimes iron-stained. A marked banding of coarse and fine layer is displayed

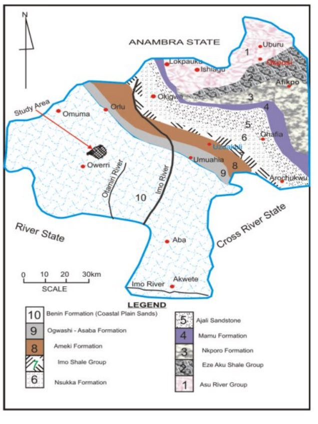

Fig. 2: Geological Map of Imo and Abia States showing the Study Area Adapted from Imo Water Development Agency (IWADA, 1999)

(Kogbe, 1989).The Ajali Formation is often overlain by a considerable thickness of red earth, which consists of red, earthy sands formed by the weathering and ferruginisation of the formation (Kogbe, 1989).

The three major regional aquifers identified in Imo State are:
(i) The Coastal Plain Sands (Benin Formation);
(il) The Bende Ameki Group (Part of Anambra Basin);
(iii) The Ajali Sandstones.

The Coastal plain sands that cover part of the study area underlies almost half of the State and has an annual replenishment of about 2.5 billion cubic metres per year. It is built of alternating layers of sands, sandstones, and seams of clays. As the sandy component in most areas forms more than 90% of the sequence of layers, permeability, transmssivity and storage coefficients are high (Maduagwu, 1990; Nwankwo et al., 2013; Nwosu et al., 2013).

The Coastal sedimentary lowlands are underlain by the Tertiary sediments of the Deltaic Plain, the coastal plain sand, the Bende Ameki and the Imo Shales. With the exception of the Imo Shales, most of the formations consist of predominantly unconsolidated sands that are porous. The high yearly average rainfall over the area ensures adequate groundwater recharge.
Groundwater occurs in essentially unconfined conditions over most of the area and the water table generally trends South towards the coast. The depths to the aquifer vary from a few feet in the South to maximum of 501 ft (152.7m) with average depth of 150ft (45.7m) below the ground surface (Ayoade, 1995). On the other hand the depth of water table in the Bende Ameki is often considerable, reaching as much as 587ft (178.9m) (Ayoade, 1995). The Bende Ameki Group is composed mainly of sands intercalated with shales, lignites and calcareous shales. The sand parts have more or less the same coefficients of permeability as the Coastal Plain Sands but the transmissivity coefficient is lower because of high percentage of shales. Egwebe and Ifedili (2006) observed that the depth to aquifer in the Ameki Formation around Orlu in Imo State is between 70m to 83m and can reach a value of 122m in Asaba and Ogwashiukwu west of the Niger.

The Ajali Formation extends through the North Eastern Parts of the State and dips towards the South West. The rate of replenishment is about 250 million cubic metres per year. When compared with the other formations, it is the least prolific for groundwater (Maduagwu, 1990).

Methodology

A total of 120 vertical electrical soundings (VES) were carried out in the district using the Schlumberger electrode configuration with a maximum electrode spacing of 900 m in some occupied stations. The ABEM Terrameter (SAS) 300B was used to acquire the data. It has a liquid crystal digital read-out and an automatic signal averaging microprocessor. Four stainless steel electrodes made up of two current and two potential electrodes were used. A 12V dc source was used to power the instrument.

The current electrode spacing was increased symmetrically about the centre, keeping the potential electrodes constant until it became necessary to increase the potential electrode spacing as the strength of 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. 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 thicknesses) for computer aided interpretation. The field measurements were inverted using the Schlumberger automatic analysis version 0.92 software package (Hemkler, 1985) to determine the true resistivities and depths of subsurface formations. The resulting model curves have three to five interpretable geoelectric layers with less than 5% RMS errors. Relevant borehole data for the area were obtained (Table 1) and used to compute the aquifer parameters and for subsequent interpretation of the VES data. The lithologic log of the boreholes located in the area and the static water level (SWL) values were used to delineate the aquifer layers and the probable depth to aquifer.

Aquifer parameters from pumping test data and surface geoelectric sounding data were computed as follows. The average hydraulic conductivity is determined using the equation

$$K = \frac{1.18Q}{hS_{mw}} \qquad 1$$

Where Q = well discharge in m^3 / day, K = average hydraulic conductivity in m / day,

h = thickness of the aquifer in m, S_{mw} = maximum drawdown in the pumped well in m, Aquifer transmissivity is obtained using the equation

$$T = Kh \qquad 2$$

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Table 1 shows the pumping test data obtained for some boreholes in the study area. Computation of the aquifer parameters based on the data gave the values displayed in Table 2 for parameters 1 to 6.

The total transverse unit resistance R and total longitudinal conductance S are given respectively using the equations:

$$R = \rho h \qquad 3$$

$$S = \frac{h}{\rho} \qquad 4$$

where ρ and h are the resistivity and thickness of the Layer. The parameters R and S are called the Dar Zarouk parameters.

Niwas and Singhal (1981) gave the analytical relationship between transmissivity and transverse resistance, and that between transmissivity and longitudinal conductance as flows:

$$T = K\sigma R = \frac{KS}{\sigma} \qquad 5$$

According to the authors, in areas where the geologic setting and water quality do not vary greatly, the product Kσ remains fairly constant. 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.

TABLE 1: EXISTING BOREHOLE/PUMPING TEST DATA OF THE STUDY AREA

S/N 0	LOCATION	DRILL DEPTH (m)	CASING DIAMETER (m)	SCREEN DIAMETER (m)	CASING DEPTH (m)	SCREEN LENGTH (m)	STATIC WATER LEVEL SWL(m)	DRAW DOWN (m)	YIELD (m^3/day)
1	Avutu No.2 BH	170.7	0.34	0.20	146.3	21.3	53.0	10.7	4364.25
2	Anara 1	73.2	0.30	0.20	54.9	15.2	52.4	Abortive	218.21
3	Umunumo 1	73.2	0.30	0.20	54.9	15.2	23.8	28.7	618.99
4	Umunumo 2	79.3	0.30	0.20	67.1	9.2	21.6	27.1	392.78
5	Amaraku 1	99.4	0.20	0.15	76.2	1.5	31.1	-	1091.06
	Amaraku 2	118.9	0.30	0.25	83.5	6.1	74.4	1.8	
6	Madona I Ihitte Uboma	128.0	0.34	0.25	97.5	30.5	95.1	6.3	654.64
7	Madona II Ihitte Uboma	182.9	0.34	0.25	151.8	22.0	93.3	6.4	2618.55
8	Nsu	143.3	0.20	0.15	125.6	17.7	35.3	Collapsed	781.96
9	Ugiri	121.9	0.25	0.20	103.6	15.2	71.3	6.1	1745.70
10	Mbano	91.4	0.13	0.12	73.8	6.1	46.0	20.1	78.56
11	Mbano Hospital	85.6	0.25	0.15	78.9	9.8	44.8	3.7	1854.80
12	Umuelemai	140.2	0.30	0.20	121.9	15.2	30.9	3.8	5237.10
13	Isinweke LGA	155.5	0.30	0.20	121.9	12.2	87.6	2.0	8292.07
14	Okigwe	94.0	0.17	0.13	85.3	5.4	23.2	-	327.32

SOURCE: IMO STATE WATER DEVELOPMENT AGENCY (IWADA)

RESULTS AND DISCUSSION

The geoelectric survey revealed that the study area is multi-layered and showed variation in resistivity with depth. The geoelectric section compares favourably with the borehole lithology. The resistivity model gave the resistivity of the probable aquifer, the depth to aquifer and the aquifer thickness. Figures 3 shows typical modelled VES curves while Figure 4a shows the interpreted geoelectric section obtained for VES 63 near Umuelemaii borehole in Isiala Mbano, VES 78 near Umuiyi Isinweke in Ihitte Uboma, VES 88 hear Avutu borehole Obowo and VES 113 near Okigwe borehole. These were constructed using the borehole lithology for the study area shown in Fig 4a and 4b.

The depth to aquifer varies across the entire study area and correlates with the static water level (SWL) values for the area. The value for VES 109 around Okigwe is about 23m. It is 53.2m at Anara (VES 34) while deep aquifers are observed in the Southern area with a value of 94.0m recorded at Isinweke (VES 79). The aquifer thickness increases southwards with a maximum value of 104.4m recorded at Amonze (VES 95). Generally, the aquifer is thick enough in the Southern and North-eastern parts of the study area for drilling productive boreholes.

The distribution of layer resistivity of the aquiferous zones (Fig. 5) shows that the area around the Northwestern part of the study area have relatively lower resistivity. This area covers part of Okigwe and Onuimo in the study area (Nwosu et al., 2013). The low aquifer resistivity values observed in this area is consistent with the nature of the depositional environment. The area is underlain by clay, clay-shale members of the Imo Shale Formation. Separating this zone from higher resistivity aquifer horizon in the North-eastern part 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 resistivity value of about 5000 Ωm also, coinciding with the channels of Efuru and Eze Rivers that drain the area. There is sharp variation in resistivity observed in the South-South zone covering Obowo L.G.A. This could be attributed to the inhomogeneous nature of the thick aquifers in the region and the water quality within the aquifer as well as the nature of the depositional environment (Ekine and Iheonunekwu, 2009). Aquifer resistivity values varies from formation to formation. Egwebe, and Ifedili (2006) recorded resisitivity values of 8955 to 9965Ωm and observed depth to aquifer between 70m to 83m in a study of Ameki aquifers around Orlu in Imo State, a few kilometers from the present study area. Relatively high aquifer resistivity values are recorded for Isiala Mbano and Ehime Mbano.

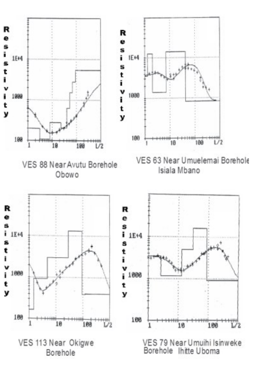

Fig. 3: Typical Interpreted Geoelectric Model Curves

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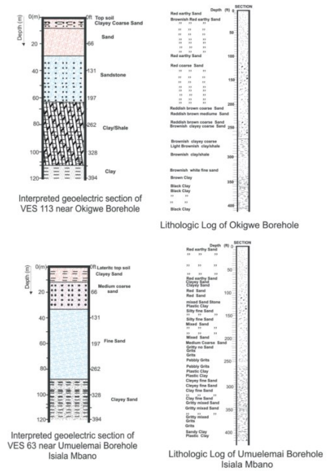

Fig. 4a: Interpreted Geoelectric Sedtions of typical VES Stations near Boreholes and Lithologic Log of the area

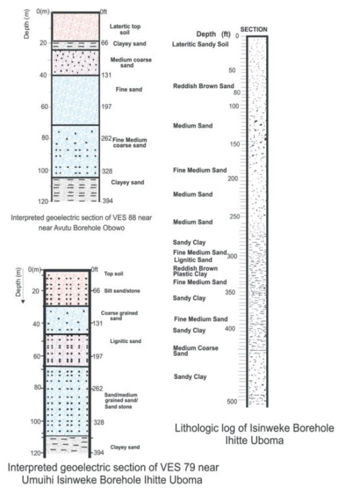

Fig. 4b: Interpreted Geoelectric Sedtions of typical VES Stations near Boreholes and Lithologic Log of the area

Estimation of Transmissivity and other Aquifer Parameters from Pumping Test Analysis

Hydraulic conductivity K, was computed applying equation 1 to the pumping test data of Table 1 while electrical conductivity σ, transverse resistance R and longitudinal conductance S were determined from vertical electrical soundings result. Equation 5 was used to estimate the transmsissivity of the aquiferous zones and its variation in the geopolitical zone including the areas without borehole information. This was achieved using the analytical relationship between aquifer transmissivity and transverse resistance, and between transmissivity and longitudinal conductance (Mbonu et al., 1991; Zhody at al., 1974). Table 2 compares aquifer characteristics determined from pumping test data with those calculated on the basis of VES data. Parameters 1 to 6 were determined from pumping test data while parameters 7 to 15 were computed from VES results The computation was based on the screened sections of the aquifer in the borehole. The true transmissivity values calculated for the entire aquifer thicknesses obtained from VES results are shown as parameter 14 of Table 2 . Notice the close agreement between parameters 2 and 15 for Madonna II Ihitte Uboma. Table 3 shows the summary of aquifer characteristics determined for some of the sounding stations in the area.

Using an average transmissivity of 1038m^2/day determined from pumping test analysis, a mean conductance value of 19.222m/day was obtained for the study area. The hydraulic conductivity values range from 9.885 to 115.965m/day. The transmissivity values are quite high especially in the Northeastern and Southern zones. The distribution of aquifer transmissivity is shown in Figure 6. The distribution suggests possible existence of different aquifer systems. The Northeastern to North central part has transmissivity value of 1032 m^2/day; the Northeastern part has values reaching 1040m^2/day; the Southwestern part covering Isiala Mbano and Ehime Mbano L.G.As has values reaching 1078m^2/day recorded at Ezeoke (VES 68) and 1038 m^2/day observed at Umuinyi (VES 94) in Obowo. This observation is consistent with the geology of the area. The relatively higher transmissivity values were observed in the Southern area underlain by Coastal Plane sands with high aquifer thickness. Transmissivity is a function of aquifer thickness.

Distribution of Hydraulic and Electrical Conductivity Product (Kσ) values

Figure 7 shows the distribution of diagnostic Kσ for the study area. Correlating this distribution with that of transmisivity values (Fig. 6) identifies three possible aquiferous zones. Zone A is located in the Southeastern part and in the Southern part of Isiala Mbano, Ehime Mbano, Ihitte Uboma and the entire Obowo LGA. Zone B covers the least area in the Study area and includes Ihitte Uboma LGA and the Northern parts of Ehime Mbano and Isiala Mbano. Zone C is underlain by Imo Shale Formation and may not be good prospect for drilling borehole with high yield expectation. Relating the distribution to the well discharge (groundwater yield) of boreholes (Table 1), zones of sites for productive boreholes can be identified. The yield is least at Anara in the Southern area (VES 34) with a value of 218m^3/day followed by that recorded at Okigwe (VES 109) having a value of 327m^3/day. Generally, groundwater yield increases Southwards reaching a maximum value of 8292m^3/day recorded at Isinweke (VES 79). Zones A and B are prospective zones for groundwater with Zone A being the most prolific. This is consistent with the geology of the area. Zone B is less prolific due to high percentage of shale of the Bende-Ameki Formation in the area.

TABLE 2: AQUIFER CHARACTERISTICS CALCULATED FOR SOME BOREHOLES LOCATED IN THE STUDY AREA

S/No	Parameters	Avutu BH	Anara BH	Umunumo 2 BH	Amaraku 2 BH	Madona 2 Ihitte/ Uboma BH	Nsu BH	Ugiri BH	Mbano Hosp.Umuelemai BH	Isinweke Bh	Okigwe BH
1	Screen length (m)	21.34	15.24	15.24	5.10	21.95	17.68	15.24	9.75	0.18	5.39
2	Average filled hydraulic conductivity k (m/day)	22.70	-	1.6729	115.3321	21.9952	-	22.158	61.333	393.463	-
3	Transmissivity (m^2/day)	483.51	-	25.4950	703.5285	482.7946	-	136.272	597.997	4792.314	-
4	Storativity	0.000257	-	0.000210	0.000375	0.000226	-	0.000073	0.000319	0.02588	-
5	Specific Storage	0.000012	-	0.000014	0.000061	0.000010	-	0.000005	0.000033	0.000210	-

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6	Specific Capacity (m^3/day)	409.8634	-	21.6707	577.997	410.3754	-	287.035	508.297	4076.867	-
7	Resisstivity of Aquifer (Ωm)	5810	13400	12500	15000	16200	2430	6080	14800	4368	13950
8	Aquifer Thickness h (m)	24.80	18.20	16.00	35.50	38.20	23.6	24.50	71.70	18.40	16.40
9	Conductivity σ ($\Omega^{-1}m^{-1}$)	0.000172	0.000075	0.000079	0.000067	0.000062	0.00412	0.000164	0.000068	0.000229	0.000072
10	Longitudinal Conductance S	0.0043	0.0014	0.0013	0.0024	0.0024	0.0097	0.0040	0.0048	0.0042	0.0012
11	Transverse Resistance R	144088	243880	201600	532500	618840	57348	148960	1061160	80371.20	228780
12	Kσ Value	0.00716	0.0045	0.005095	0.001948	0.001675	0.018018	0.006909	0.000979	0.012845	0.004531
13	K/σ	241918.6	756000	816522.8	433907.5	435,772.6	106,146.6	619,498.5	211,683.8	244,611.4	874,055.6
14	Transmissivity of Aquifer Zone Tr (m^2/day)	1031.67	1037.10	1027.337	1037.245	1036.625	1033.282	1029.112	1038.691	1032.366	1036.626
15	Hydraulic Conductivity	41.61	56.70	64.5053	29.0728	27.0179	43.7324	42.1259	14.3945	56.0916	62.9320

TABLE 3: SUMMARY OF AQUIFER CHARACTERISTICS FOR SOME OF THE SOUNDING STATIONS

VES S/N	Resistivity of aquifer (Ωm)	Probable depth to aquifer (m)	Thickness (m)	Conductivity ($\Omega^{-1}m^{-1}$)	Transverse resistance R (Ω)	Longitudinal conductance S (Ω^{-1})	Hydraulic conductivity K (m/day)	Transmissivity T_r (m^2/day)	Conductivity product Kσ
1	9600	26.6	18.2	0.000104	174720	0.000190	56.71	1030.43	0.005898
5	13300	30.2	36.8	0.000075	4894	0.000028	28.05	1029.58	0.002104
8	13880	29.5	35.5	0.000072	492740	0.000026	29.07	1031.42	0.002073
16	131	37.2	26.0	0.007634	3406	0.198473	39.70	1032.14	0.303036
20	93	32.1	12.6	0.010753	1172	0.135484	81.91	1032.11	0.880794
26	780	68.0	6.8	0.001282	5304	0.008720	151.78	1032.04	0.194578
33	4200	44.7	57.3	0.000238	240660	0.013643	18.01	1031.67	0.004287
34	13400	53.2	18.2	0.000075	243880	0.001358	56.71	1031.71	0.004230
39	6020	33.7	72.0	0.000166	433440	0.001196	14.33	1031.38	0.002380
41	2825	75.5	18.7	0.000364	52827	0.006620	55.19	1032.08	0.019537
42	15000	72.0	35.5	0.000067	532500	0.002367	29.07	1037.25	0.001948
49	6080	84.5	24.5	0.000164	148960	0.004030	42.13	1029.11	0.006909
59	12600	24.0	24.0	0.000083	302400	0.001905	43.00	1030.81	0.003570
63	14800	32.0	71.7	0.000068	1357160	0.004845	14.39	1328.48	0.000988
70	2430	35.5	23.6	0.000412	64638	0.009719	43.73	1164.63	0.018018
78	2500	94.0	86.0	0.000105	215000	0.034400	12.00	1032.09	0.001260
79	5110	88.0	90.1	0.000196	4604	00111.45	11.45	1033.37	0.002245
81	2500	90.0	75.3	0.000400	187400	0.030320	13.62	1032.08	0.005446
84	3700	52.0	50.0	0.000270	185000	0.013514	20.65	1031.05	0.005573
85	7450	51.8	24.0	0.000134	178800	0.003222	43.04	1031.09	0.005767
88	5810	53.0	24.8	0.000172	144088	0.004269	41.62	1031.38	0.007158
95	2229	85.0	104.4	0.000451	231768	0.04703	9.89	1032.036	0.004458
97	6200	80.0	94.4	0.000161	337280	0.008774	18.97	1030.23	0.003055
99	2300	86.0	36.7	0.000434	84410	0.015957	28.12	1008.86	0.011950
109	13950	23.0	16.4	0.000072	228780	0.000176	62.93	1036.63	0.004531
113	17210	108.0	12.0	0.000058	206520	0.00693	86.01	1030.21	0.004989

Conclusion

On the basis of transmisssivity values and K distributions, the aquifer system in the study area can be divided into three distinct zones. The southern zone which covers Obowo, parts of Isiala Mbano, Ehime Mbano and Ihitte Uboma Local Government Areas form the most prospective zone for groundwater exploitation. The high transmissivity values recorded over most parts of this zone agree with the geology of the Coastal Plain Sands (Benin Formation) which consists of fine to medium to coarse grain sands. The Northeastern part of the study area around Okigwe is also homogenous in terms of hydraulic properties and water quality but distinct from the Northwestern zone. This difference between these zones result from changes in either subsurface geology or water quality or both. The Northwestern zone lies within the Imo Shale Formation which is difficult in terms of groundwater exploitation. The Northeastern zone lies within the Ajali sandstone aquifer. The area around the Northern part of Ehime Mbano and Ihitte Uboma form prospective zone for drilling productive borehole but not as prolific as the Southern and Northeastern parts due to high percentage of shale in the Ameki Formation underlying this zone. Hydrochemical analysis is required to ascertain the degree of variation in the water quality in these zones. However, it was not possible to access such data. From the results of this study, transmisivity values together with other parameters determine from pumping test analysis and surface geoelectric sounding results have been used successfully to delineate sites for drilling productive water boreholes in Okigwe district.

Volume : 6 | Issue : 11 | November 2016 | ISSN - 2249-555X | IF : 3.919 | IC Value : 74.50

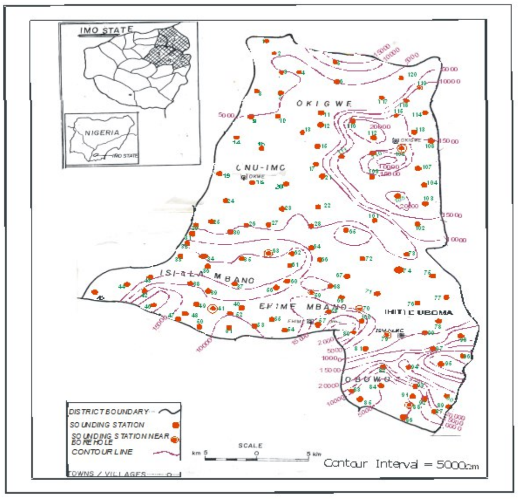

Fig. 5: Layer Resistivity Contour Map of the Aqferours Zone

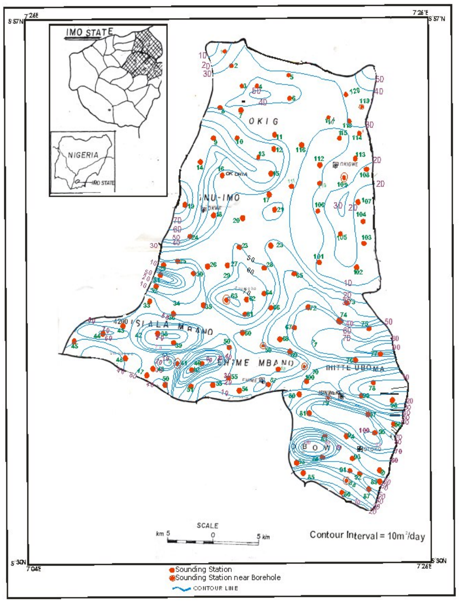

Fig. 6: Isopach map of the aquiferous zones in the study area

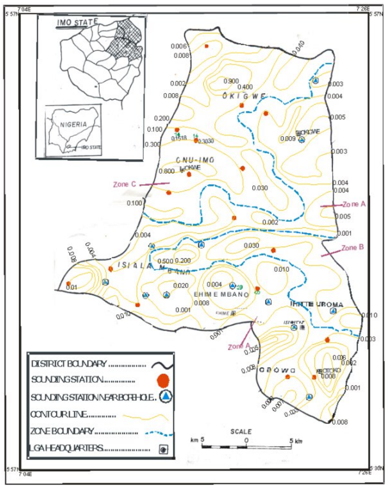

Fig. 7: Distribution of Electrical Conductivity and Hydraulic conductivity Product (k) of the Aquiferous Zone

Acknowledgment

The authors are grateful to Imo State Water Development Agency (IWADA) and Imo State Water Board for providing relevant borehole information that greatly enhanced this study.

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