*Original research paper

Geoelectric Survey for Mapping Grounwater Flow Pattern in Okigwe District, Niger Delta Sedimentary Area of Southeastern Nigeria.

Leonard I. Nwosu*, Anthony S. Ekine, Cyril N. Nwankwo

Department of Physics, *University of Port Harcourt, Nigeria.*
E-mail Address: leowos@yahoo.com, cyrilnn@yahoo.com

ABSTRACT

Geoelectric survey of Okigwe District was carried out using a total of 120 vertical electrical soundings (VES) to map the groundwater flow patterns. The Schlumberger electrode array and a maximum electrode spread of 900m were adopted. 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 (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. 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.

*Key Words***:** *Aquifer, Groundwater flow, groundwater converging centre. Hydraulic conductivity.*

1. 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 L.G.A is still not functional in terms of supplying portable water from Imo River channel. There are many failed boreholes in the area in places like Uturu Isukwuato (in old Okigwe District), Umunakanu Ehime and some areas around Okigwe as the geology of these areas is predominantly clay and shale. Available records in Imo Water Development Agency (IWADA) also show that the lithologic units in Ezeoke Nsu do not show any water bearing sand even at a drill depth of 360ft. Areas around Avutu fall within the transition zone of Benin Formation to Bende Ameki group, Amuzu Ihube in Okigwe falls within the portion of Ajalli 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.

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 (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

UNDER PEER REVIEW

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.

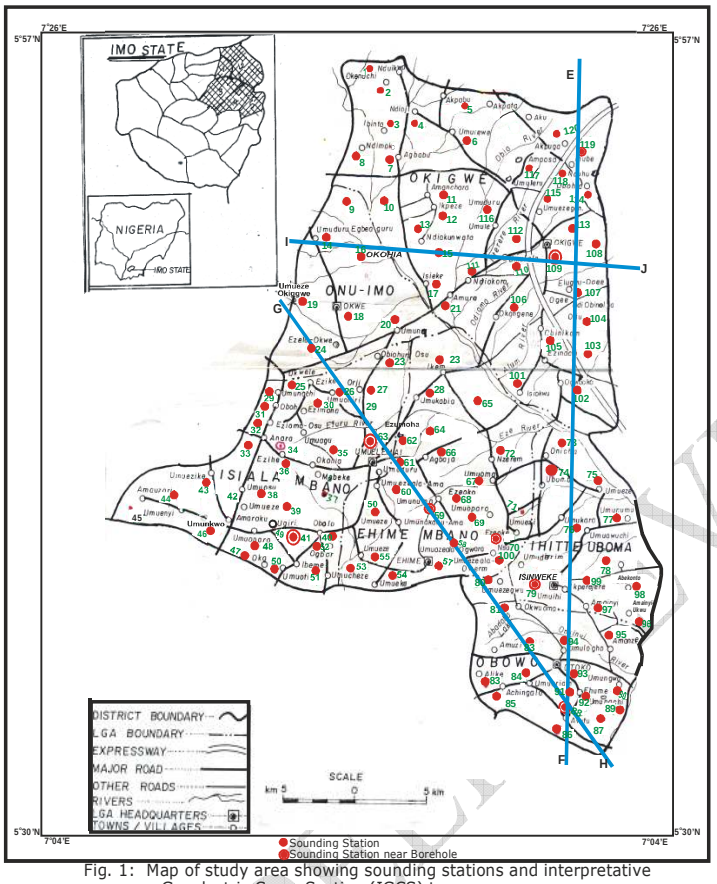


Fig. 1: Map of study area showing sounding stations and interpretative Geoelectric Cross-Section (IGCS) traverse.

2. METHODOLOY

2.1 Experimental Area

The geology of the study area 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 Ajalli Formation (Akaolisa et al, 2009; Nwosu et al, 2011).
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 intercalalions 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 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 (Maduagwu, 1990).

2.2 Electrical Resistivity Measurements

UNDER PEER REVIEW

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 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 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.

2.3 Determination of Aquifer Parameters from Pumping Test Data

Aquifer parameters from pumping *test* data were determined using the Logan (1964) approximation method for calculating the transmissivity T_r and hydraulic conductivity k. The basis of this approximation is Thiem's (1906) in Logan (1964) - equations for steady state flow conditions in confined aquifer.

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

$$Q = \frac{2\pi tkhS_{mw} - S_{m1}}{\ln \frac{r_1}{r_w}} \quad \text{.....1}$$

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 Logan (1964) for steady state flow in confined aquifer as follows:

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

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:

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

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:

$$Kh = \frac{1.18Q}{S_{mw}} \quad \text{.....4}$$

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

UNDER PEER REVIEW

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

2.4 Determination of Aquifer Parameters from VES Results

The layer transmissivity, T_{ri} used in groundwater hydrology (Mbonu et al., 1990), is given by:

$$T_{ri} = K_i h_i \quad \text{.....} 6$$

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 Niwas and Singhal (1985) as follows:-

$$T_r = K\sigma \quad R = \frac{KS}{\sigma} \quad \text{.....} 7$$

According to Niwas and Singhal (1981), 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 modeled curve of the geoelectric section and lithology of VES 17 are displayed in figure 2 while figure 3 shows that the aquiferous zone occur most in the fourth geoelectric layer. The curves are a combination of H- type and K-type (Ekine, 2010) and HKH-type and KQH-type (Oseji 2005).

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. The transmissivity values ranged from 992.04 to 10263.65m^3/day while the storativity values determined for the area ranged from 1.59×10^{-4} to 7.80×10^{-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.

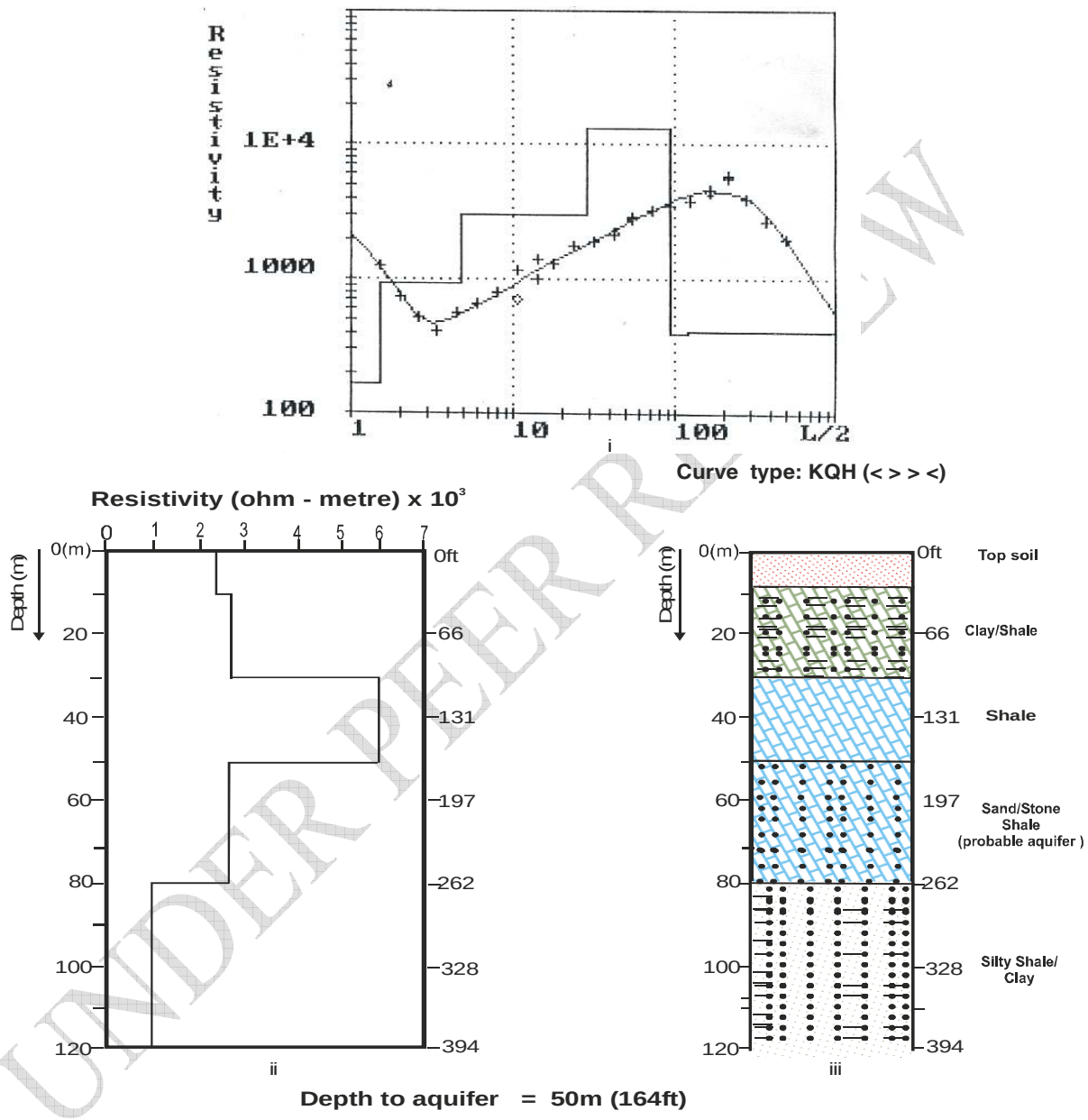
Typical interpretative geoelectric cross-sections EF, GH and IJ constructed using the result of the VES and the geoelectrical data obtained from the existing boreholes (Figs. 1 & 4) show that the top layers are generally not continuous and reveal large variations in layer resistivity and aquifer thickness. Figure 4a was constructed in the Northern part of the study area while figure 4b runs along the high groundwater potential areas. Northeastern part to Southern part. The aquiferous layer is underlain by conductive layer composed of claysand/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.

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 (Fetter, 2007). There is usually a deep unsaturated zone between the water

UNDER PEER REVIEW

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,



Depth to aquifer = 50m (164ft)

i Model curve
ii Geoelectric section
iii Lithology

Fig. 2 : Model curve, geoelectric section and lithology of VES 17 at Okai Umuna

UNDER PEER REVIEW

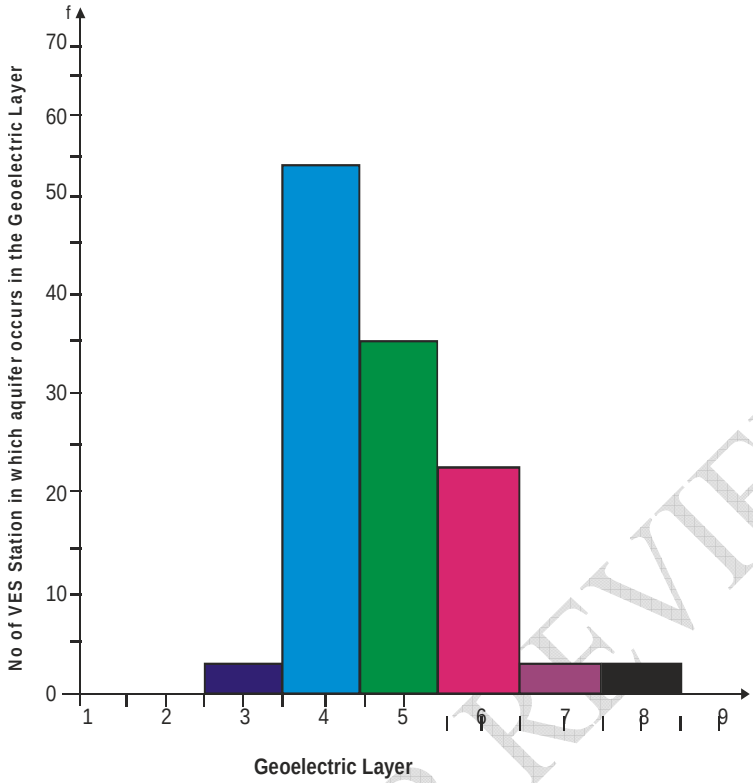


Fig. 3 Showing the distribution of aquiferous zones within the geoelectric layers.

lake or stream (Fetter, 2007; Sighal and Singhal, 1986). 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 (IWADA 2002). 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 (Olorunfemi et al., 1999). 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. 5). Depth to the static water level within Okigwe District vary 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.

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 low water table zone to a high 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 other results of the survey. These zones also have high aquifer thickness and transmissivity values (Nwosu et al., 2011).

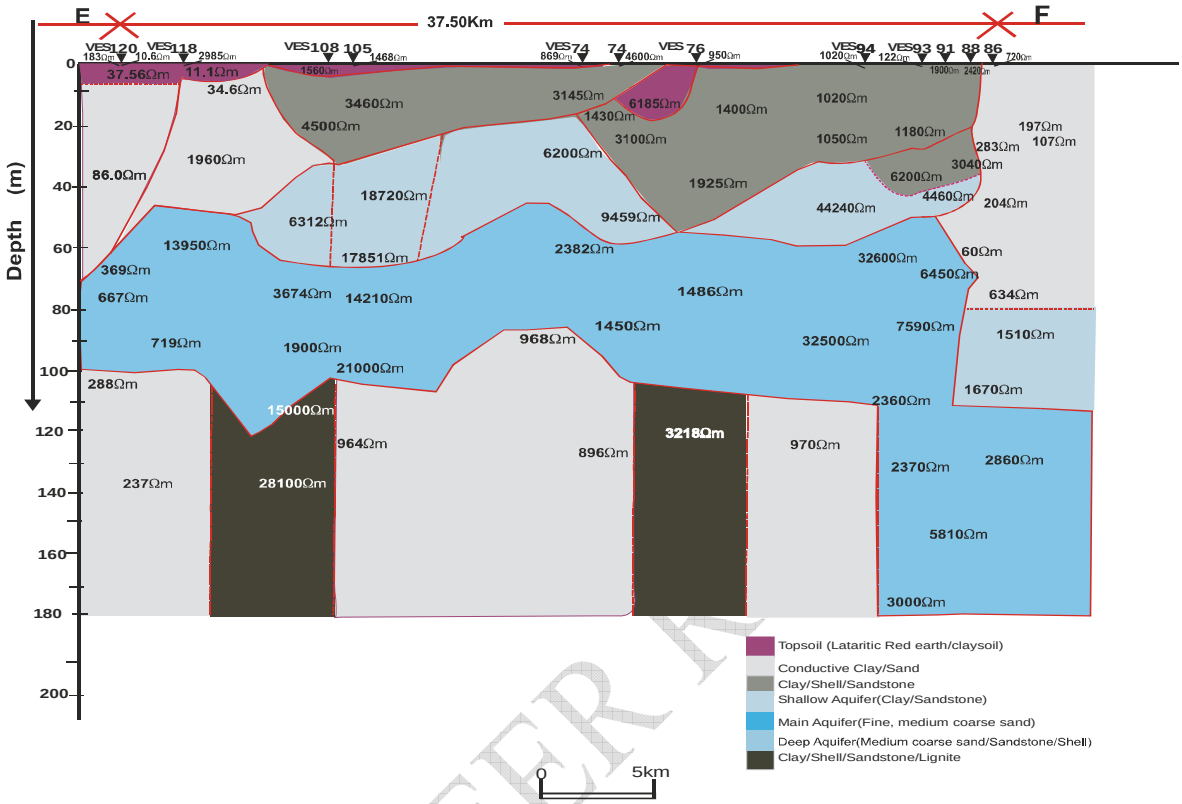


Fig. 4a Interpretative Geoelectric Cross-Section (IGCS) along profile line EF

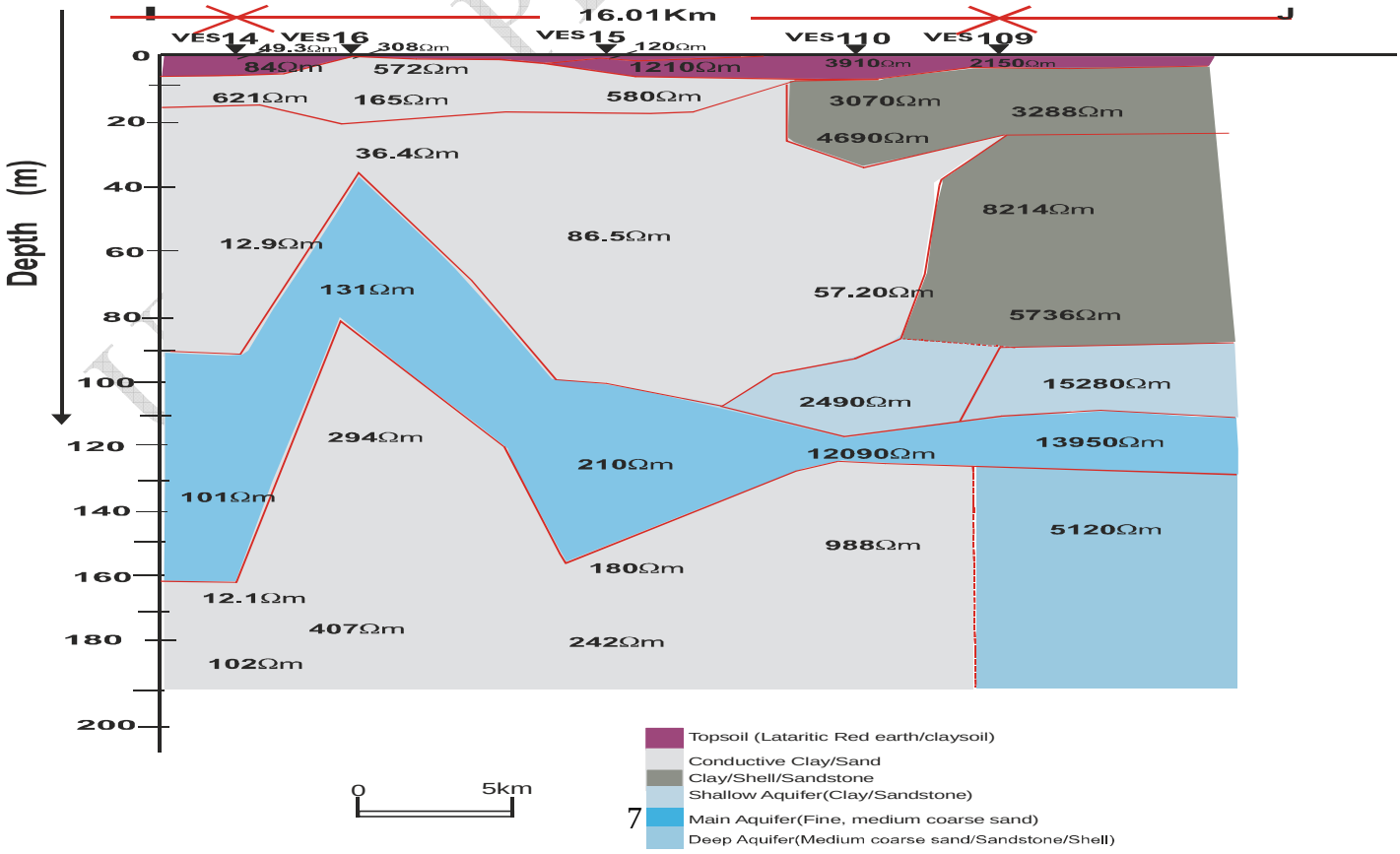


Fig. 4 b: Interpretative Geoelectric Cross-Section (IGCS) along profile IJ

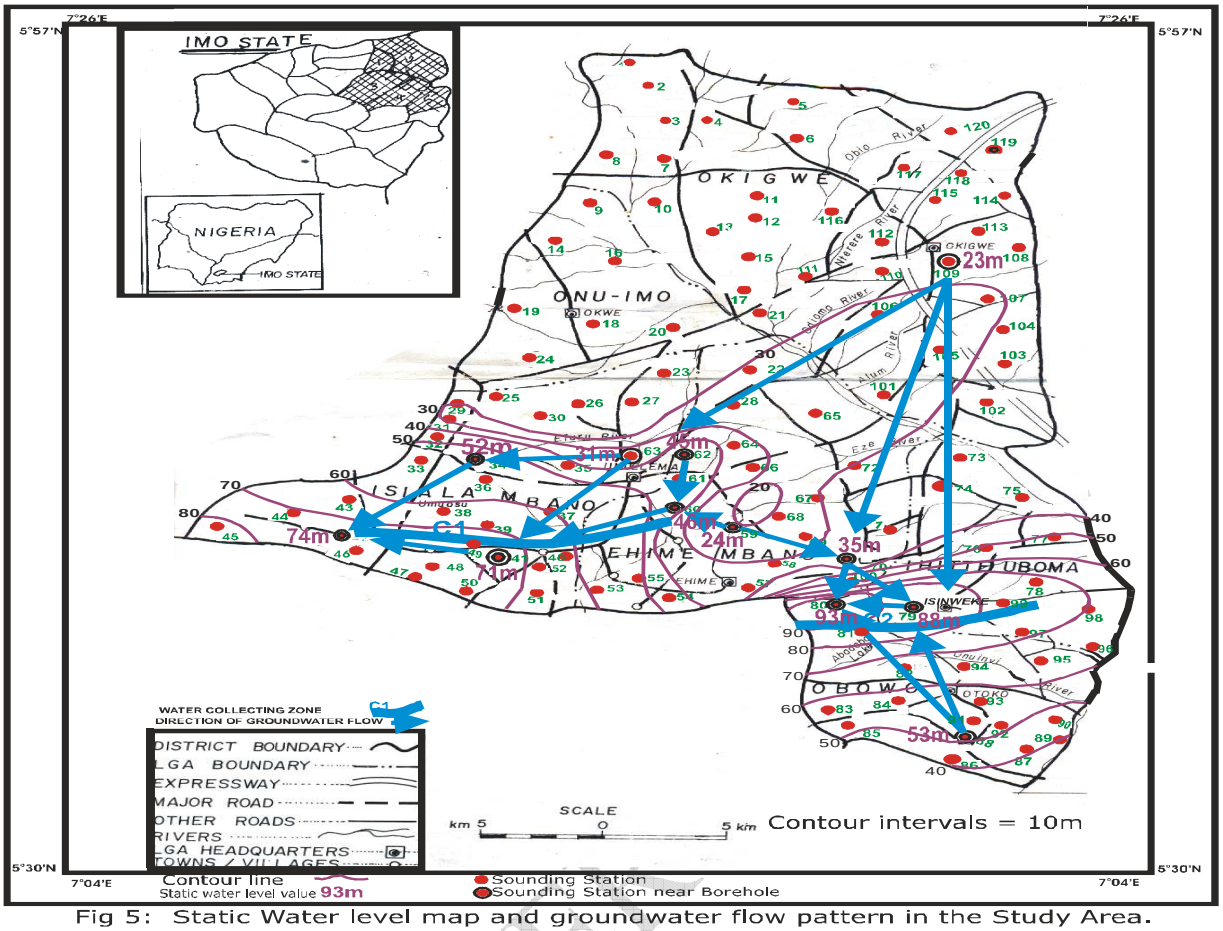


Fig 5: Static Water level map and groundwater flow pattern in the Study Area.

UNDER PEER

4. CONCLUSION

In spite of the limitations encountered in this study, the results are consistent with the geology of the area and very reliable. The determination of the groundwater flow direction has beenbased 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. Groundwater flows from the Northeastern part to the Southeastern part, and to the South central and South-western parts of the study area. It also flows from the South-South area to the South-central part.

ACKNOWLEDGMENT

We are grateful to the Imo Water Co-operation, Owerri and the Imo Water Development Authority (IWADA) for supplying the relevant borehole data and geological information of the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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

UNDER PEER REVIEW

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 Tr (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

UNDER PEER REVIEW

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 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

UNDER PEER REVIEW

REFERNCES

Akaolisa, C.C.Z. and Selemo, A.O.I.. 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. Nigeria Journal pf Physics, Vol 21, No 81 88.

Ekine A S. and Iheonunekwu E.N. 2007: Geoelectric Survey for Groundwater in Mbaitoli Local Government Area. Imo State Nigeria. Scientia Africana. Vol. 6 (No. 1) 39-48.

Ekine,A.S. 2010: Fundamentals of Applied Geophysics, Peare Publishers, P/H, Nigeria pp 35-36.

Fetter, C.W. 2007: Applied Hydrogeology, 2ndEd. C.B.S. Publishers & Distributors, New Delhi India pp 161-201, 550.

Gaarg, S.K. 2003: Physical and Engineering Geology. 4th Edition. Khana Publishers, 2-B Market, Nai Sarak, Delhi pp 330 – 351.

Hemker C.J. 1985: Schlumberger Automatic analysis version 0.92, serial No. 586 for the free University, Amsterdam. Copyright (c) C.J. Hemker Ele and Sgracht 83 Amsterdam.

IWADA, 2002: Imo Water Development Agency Documentary on Groundwater Resources Potential of Imo State., Nigeria (Unpublished). Pp. 20-50.

Logan .J. 1964: Estimating transmissivity from routine production tests of water wells. Groundwater, 2, 35-37.

Maduagwu G.N, 1990: Water Resources Potential (Unpublished). Hydrogeological documentary, Imo State Public Utilities Board Owerri. 1-12.

Mbonu P.D.C., Ebeniro J.O., Ofoegbu C.O., and Ekine A.S., 1990: Geoelectric sounding for the determination of aquifer characteristics in parts of the Umuahia area of Nigeria. Geophysics, Vol 56, No. 2, 284 291.

Niwas, S and Singhal, D. C. 1985. Estimation of aquifer transmissivity from Dar Zarouk parameters in porous media. Hydrology, Vol. 50, pp. 393-399.

Nwosu, L.I., Nwankwo C.N., Emujapore. G., 2011: Determination of Dar-Zarouk Parameters for the Assessment of Groundwater Resources Potential: Case Study of Imo State, South Eastern Nigeria. Journal of Economics and Sustainable Development. Vol. 2, No. 8, Pg 57-71.

Olorunfemi, M.O., Ojo, J.S.; Akintunde, O.M., 1999: Hydro-geophysical evaluation of the groundwater potentials of the Akure Metropolis, Southestern Nigeria. Journal of Mining and Geology Vo. 35(2). Pp 207 - 228

Onyeaguocha, A.C., 1980 Petrogrphy and Depositional Environment of the Benin Formation Journal of Mining Geology 17(2) 147 – 151

Oseji, J.O., Atajepo, E.A., Okolie, E.C. 2005: Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwele Delta State Nigeria. Journal of applied Science and Environmental management. Vol. 9(i) 157 – 160.

UNDER PEER REVIEW

Rijks Waterstaat 1988: Standard Graphs for resistivity prospecting . Swets and Zeithinger, B.V. the Netherlands.

Short, K.C. and Stauble, A.J., 1976: Outline of geology of Niger Delta: Amer, soc. Petr. Geol. Bull., 51, 76-79.

Singhal, B.B.S. and Singhal, D.C. 1986: Evaluation of Aquifer Parameters and Well characteristics in fractured rock formation on Karnataka India. University of Rookee, Rookie India pp. 351-363

UNDER PEER REVIEW