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Geoelectric Survey for Mapping Groundwater Flow Pattern in Okigwe District, Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author LIN designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors ASE and CNN managed the analyses of the study. Author CNN managed the literature searches. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Aims: This study was carried out to determine the groundwater flow pattern in order to identify the converging centres with high yield expectations.
Study Design: The study area, Okigwe District in Imo State Nigeria, lies between latitude 5º30′N to 5º57′N and longitude 7º04′E to 7º26′E and covers an area of approximately 1,824 km^2.
Methodology: One hundred and twenty (120) vertical electrical sounding (VES) results, using the Schlumberger configuration were acquired in order to map the ground water flow pattern within the study area. The maximum current electrode spacing for the survey was 900 m.
Results: Twelve of the VES stations were sited near existing boreholes to enhance interpretation. The resistivity of the aquiferous zones varied across the study area ranging from 33.1Ωm obtained at Umuedi (VES 7) in the northern part to 32600Ωm at Otoko (VES 93) in the southern part of the area. 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. Analysis of VES data shows that the groundwater flows from the Northern part of the district towards the Southeastern part, South central and South Western parts. It also flows from the South-South area to Southeastern and South central parts of the study area forming two main collecting

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(converging) centres **C1** and **C2** having approximately West-East trend. **C1** lies within the valleys of Efuru and Eze Rivers while zone **C2** lies almost parallel to the Onuinyi River and the Abadaba Lake.
Conclusion: The survey results show that the Southern and Northeastern parts of the district are more promising for siting borehole with high yield expectations than the North Western part. The occurrence of aquifer in this area is linked to the presence of fractures in the shale members.

Keywords: Aquifer; groundwater flow; groundwater converging centre; hydraulic conductivity.

1. INTRODUCTION

Majority of the people in the study area do not have access to portable water. This is compounded by the fact that the Okigwe regional water scheme is not functional. Available records in the Imo State Water Development Agency (IWADA) and the Imo State water board, show that a number of isolated pre-drilling geophysical surveys have been carried out for sitting boreholes in some parts of the area. These records revealed problems that have militated against development of both rural and urban water projects to bother mainly on the complex geological nature of the study area, especially in the northern part of the district. The Anambra Imo River Basin Development Authority report of the pre-drilling geophysical study for a water borehole project at Ihube Okigwe shows that clay and shale members of the Ajali Formation are predominant and thick which makes groundwater exploitation difficult [1].

In Onuimo area of the District the reports show that the geologic units are clays and shales. Hence drilling is not recommended. Umuna in the same Local Government Area falls within Imo Shale Formation [1]. The geologic units consist of shaley sand and shale, and being that shale does not contain much water, the prospective unit could result from possible presence of fractured shale in that area. The borehole record for the study area equally shows the need for this detailed regional geophysical survey. The boreholes include Umunumo 1 and 2; Amaraku 1 and 2; and Madona 1 and 2 where there is marked variation in the yield obtained for the same locality.

The difficulty encountered in the development of both rural and urban water projects and the borehole failures recorded in the area may have resulted from the fact that no detailed geophysical survey for mapping groundwater flow pattern has been carried out in the study area [2]. The objective of this study is therefore to determine the groundwater flow pattern in order to identify the converging centres which are high groundwater potential zones with high yield expectations.

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 5º30′N to 5º57′N and longitude 7º04′E to 7º26′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.

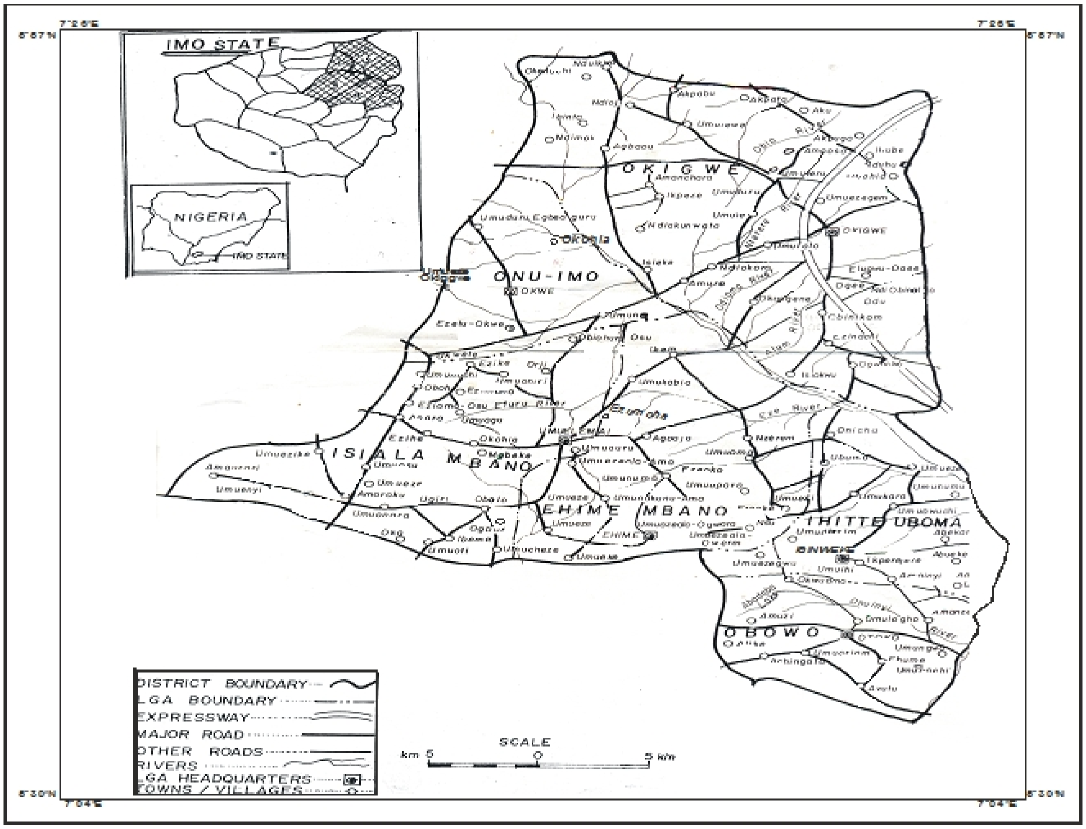


Fig. 1. Map of study area showing sounding stations

1.1 Geology of the Study Area

The geology of the study area (Fig. 2) shows that 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 [3], [4]. 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 [5]. The Benin Formation consists of coarse grained, gravelly sandstones with minor intercalalions of shales and clay. The sand units which are mostly coarse grained, pebbly and poorly sorted contain lenses of fine grained sands [6], [7]. 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 Imo Shale group characterized by lateral and vertical variations in lithology. The Imo 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 [8].

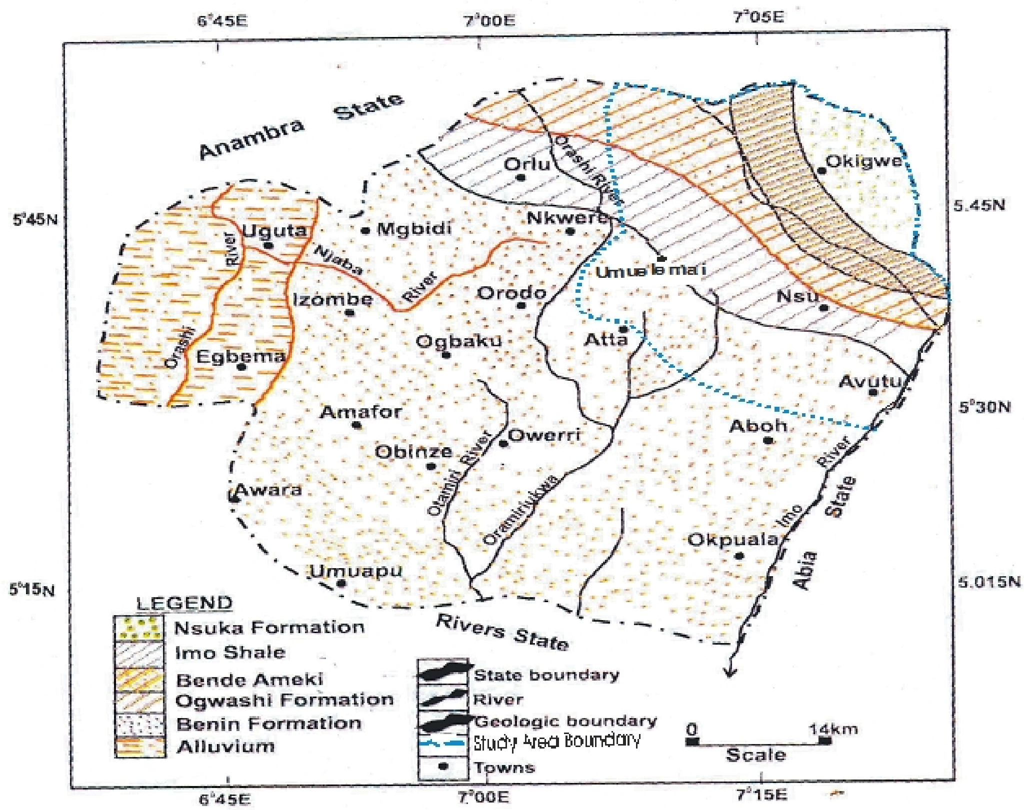


Fig. 2. Geological map of the study area (Adapted from [4])

2. METHODOLOGY

2.1 Electrical Resistivity Measurements

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 900m. The ABEM Terrameter (SAS) 300B 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 12V 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 [9] 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 [10]. Twelve of the VES stations were sited near existing boreholes to enhance interpretation.

2.2 Determination of Aquifer Parameters from Pumping Test Data

Aquifer parameters from pumping test data were determined using the [11] approximation method for calculating the transmissivity T_r and hydraulic conductivity K. The basis of this approximation is Thiem's (1906) in [11] - equations for steady state flow conditions in confined aquifer.

Thiem's equation for an observation well a distance r_1 from the pumped well is given by:

$$Q = \frac{2\pi tKhS_{mw} - S_{m1}}{\ln \frac{r_1}{r_w}} \quad (1)$$

Where Q= well discharge in m^3 / day.
K = average hydraulic conductivity in m / day.
H= thickness of the aquifer in metre.
S_{m1}= steady state drawdown in observation well in metres.
S_{mw} = maximum drawdown in the pumped well in metres.
r_1 = distance of the observation well from the pumped well.
r_w = radius of the pumped well in metres.

This equation was modified by [11] for steady state flow in confined aquifer as follows:

$$Q = \frac{2\pi S_{mw} Kh}{2.3 \log \frac{r_{max}}{r_w}} \quad (2)$$

r_{max} = radius of influence in metres of the pumping. The area circumscribed by r_{max} is the area in the borehole environment that contributes water to the well.
Equation 2 can be re-written as:

$$Kh = \frac{2.3Q \log \frac{r_{max}}{rw}}{2\pi S_{mw}} \quad (3)$$

And since the logarithm of the ratio of r_{max} to r_w is very small, assuming average condition of radii; this equation further reduces to:

$$Kh = \frac{1.18Q}{S_{mw}} \quad (4)$$

Thus $K = \frac{1.18Q}{hS_{mw}}$ (5)

Table 1 shows the pumping test data obtained for some boreholes in the study area.

TABLE 1 : EXISTING BOREHOLE /PUMPING TEST DATA - CONVERTED VALUES (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

2.3 Determination of Aquifer Parameters from VES Results

The layer transmissivity, T_{ri} used in groundwater hydrology [5], is given by:

$$T_{ri} = K_i h_i \qquad (6)$$

where K_i is the hydraulic conductitivty of the ith layer of thickness hi. The relationship between aquifer transmisivity T_r and transverse resistance R and that between T_r and longitudinal conductance, S have been derived analytically by [12] as follows:-

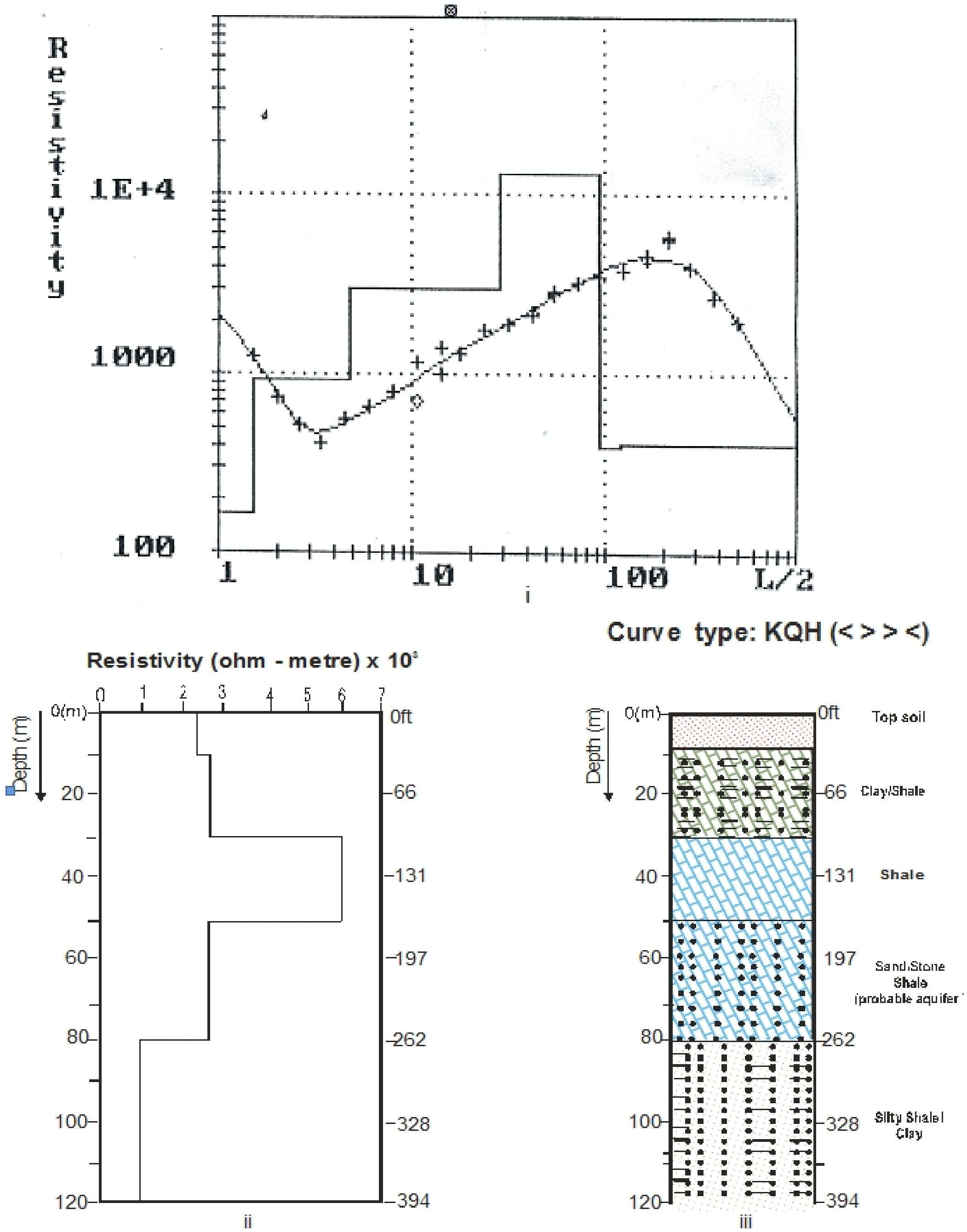
$$T_r = K\sigma \quad R = \frac{KS}{\sigma} \qquad (7)$$

According to [12], 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.

3. RESULTS AND DISCUSSION

The survey revealed multi geoelectric layers ranging from four to nine 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. Typical modelled curve of the geoelectric section and lithology of VES 17 are displayed in Fig. 3 while Fig. 4 shows that the aquiferous zone occur most in the fourth geoelectric layer. The curves are a combination of H- type and K-type [13] and HKH-type and KQH-type [14].

Table 2 shows the aquifer parameters determined for the boreholes in the study area. Parameters 1 to 6 were calculated on the bases of pumping test data while parameters 7 to 15 were based on the VES results. Although the computation was based only on the screened section of the aquifer, which makes variation inevitable, the close agreement between parameters 2 and 15 for Madonna II borehole in Ihitte Uboma attest to the reliability of the VES results. 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.



Depth to aquifer = 50m (164ft)

i Model curve
ii Geoelectric section
iii Lithology

Fig. 3a. Model curve, geoelectric section and lithology of VES 17 at Okal Umuna

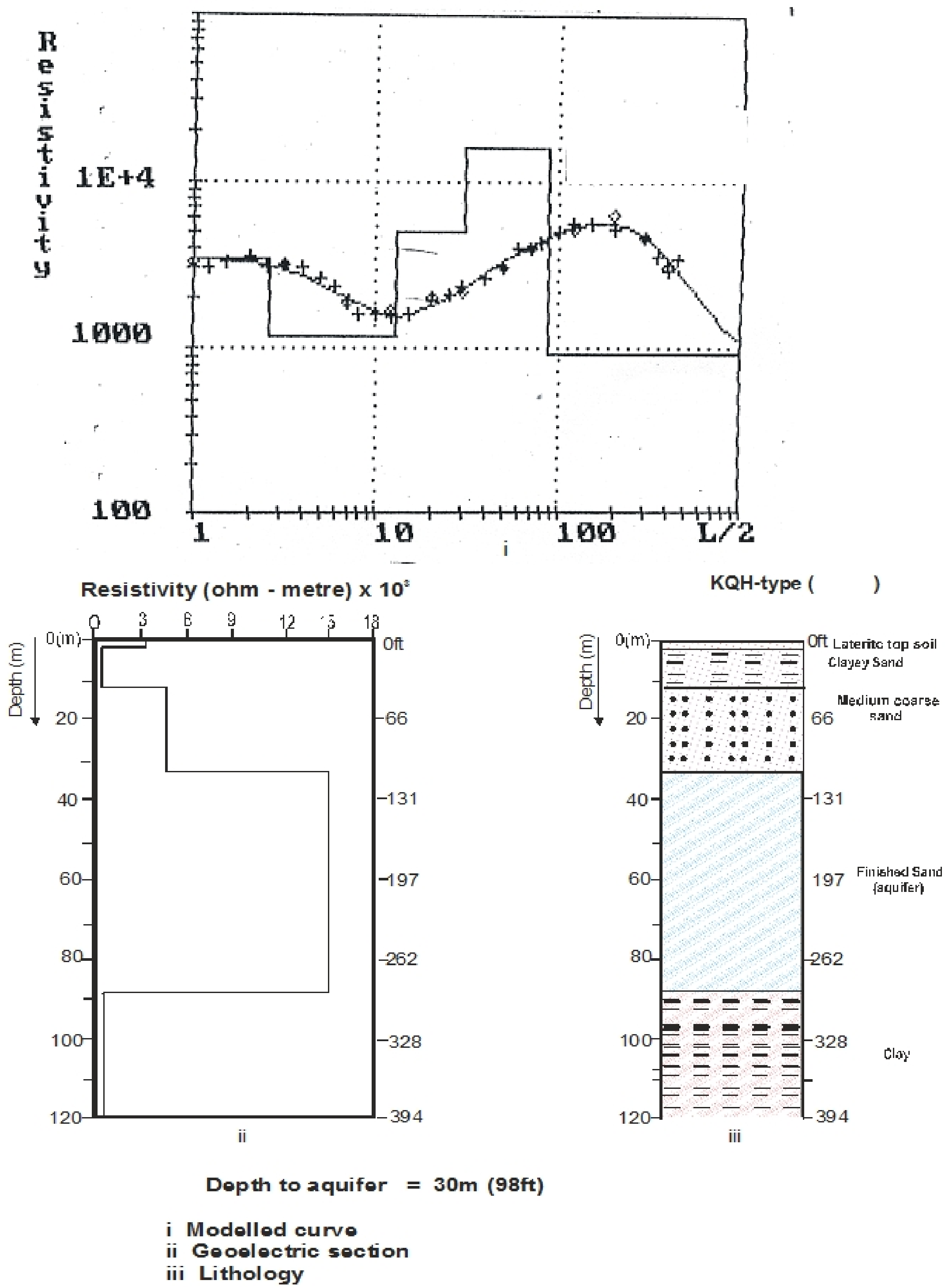


Fig. 3b. Model curve, geoelectric section and lithology of VES 48 near Ugiri borehole

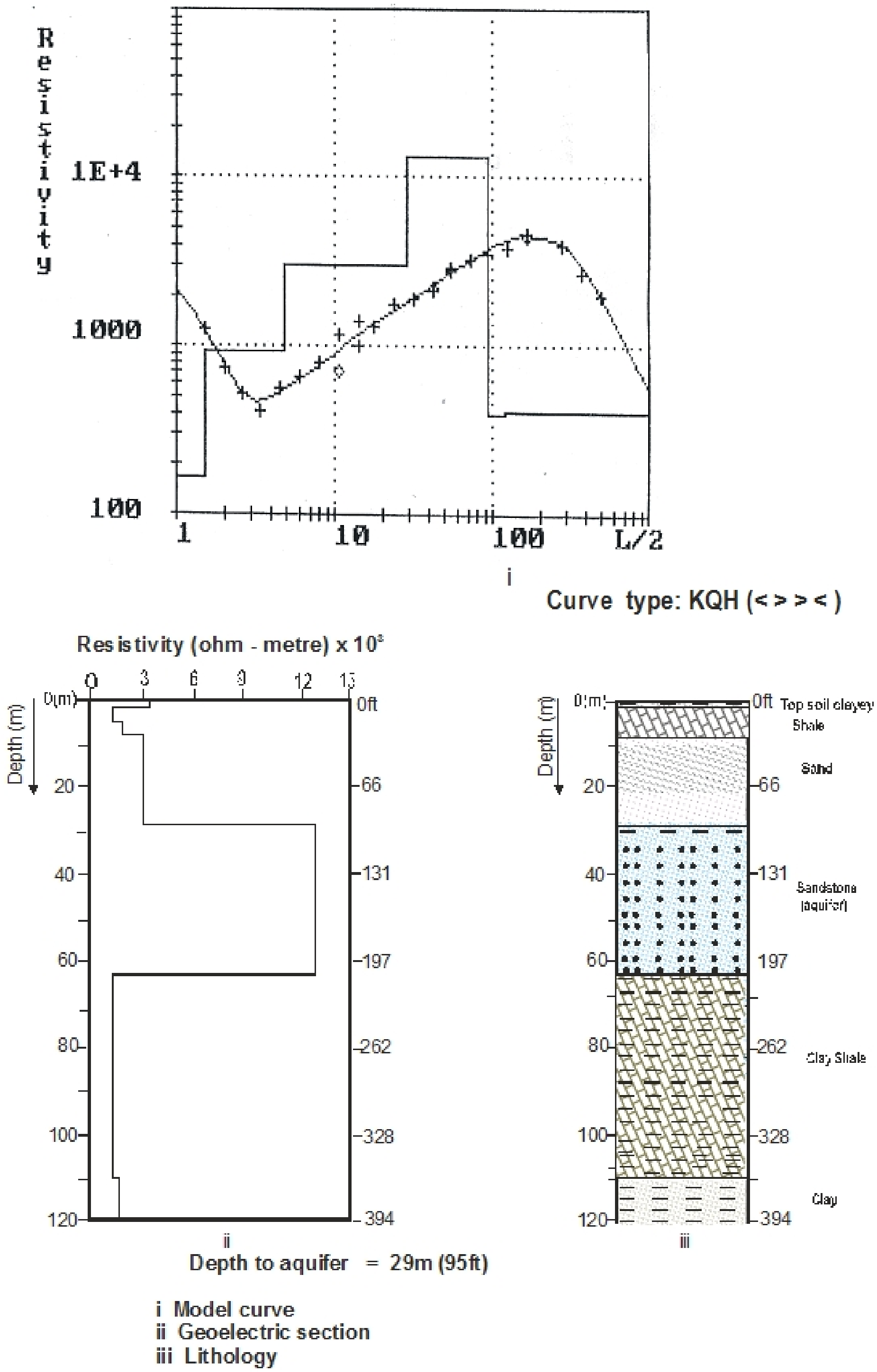


Fig. 3c. Model curve, geoelectric section and lithology of VES 119 near Ihube Okigwe borehole

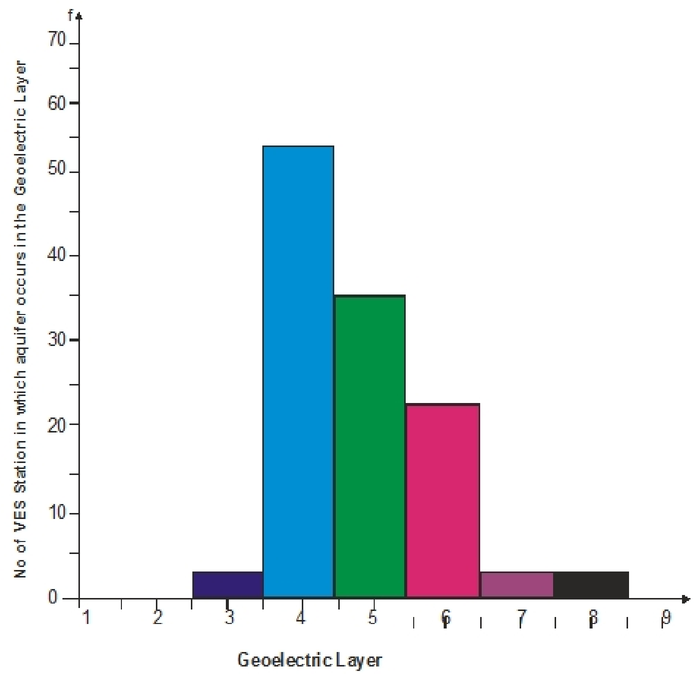


Fig. 4. The distribution of aquiferous zones within the geoelectric layers

The transmissivity values ranged from 992.04 to 10263.65m^3/day while the storativity values determined for the area ranged from 1.59x10^{-4} to 7.80x10^{-3}. The specific capacity is fairly uniform with magnitude of about 877. The summary of aquifer characteristics for all the sounding stations is shown in Table 3 for VES 1 to 20. The distribution of transmissivity values suggests possible existence of different aquifer systems. The sharp variations in resistivity observed in the South-South zone could be attributed to the inhomogeneous nature of the thick aquifers in the region and the water quality within the aquifers [2].

Typical interpretative geoelectric cross-sections EF, GH and IJ constructed using the result of the VES and the geoelectrical data obtained from the existing boreholes (Figs. 5 & 6) show that the top layers are generally not continuous and reveal large variations in layer resistivity and aquifer thickness. Fig. 4a was constructed in the Northern part of the study area while Fig. 4b runs along the high groundwater potential areas. Northeastern part to Southern part. The aquiferous layer is underlain by conductive layer composed of clayey sand/lignite and shale. In some locations the aquifer extends deeper into this layer. 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. This agrees with the geology of the area as the aquifer occurs between impervious clay layers.

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^3/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

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 Ω^{-1})	Hydraulic conductivity K (m/day)	Transmissivity Tr (m^2/day)	Kσ	Storativity	Specific Capacity (m^3/day)
1	9600	76.6	18.2	0.000104	174,720.00	0.000190	56.7080	1030.43	0.005898	$8.97x10^{-4}$	877.273
2	4820	58.0	30.3	0.000207	146046.00	0.000629	34.0622	1029.75	0.007051	$1.49x10^{-3}$	877.2673
3	15000	28.0	35.5	0.000067	532500.00	0.000024	29.0728	1037.24	0.001948	$1.75x10^{-3}$	877.272
4	222	68.0	56.0	0.021534	2727.2	1.14990	18.4309	1032.14	0.378460	$2.76x10^{-3}$	877.311
5	13300	30.2	36.8	0.000075	4894.40	0.000028	28.0478	1029.58	0.002104	$1.81x10^{-3}$	877.335
6	66.2	103.0	44.0	0.015102	2912.80	0.066465	23.4565	1032.10	0.354334	$2.17x10^{-3}$	877.273
7	33.1	10.9	34.1	0.030211	1128.71	1.030211	30.3554	1031.69	0.914046	$1.68x10^{-3}$	879.851
8	13880	29.5	35.5	0.000072	492740.00	0.000026	29.0728	1031.42	0.002073	$1.75x10^{-3}$	877.727
9	299	160.0	116.0	0.003344	4784	0.053512	64.5053	1031.94	0.215706	$7.89x10^{-4}$	877.272
10	1120	32.1	49.0	0.000893	54880.00	0.043750	21.0630	1032.25	0.018809	$1.75x10^{-3}$	877.274
11	1342	30.4	4.2	0.000745	5636.40	0.003130	245.7345	1031.50	0.183072	$2.07x10^{-4}$	877.272
12	1215	26.7	41.5	0.000823	50422.50	0.034156	24.8695	1032.03	0.020470	$2.05x10^{-3}$	877.271
13	1326	28.5	48.3	0.000754	64045.80	0.036425	21.3682	1031.58	0.016110	$2.38x10^{-3}$	877.271
14	101	74.7	67.3	0.009901	6797.30	0.666337	15.3359	1032.09	0.151838	$2.32x10^{-3}$	877.290
15	210	80.2	57.8	0.004762	12138.00	0.275238	17.8561	1032.11	0.085031	$2.85x10^{-3}$	877.270
16	131	37.2	26.0	0.007634	3406.00	0.198473	39.6956	1032.14	0.303036	$1.28x10^{-3}$	877.273
17	1310	80.8	29.5	0.000763	38645.00	0.022519	34.9859	1031.60	0.026694	$1.45x10^{-3}$	877.271
18	1225	78.2	36.8	0.000816	45080.00	0.030041	28.0458	1031.67	0.022885	$1.81x10^{-3}$	877.273
19	15.9	46.2	77.8	0.062893	1237.02	4.893082	13.2659	1032.08	0.834330	$3.84x10^{-3}$	877.274
20	93	32.1	12.6	0.010753	1171.80	0.135484	81.9115	1032.11	0.880794	$6.21x10^{-4}$	877.272

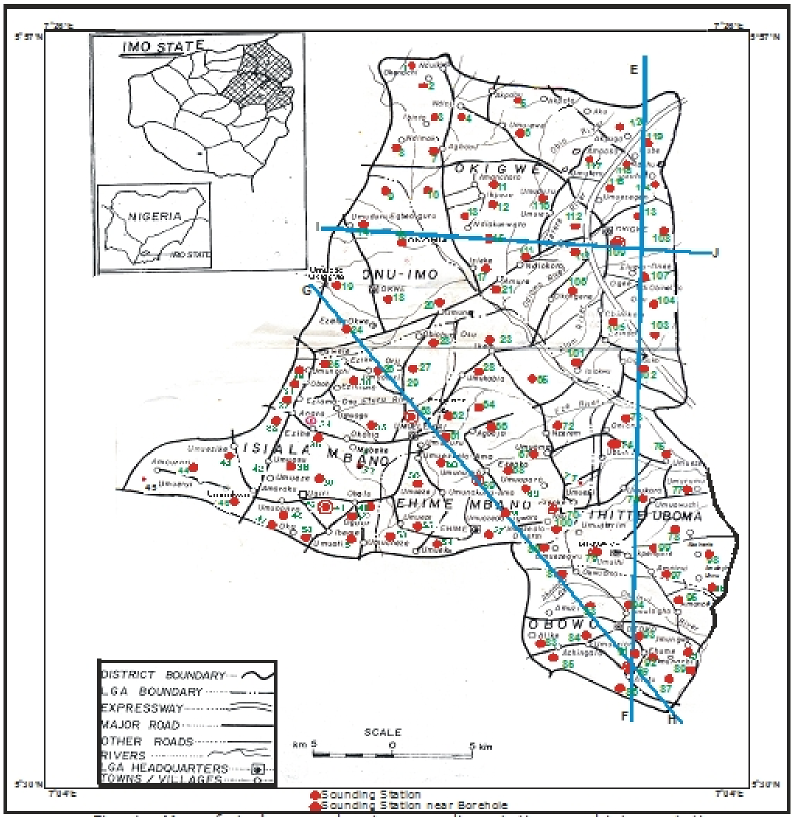


Fig. 5. Interpretative Geoelectric Cross-Section (IGCS) traverse

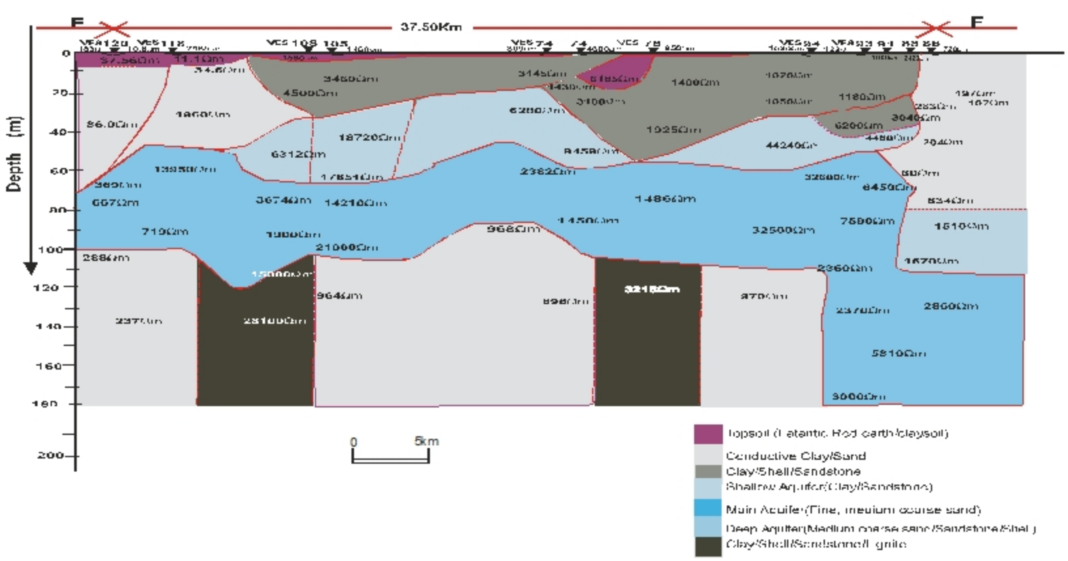


Fig. 6a. Interpretative Geoelectric Cross-Section (IGCS) along profile EF

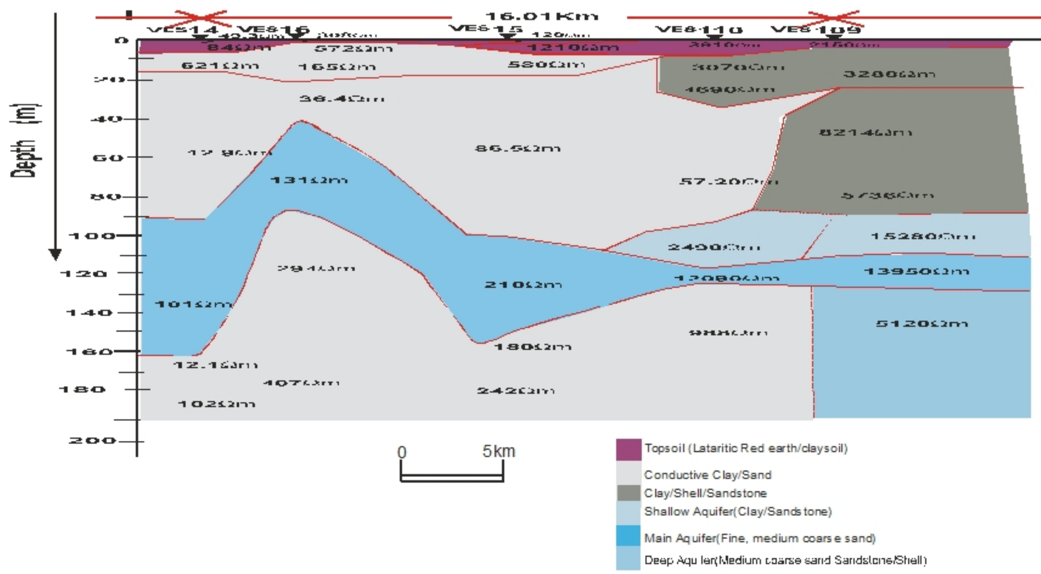


Fig. 6b. Interpretative Geoelectric Cross-Section (IGCS) along profile IJ

3.1 Groundwater Flow Patterns in the Study Area

In the zone of actively flowing groundwater, the water moves through the porous media under the influence of the fluid potential. Water usually flows from recharge areas to the discharge areas. Recharge areas are usually in topographical high places while discharge areas are located in topographical lows [15], [16]. There is usually a deep unsaturated zone between the water table and the land surface in the recharge areas. On the other hand in the discharge areas the water table is either close to or at the land surface. In the field, vegetation and surface water can sometimes be used to locate discharge area which may manifest in the form of a spring, seep, lake or stream [15], [17]. Areas around Okigwe town corresponding to topographic high areas are expected to form recharge zones. There are hills which range in height of about 60 to 90m [1]. The development of streams and rivers which join to flow southwards into the Imo River can suggest the direction of flow of the groundwater. In the Southern part, the development of stream and river network and the Abadaba lake in Obowo L.G.A are indicative of this zone corresponding to discharge zone.

Groundwater flow pattern can be determined from static water level map [18]. In this study, the determination of the groundwater flow direction was based on the use of static water level values from borehole record of the area, the observable topographic features and the pattern of the drainage system in the area (Fig. 7). Depth to the static water level within Okigwe District varies from 33m to 93m. It is relatively deep in the Southern and Southwestern parts of the district and shallow within the central and Northeastern parts. This southern area also corresponds to region of high aquifer resistivity (Fig. 8).

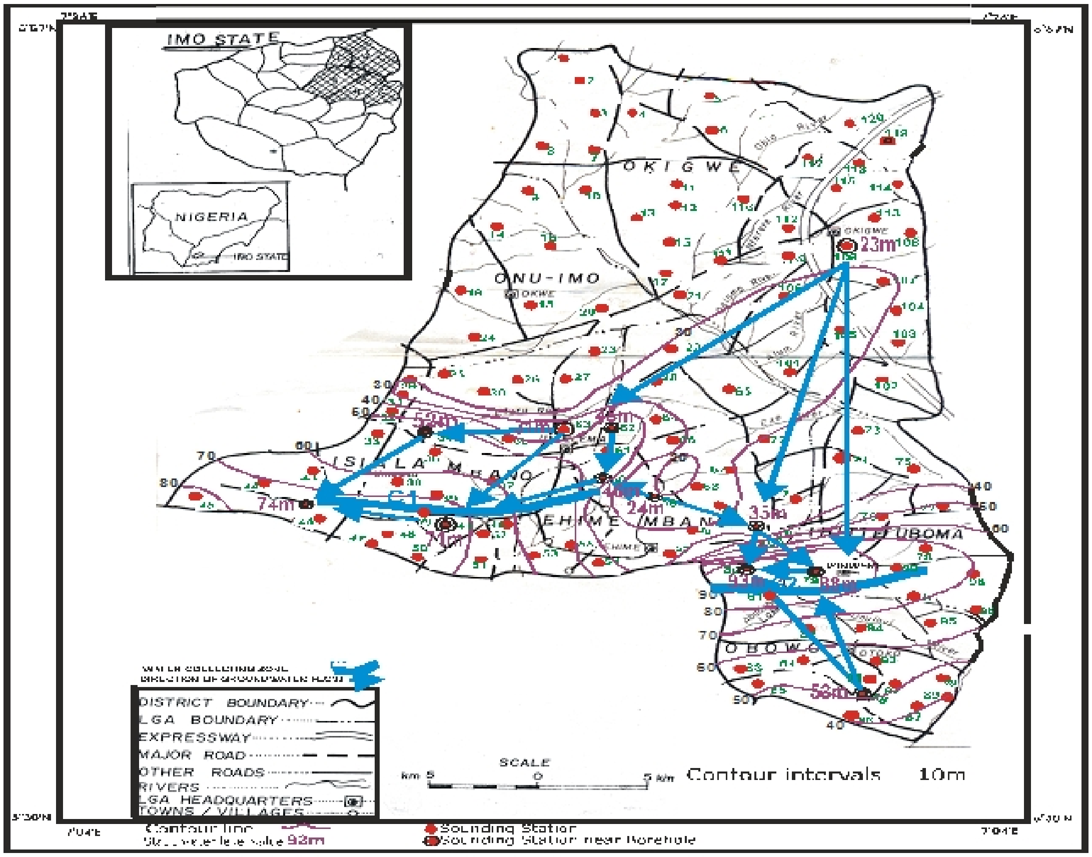


Fig. 7. Static water level map and groundwater flow pattern in the study area

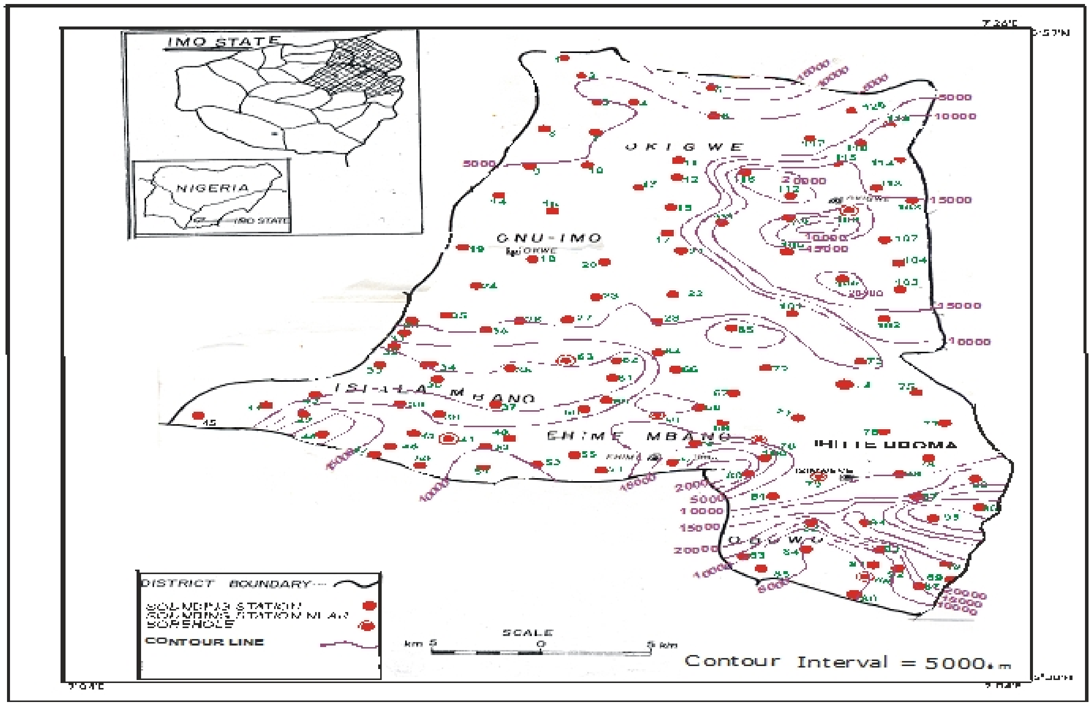


Fig. 8. Layer resistivity contour map of the aquiferous zone

The groundwater flows into two main collecting (converging) centres designated zones C1 and C2 .The principal groundwater flow directions must have been influenced by the structural trends, the drainage system and topography of the district. The groundwater flows away from the shallow water table zone to a deep water table zone (Olorunfemi et al., 1999). Thus, groundwater flows from the Northeastern part around Okigwe area to the Southeastern part covering parts of Obowo and Ihitte Uboma L.G.As; and to the South central and South-western parts of the study area, covering part of Isiala Mbano and Ehime Mbano. It also flows from the South-South area to the South-central part. Zones C1 and C2 have approximately West-East trend. Zone C1 lies within the valleys of Efuru and Eze Rivers while Zone C2 lies almost parallel to the valleys of Onuinyi River and the Abadaba Lake. The flow pattern of the groundwater shows that the rivers are significantly recharged through groundwater base flow while the major rivers and their tributaries also recharge the groundwater resource. Thus based on the flow pattern of the groundwater, zones C1 and C2 are high groundwater potential zones which is consistent with the geology of the area and also with the interpreted aquifer resistivity values. These zones also have high aquifer thickness and transmissivity values [4].

This Southern part corresponds to high resistivity aquiferous zone (Fig. 7). As transmissivity values increase from the Northern part to the Southern part, it follows that groundwater flows from the area with low transmissivity values to that of high transmissivity values within the study area. The distribution of hydraulic conductivity and electrical conductivity product (kδ) values as well as longitudinal conductance values (Table 1) also indicate the existence of different aquifer systems with possible variation in water quality. The same trend was observed in respect of variation in storativity and specific capacity for the study area. The Southern part has the capacity to store water more than the Northern part. Hence groundwater flows from area of low storativity to that of high storativity. This Southern zone equally corresponds to the area having the high groundwater yield of borehole determined from pumping test data as displayed in Table 3 for Avutu, Amaraku, Ugiri, Nsu, Mbano Hospital, Umuelemai and Isinweke.

4. CONCLUSION

Groundwater flow pattern in the study area has been mapped out based on the aquifer characteristics such as resistivity, transmissivity, storativity and the static water level values obtained from geophysical and pumping test data of the area. The groundwater converging centres are high groundwater potential zones and these zones correspond to the areas having high groundwater yield of boreholes in the study area. The Southern part of the district is therefore the most prolific in terms of groundwater exploitation and thus the most promising in sitting productive boreholes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist

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