Evaluation of Groundwater Potential from Pumping Test Analysis and Vertical Electrical Sounding Results: Case Study of Okigwe District of Imo State Nigeria.

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ABSTRACT

Groundwater potential evaluation of Okigwe District of Imo State of Nigeria was carried out based on 120 vertical electrical soundings (VES) in the area. The Schlumberger electrode array was adopted with a maximum electrode spread of 900m. Twelve of the VES stations were sited near existing boreholes to enhance interpretation. The results revealed a multi- layered earth. The resistivity of the aquiferous zones ranged from 33.1Ωm obtained at Umuedi (VES 7) in the northern part to 32600Ωm obtained at Otoko (VES 93) in the southern part of the area. The highest aquifer thickness of 104.4m was recorded at Amonze (VES 95). The hydraulic conductivity values obtained from the VES results varied from 9.8854 to 115.9646 m/day. The transmisivity values ranged from 992.04 to 10263.65m^3/day. The storativity values determined for the area ranged from $1.59x10^{-4}$ to $7.80x10^{-3}$ while the specific capacity is fairly uniform with magnitude of about 877. Groundwater potential evaluation of the district based on borehole hydrogeological information revealed that the Southern part of the district recorded the highest values of groundwater yield of 8292m^3/day at Isinweke, 1746 m^3/day at Ugiri and 5237 m^3/day at Umuelemai. This clearly indicates that the southern zone is the most prolific in terms of groundwater exploitation and thus the most promising for siting productive boreholes.

(Keywords: transmissivity, storativity, groundwater yield, specific capacity, VES)

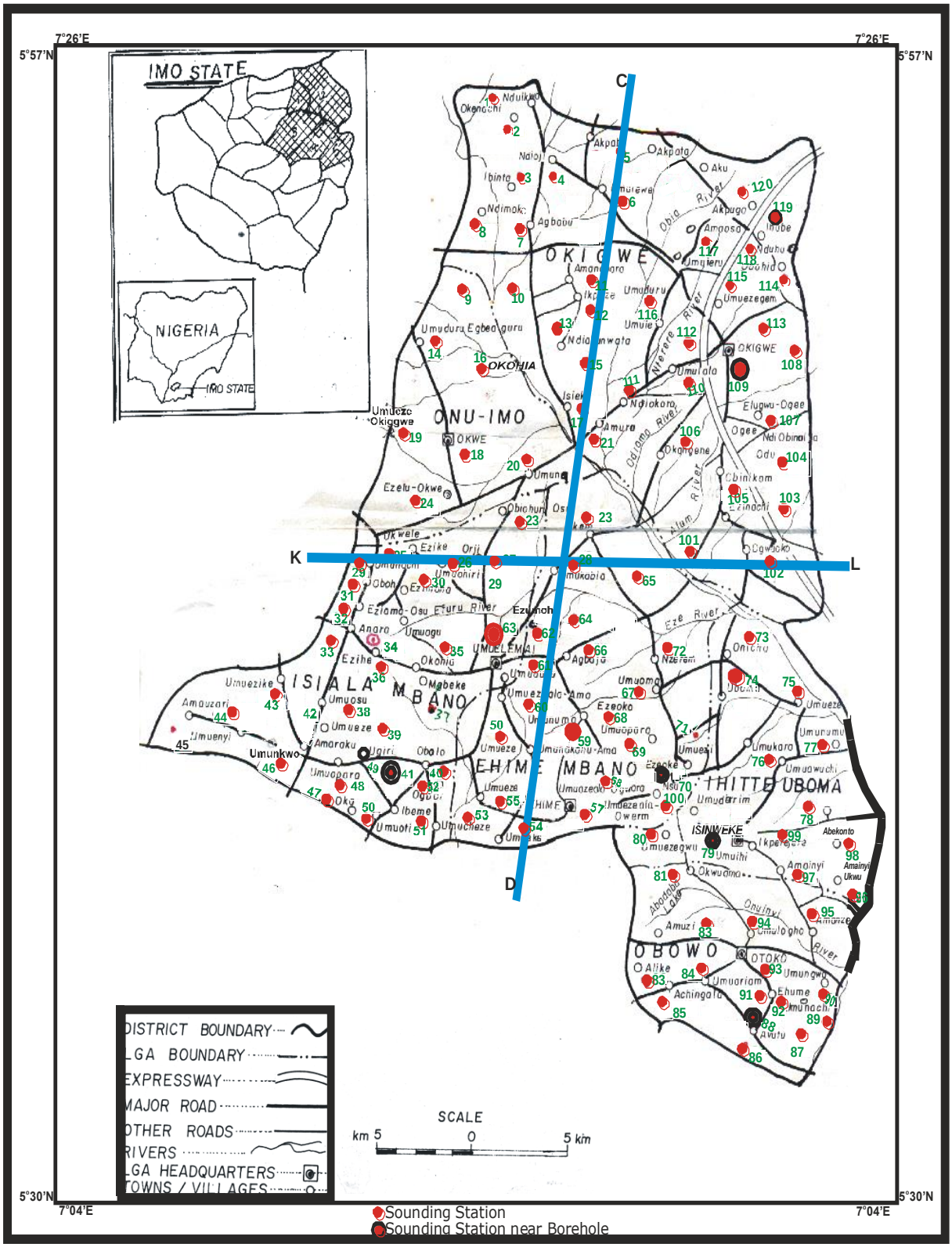
INTRODUCTION

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). Adequate water supply is essential to public health and wellbeing as well as agricultural and industrial activities. Majority of the people in the study area do not have access to potable water. This is compounded by the gradual increase in the rate of industrial and commercial activities in the district.

Certain aquifer characteristics are useful in assessing the water resources potential of a place. These parameters include the hydraulic conductivity (K), transmissivity (T), and storativity (S). 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). 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 abstraction (Ekwe *et al.*, 2006; Oseji *et al.*, 2005; Odoh *et al.*, 2009). This study is therefore aimed at utilizing the aquifer characteristics determined from pumping test data and those calculated from surface geoelectric soundings to establish the ground water potentials of the study area.

GEOLOGY AND HYDROGEOLOGY 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 $5^o03'$N to $5^o57'$N and longitude $7^o04'$E to $7^o26'$E (Figure 1), covering a land area of about 1,824 km^2. The study area is situated in a complex geological setting. The stratigraphic units observed include: the Benin Formation, The Ogwashi - Asaba Formation, the Bende - Ameki Formation, Imo Shale Formation, Nsukka Formation and Ajali Formation. (Akaolisa and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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 which are mostly coarse grained, pebbly and poorly sorted, contain lenses of fine grained sands (Onyeaguocha, 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 seems of lignite. It also forms part of the study area while the Ameki Formation consists of greenish - grey clayey sandstones, shales and mudstones with interbedded limestones. This Formation in turn overlies the impervious Imo Shale group characterized by lateral and vertical variations in lithology. It is underlain in succession by Nsukka Formation, Ajali Sandstones and Nkporo Shales.

METHODOLOGY

A total of 120 vertical electrical soundings (VES) were carried out in the study area (Figure 1) using the Schlumberger electrode configuration and a maximum electrode spacing of 900m. The ABEM terrameter (SAS) 300B was used to acquire the data. Four stainless non polarizable electrodes were used, two current electrodes and two potential electrodes. A freshly charged 12V dc supply 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 (1988) 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 (Hemker, 1985). Twelve of the VES stations were sited near existing boreholes to enhance interpretation.

Analysis of Pumping Test Data

The pumping test data obtained for the study area is displayed in Table 1.

The Hydraulic Conductivity was determined using the Logan (1964) approximation of Thiem's equation given by Equation 1, for hydraulic conductivity.

$$K = \frac{1.18Q}{hS_{mw}} \quad \textbf{(1)}$$

and the transmissivity obtained from,

$T_r = Kh$ **(2)**

where

Q = well discharge
h = screen length
S_{mw} = draw down.

Values of K and T_r were computed for the boreholes using the pumping test data in Table 1.

Fetter, (2007) gave the following equations for determination of storativity of wells:

$$h_o - h = \frac{15.3QW(u)}{T_r} \quad \textbf{(3)}$$

and

$$S = \frac{T_r tu}{360r^2}. \quad \textbf{(4)}$$

u = argument in the solution of the differential equation of the confined flow of water in the aquifer.

$h_o - h = S_{sw}$ = draw down

r = radial distance of the Pumping Well

W(u) = Well function

S = Storativity

t = time of pumping

Table 1: Existing Borehole/Pumping Test Data – Converted Units
(Source: Imo State Cooperation, Owerri, Imo State).

S/No	LOCATION	DRILL DEPTH (m)	CASING DIAMETER (m)	SCREEN DIAMETER (m)	CASING DEPTH (m)	SCREEN LENGTH (m)	SWL (m)	DRAW DOWN (m)	YIELD (m^3/day)
1	Avutu No. 2 BH	170.69	0.34	0.20	146.30	21.34	53.04	10.68	4364.24640
2	Anara 1	73.15	0.30	0.20	54.86	15.24	52.43	Abortive	218.21232
3	Umunumo 1	73.15	0.30	0.20	54.86	15.24	23.78	28.65	618.99450
4	Umunumo 2	79.25	0.30	0.20	67.06	9.15	21.56	27.13	392.78218
5	Amaraku 1 Amaraku 2	99.36 118.87	0.20 0.30	0.15 0.25	76.20 83.52	1.52 6.10	31.10 74.37	- 1.83	1091.06160
6	Madona I Ihitte Uboma	128.02	0.34	0.25	97.54	30.48	95.07	6.25	654.63696
7	Madona II Ihitte Uboma	182.88	0.34	0.25	151.79	21.95	93.27	6.40	2618.54784
8	Nsu	143.26	0.20	0.15	125.58	17.68	35.3	Collapsed	781.95544
9	Ugiri	121.92	0.25	0.20	103.63	15.24	71.32	6.10	1745.69656
10	Mbano	91.44	0.13	0.12	73.76	6.10	46.02	20.12	78.55644
11	Mbano Hospital	85.65	0.25	0.15	78.94	9.75	44.81	3.66	1854.80472
12	Umuelemai	140.21	0.30	0.20	121.92	15.24	30.91	3.78	5237.09568
13	Isiweke LGA H/Q	155.45	0.30	0.20	121.92	12.19	87.57	2.04	8292.06816
14	Okigwe	94.49	0.17	0.13	85.34	5.39	23.17	-	327.31848

Using Equation 3 the value of the well function W(u) was obtained and the equivalent value u, obtained from the table and this enabled the computation of S to be achieved using Equation 4.

The storativity values for the seven boreholes with draw down values are displayed in Table 2. The storativity values are fairly uniform and varied from 7.3×10^{-5} to 2.558×10^{-3} which agrees with the standard value, $S \leq 0.005$ (Fetter, 2007).

The specific storage S_s is obtained from the equation:

$$S = S_s h \qquad \textbf{(6)}$$

where h = screen length

The values obtained for the bore holes ranged from 5.0×10^{-6} to 2.1×10^{-4} with an average values of 4.93×10^{-5} .

The Specific Capacity of the wells (S_c) was determined using Chatter Jee (2005) formula:

$$S_c = 2.73kh\frac{1}{\log_{10} 2/r} \qquad \textbf{(7)}$$

Equation 6 can be modified by correct substitutions to give:

$S_c = 0.85kh$
K = hydraulic conductivity
h = screen length

Table 2: Aquifer Characteristics Calculated for some Boreholes Located in the Study Area.

S/No	PARAMETER	AVUTU BH	ANARA BH	UMUNUMO 2 BH	AMARAKU 2 BH	MADONNA 2 IHITTE UBOMA BH	NSU BH	UGIRI BH	MBANO HOSP. UMUELEMAI BH	ISIWEKE BH	OKIGWE BH
1	Screen Length (m)	21.34	15.24	15.24	6.10	21.95	17.68	15.24	9.75	12.19	5.39
2	Average field hydraulic conductivity K (m/day)	22.5957	-	1.6729	115.3321	21.9952	-	22.158	61.333	393.463	-
3	Transmissivity (m^2/day)	482.1922	-	25.4950	703.5285	482.7946	-	136.272	597.997	4796.314	-
4	Storativity	0.000257	-	0.000210	0.000375	0.000226	-	0.000073	0.000319	0.02558	-
5	Specific Storage	0.000012	-	0.000014	0.000061	0.000010	-	0.000005	0.000033	0.000210	-
6	Specific capacity (m^2/day)	409.8634	-	21.6707	577.997	410.3754	-	287.035	508.297	4076.867	-
7	Resistivity of Aquifer(Ωm)	5810	13400	12600	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	0.000746	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	1440.88	1243880	201600	532500	618840	57348	148960	1061160	80371.20	228780
12	Kσ value	0.007158	0.042304	0.005096	0.001948	0.001675	0.018018	0.006909	0.000979	0.012845	0.004531
13	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
14	Transmissivity of aquiferous zone T_r (m^2/day)	1031.382	10317.141	1027.337	1037.245	1036.625	1033.282	1029.112	1038.691	1032.366	1036.626
15	Hydraulic conductivity	41.6163	56.7080	64.5053	29.0728	27.0179	43.7324	42.1259	14.3945	56.0916	62.9320

The values calculated for the boreholes are shown in Table 2.

Aquifer Characteristics Determined from VES Results

The aquifer characteristics for the VES stations were determined using the following equations:

Hydraulic Conductivity (K)

$$K = \frac{T_r}{h} \quad (8)$$

T_r = average transmissivity obtained from pumping test data.
h = aquifer thickness

Transmissivity of Aquifer Layer (T_r)

$$T_r = K\sigma R \quad (9)$$

R = transverse resistance
σ = conductivity

DISCUSSION OF RESULTS

The results show that the study area is composed of 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 typical modeled curve, the geoelectric section and lithology of VES 48 near Ugiri borehole are displayed in (Figure 2). The modeled curves obtained for the area are a combination of H- type and K-type (Ekine, 2010) and HKH-type and KQH-type (Oseji *et al.,* 2005).

One of the Interpretative Geoelectric Cross-Sections (I.G.C.S.) constructed for the area is profile CD (Figure 1) which transverses 30.37km. It reveals that the top 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 L.G.A. The deeper layers are more continuous than the shallow layers. The fourth layer consists of fine, medium to coarse sands, sandstone and sandy shale. This layer constitute the major aquiferrous zone (Figure 3).

The aquiferrous layer is underlain by conductive layer composed of clays sand/lignite and shale. The geoelectric cross-section also reveals the presence of confined aquifer around Onuimo L.G.A. in the North-Western part of the study area which agrees with the geology of the area as the aquifer occurs between impervious clay layers. Using an average transmissivity of 1032.0848 m^2/day determined from pumping test data of the boreholes in the area a mean conductance value of 91.222 m/day was obtained for the area.

The hydraulic conductivity values obtained from the VES results varied from 9.8854 to 115.9646 m/day. The transmisivity values ranged from 992.04 to 10263.65m^3/day. The storativity determined for the area ranged from $1.59x10^{-4}$ to $7.80x10^{-3}$ while the specific capacity is fairly uniform with magnitude of about 877 (Tables 2 and 3). In Table 2 parameters 1 to 6 were calculated on the basis of the pumping test analysis while 7 to 15 were based on VES results. The close agreement between hydraulic conductivity values computed for both methods (parameters 2 and 15) for Madonna II borehole indicates the reliability on the VES results.

Groundwater Yield of Borehole

The distribution of the groundwater yield of boreholes presented in Table 2 is shown in Figure 4. 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^2/day. Generally, groundwater yield increases Southwards reaching a maximum value of 8292m^3/day recorded at Isinweke (VES 79).

Groundwater Potential Evaluation

Groundwater potential evaluation 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). The groundwater yield of boreholes (Figure 4) can be used as an index for the assessment of groundwater potential of the district. The groundwater potential map is shown in Figure 5.

The aquifer system in Zone A in the Southern part has the highest yield; 8292 m^3/day recorded at Isinweke (VES 79), 4364 m^3/day recorded at (VES 88), 1746 m^3/day recorded at (VES 41) and 5237 m^3/day 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 siting productive boreholes. This zone corresponds 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.

Zone B is another prospective area for ground water exploitation but not as prolific as the former as transmissivity values are lower than those of Zone A due to high percentage of shale in the Bende Ameki Formation that underlie the area. Zone C covers Onuimo LGA and extends to Okigwe LGA (Figure 5). This zone falls within Imo Shale Formation in which the lithologic units are a sequence of clayey sand and shale; the Nsukka Formation and Ajali Formation (False bedded sandstones). The Okigwe area is underlain by consolidated sandstones. Zone D also lies in this Formation. Groundwater is only available through cracks and fissures throughout the false bedded sandstone (IWADA 2006). During the rainy season, streams and springs come up here and there but dry up during dry season. The underlying Formation is predominantly shale and clays that are impervious.

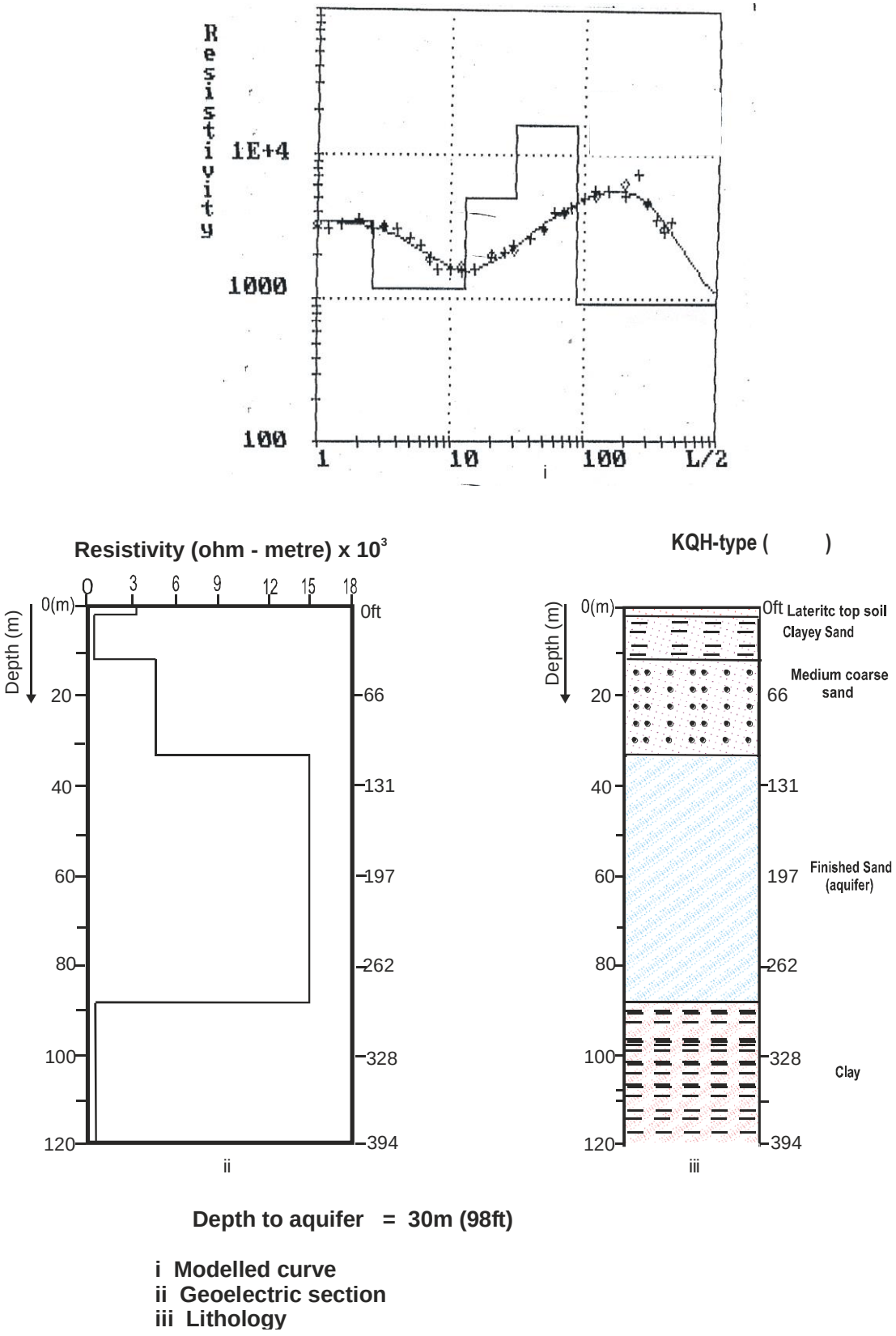

Figure 2: Modeled Curve, Geoelectric Section, and Lithology of VES 48 near Ugiri Borehole.

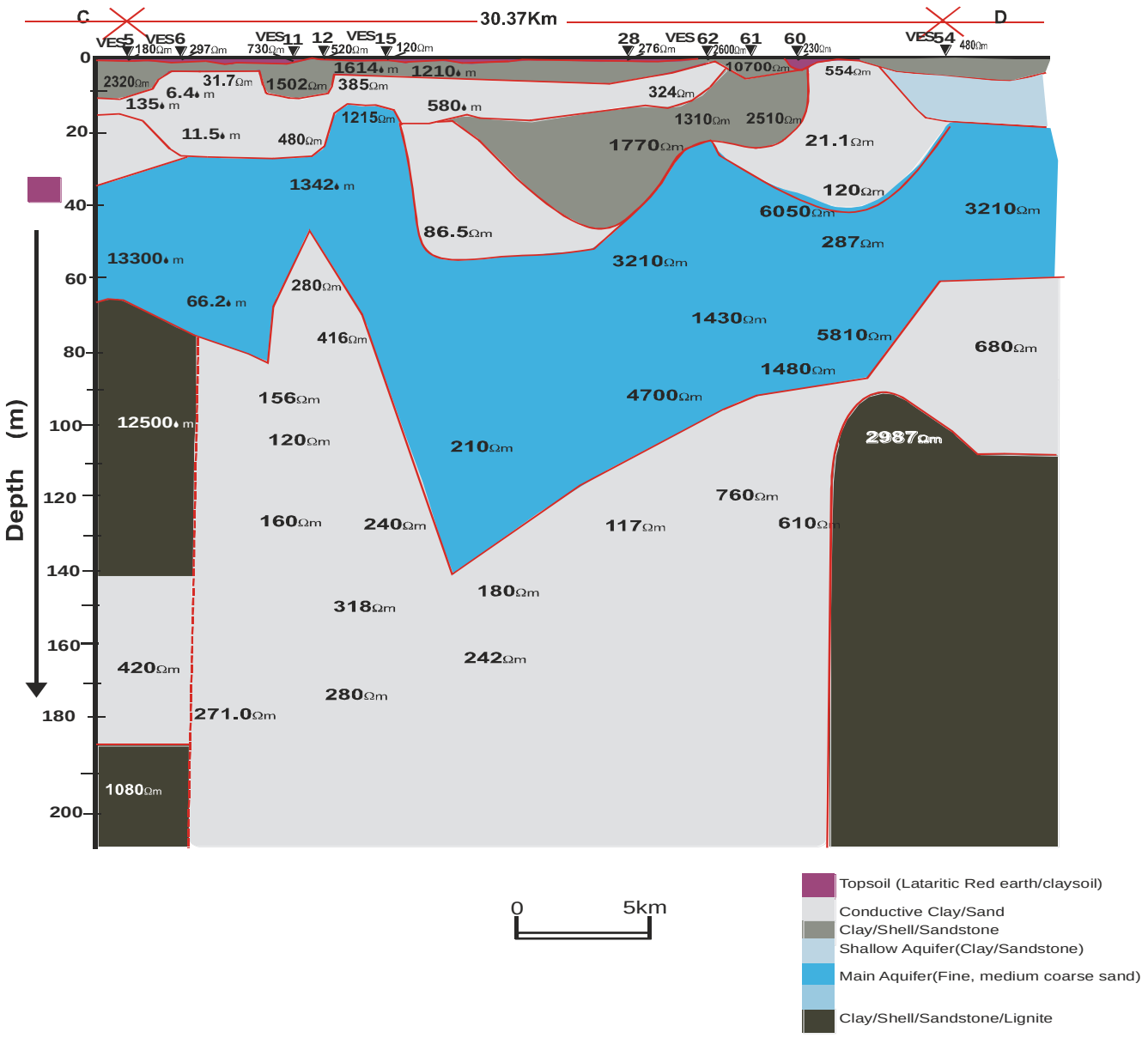

Figure 3: Interpretative Geolectric Cross-Section (IGCS) along Profile Line CD

Table 3: Summary of Aquifer Characteristics for all the Sounding Stations Showing Depth to Water Table.

S/No	Resistivity of Aquifer(Ωm)	Depth to Water Table (m)	Thickness (m)	Conductivity σ ($\Omega^{-1}m^{-1}$)	Transverse Resistance R (Ωm)	Longitudinal Conductance S ($m\,\Omega^{-1}$)	Hydraulic conductivity K (m/day)	Transmissivity T_r (m^2/day)	Conductivity Product Kσ	Storativity	Specific Capacity (m^3/day)
41	2825	75.5	18.7	0.000354	52827.50	0.006620	55.1917	1032.08	0.019537	$9.22x10^{-4}$	877.272
42	15000	41.7	35.5	0.000067	532500.00	0.002367	29.0728	1037.25	0.001948	$1.75x10^{-3}$	877.272
43	4200	44.7	57.3	0.000238	240660.00	0.013643	18.0120	1031.67	0.004287	$2.82x10^{-3}$	877.274
44	1820	34.7	61.9	0.000549	112650.00	0.034011	16.6134	1031.16	0.009154	$3.05x10^{-3}$	877.274
45	1680	65.5	56.6	0.000595	95088.00	0.033691	18.2347	1031.67	0.010850	$2.79x10^{-3}$	877.271
46	850	37.8	30.9	0.001190	26265.00	0.036353	33.4008	1043.95	0.039747	$1.52x10^{-3}$	877.272
47	4225	46.5	15.1	0.000237	63797.50	0.003740	68.3500	1033.45	0.016199	$7.44x10^{-4}$	877.272
48	16000	30.2	56.8	0.000063	908800.00	0.003550	18.1705	1040.34	0.001145	$2.80x10^{-3}$	877.271
49	6080	84.5	24.5	0.000164	148960.00	0.004030	42.1259	1029.11	0.006909	$1.21x10^{-3}$	877.272
50	2014	61.3	33.4	0.000497	67267.60	0.016584	30.9007	1033.07	0.015358	$1.45x10^{-3}$	877.271
51	14600	32.9	44.5	0.000068	649700.00	0.003048	23.1929	1024.65	0.001577	$2.19x10^{-3}$	877.271
52	9700	25.3	90.7	0.000103	879790.00	0.009351	11.3791	1031.16	0.001720	$4.47x10^{-3}$	877.272
53	2520	62.1	21.7	0.000390	55553.00	0.008477	47.5615	1030.43	0.018549	$1.07x10^{-3}$	877.272
54	3210	34.9	28.4	0.000312	123264.00	0.011963	26.8772	1033.65	0.008386	$1.40x10^{-3}$	877.272
55	3600	62.1	34.0	0.000278	122400.00	0.009444	30.3554	1032.91	0.008439	$1.68x10^{-3}$	877.271
56	5200	28.5	46.8	0.000192	243360.00	0.009000	22.0531	1030.43	0.004234	$2.31x10^{-3}$	877.272
57	14200	20.4	42.7	0.000070	606340.00	0.003007	24.1706	1025.93	0.001692	$2.11x10^{-3}$	877.272
58	6500	74.6	28.4	0.000154	184600.80	0.004369	36.3410	1033.12	0.005597	$1.40x10^{-3}$	877.272
59	12600	56.0	24	0.000083	288.00	0.020000	43.0035	1030.81	0.003570	$1.18x10^{-3}$	877.2721
60	5810	61.9	24.2	0.000172	140602.00	0.004165	42.6481	1031.32	0.007335	$1.19x10^{-3}$	877.272

The North-Eastern part of Okigwe (Zone A[1]) can be classified as Zone A based on the Kδ and longitudinal conductance values as well as the transmissivity values. However, the groundwater yield of borehole located at Okigwe gives a value of 327m^3/day (Figure 4) 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.

With the above observation and geological information groundwater potential map is constructed for the area (Fig. 5). Part A is the most promising for siting borehole with high yield expectation. It coverers the entire Obowo, part of Ihitte Uboma, Ehime Mbano and Isiala Mbano LGAs having high aquifer transmissivity, thickness and storage coefficient. Part B is the next promising for groundwater exploitation or medium groundwater potential. Part C is the low groundwater potential area while part D is a difficult area for groundwater exploitation.

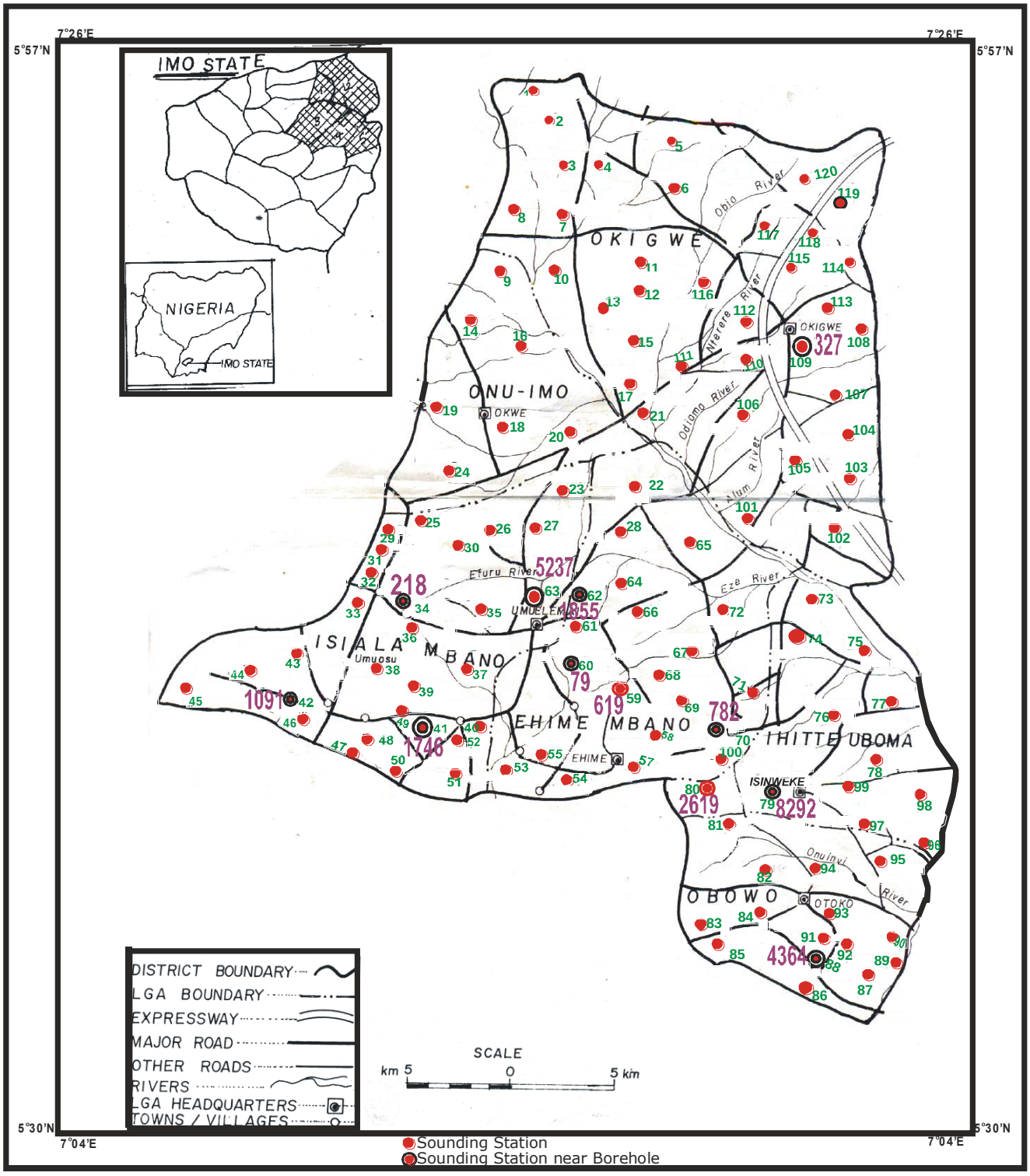

Figure 4: Distribution of Groundwater Yield m^3/day Obtained from Borehole Record of the Study Area.

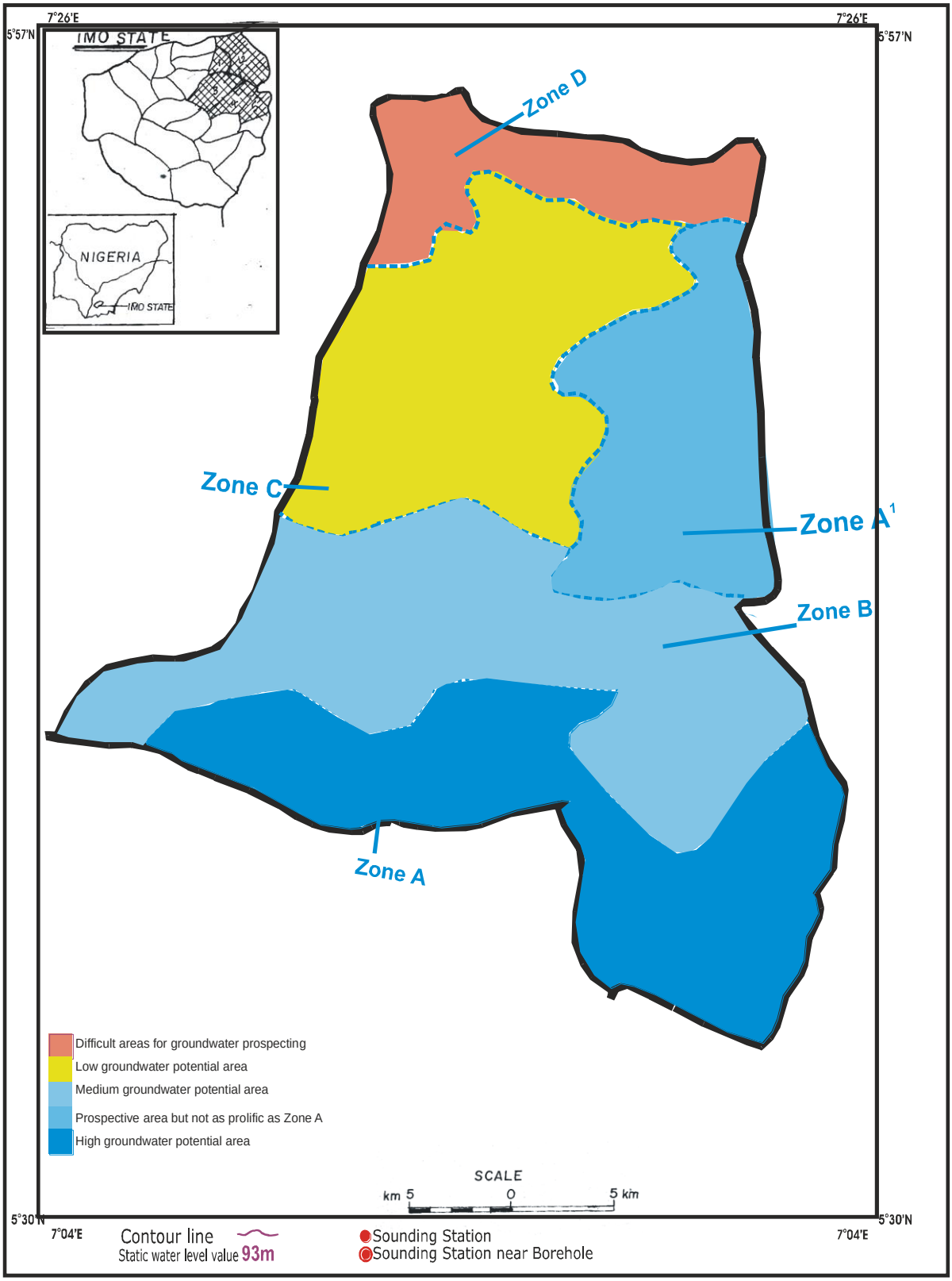

Figure 5: Groundwater Potential Map of the Study Area.

CONCLUSION

Groundwater potential evaluation of the district based on borehole hydrogeological information revealed that the Southern part of the district recorded the highest values of groundwater yield and is therefore the most prolific in terms of groundwater exploitation and thus the most promising in siting productive boreholes. Based on the 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.

ACKNOWLEDGMENT

We are grateful to the Imo Water Development Authority (IWADA) for supplying the relevant Pumping Test data which was very useful in this study.

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SUGGESTED CITATION

Nwosu, L.I., A.S. Ekine, and C.N. Nwankwo. 2013. "Evaluation of Groundwater Potential from Pumping Test Analysis and Vertical Electrical Sounding Results: Case Study of Okigwe District of Imo State Nigeria". *Pacific Journal of Science and Technology*. 14(1):536-548.