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Surface Geoelctric Survey for Delineating Aquifer Horizon for Siting Standard Water Wells in Water Problem Area of Imo State, Southeastern Nigeria

KEYWORDS Resistivity, Groundwater, Transmissivity, Water well.

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ABSTRACT *20 vertical electrical soundings (VES) were carried out in Ikeduru Area of Imo State Nigeria to delineate the aquifer horizon and identify prospective areas for standard water well development, to solve the water problem that has long challenged the residents. The Schlumberger electrode array was used with maximum spread of 700m. Five of the sounding stations were sited near existing boreholes to enhance interpretation. The field data were analyzed using the Geosciences Incorporation 1D Software package. The result revealed multi-geoelectric layers with the resistivity of the aquiferous layer varying across the study area. The hydraulic conductivity values ranges from 15.90 to 191.80 while the transmissivity values are fairly uniform and quite high, characteristic of Coastal Plain Sands Formation. It ranges from 1093m2/day to 1097m2/day. Two interpretative geoelectric cross sections (IGCS) were constructed to delineate the aquifer horizon which is thick enough for drilling and development of standard water boreholes.*

Introduction
Ikeduru Local Government Area of Imo State is located in the central part of Imo River Basin and shares boundary with Owerri capital territory. Due to its proximity to the State capital, the communities in the area have been besieged by public servants, business people and students of tertiary institutions. These Institutions include Imo State University Owerri, Alvan Ikoku Federal College of Education Owerri, Federal Polytechnic Nekede and Federal University of Technology Owerri. Thus, the area is fast witnessing rapid increase in population density as well as industrial and commercial activities. This has resulted in high demand for potable water to meet both domestic and commercial needs.

Unfortunately, there is no functional public water supply system in the area. Although the existing boreholes have reliable pumping test data as records in Imo Water Development Agency (IWADA) show, most of them are not functional either due to abandonment resulting from lack of maintenance or failure. The situation is compounded by the fact that the Mbaa River which drains the study area has become highly polluted as a result of indiscriminate dumping of solid waste and disposal of urban sewage into farm lands as fertilizer input to boost agriculture. This situation has led to individuals being constrained to the proliferation of substandard wells often recharged by surface water.

Residents of these communities still patronize commercial water tankers especially in the dry seasons while a lot more depend on harvested rain water that is stored in underground tanks of different types and surface tanks that can be seen in many homes. A lot more people depend on private/commercial water wells in the area for supply of water and pay at least ten Nigerian Naira for every 20 litre can of water fetched.

Nwachukwu et al. (2013) observed that many water wells in Imo River Basin become abortive or nonfunctional because the contractors in most cases terminate drilling soon as they penetrate the water table or as a result of poor casing materials being used during installation. They recommended pre-drilling geophysical survey to overcome this challenge.

The present study therefore aims at using surface geoelectric survey to delineate the aquifer horizon in order to recommend sites for standard water wells for development of public water supply system to serve the rapidly growing population in Ikeduru and thus address the challenges posed by water problems in the area.

Location of the Study Area
The study area is Ikeduru Local Government Area in Imo State of Nigeria which lies between latitudes $5^0 28'$N and $5^0 40'$N of the Equator and longitudes $7^0 04$E and $7^0 15'$E of the Greenwich Meridian (Fig. 1). Ikeduru has an estimated population of 149316 people (Onyekakeyah, 2010). It covers a land area of about 1500km^2 and is accessible due to good road network except in some parts of Ikembara and Okwu owing to gully erosion arising from the topographic nature of the area.

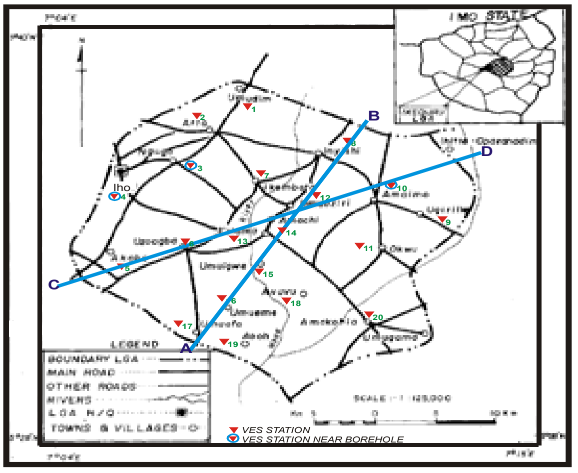

Fig. 1 Map of the Study Area showing the VES Stations and Interpretative Geoelectric Cross Section (IGCS) Traverse.

Geology and Hydrogeology
The study area is located in the central part of the Imo River Basin and within the Benin Formation. Onyeagocha (1980) has discussed the geology of the Benin Formation

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highlighting details of age and stratigraphic units of the basin as well as its potential for groundwater development.

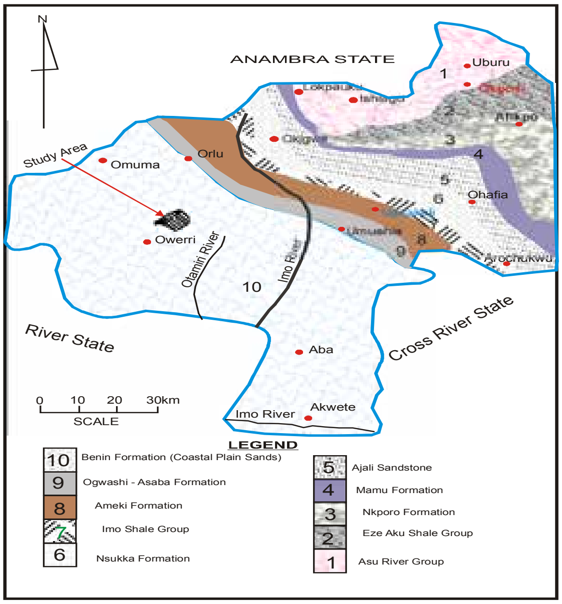


Fig. 2: Geological Map of Imo and Abia States showing the Study Area
Adapted from Imo Water Development Agency (IWADA, 1999)

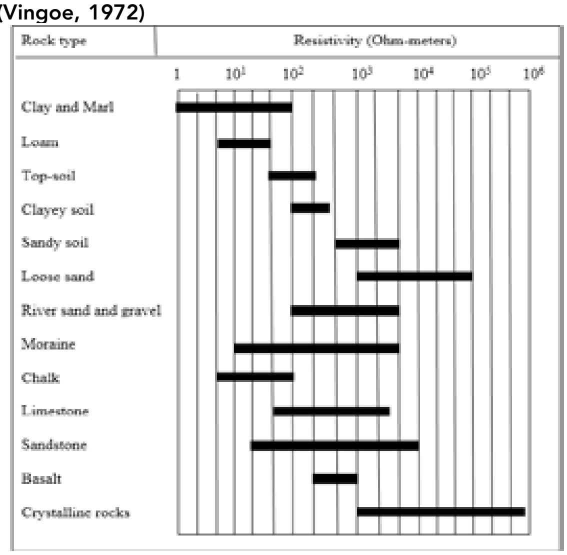
Nwachukwu et al. (2010) explained that the basin is a 140km N-S trending sedimentary syncline located at the central part of south-eastern Nigeria. The southern part of the basin belongs to the Benin Formation covering parts of Imo and Abia States (Fig. 2). The age of the Benin Formation is Oligocene to Recent. This Formation forms the prospective aquifer horizon. Other major stratigraphic units in the basin are the Ogwashi-Asaba Formation, the Bende-Ameki Formation, Imo Shale Formation, Nsukka formation and Ajali Formation (Nwosu et al., 2013).

The Benin Formation consists of unconsolidated yellow and white Coastal Plain Sands with gravel beds, occasionally pebbly with grey sandy clay lenses. Nwachukwu at al. (2010) recorded that the Benin Formation of Imo River Basin is continental in origin and represents the delta plain facies in which many aquifers with potable water occur. They observed that shallow aquifers at depth less than 70m are the main sources of potable water in the study area for both domestic and commercial uses. The annual heavy rainfall over the area ensures adequate groundwater recharge. The annual replenishment is about 2.5billion cubic metres per year. The sandy component form more than 90% of the sequence of layers. Hence permeability, transmissivity and storage coefficient are quite high (Maduagwu, 1990).

Theoretical Background of the Study
The physical principle on which this study is based is electrical resistivity which is the inverse of electrical conductivity. The electrical conductivity of any geologic strata depends on the conductivity of the rock formation (sand, clay); its porosity, the water contained in its pore spaces and salinity of the water (Vingoe, 1972) with the most important factor being the water content. Hence a determination of the resistivity structure of the substratum might reveal not only the geological structure but also the water bearing layers.

The resistivity of a rock layer is a variable property. It varies considerably not only from one layer to the other but also within a particular layer (Vingoe, 1972). Generally, the order of increasing resisitivity is from deposits of clay, sand and gravel, limestone and then crystalline rocks. Table 1 gives the approximate ranges for the electrical resistivity of rocks.

Table 1: Approximate ranges for electrical resistivity of rocks and minerals (Vingoe, 1972)



Methods of Investigation
Reconnaissance survey carried out in the study area shows that there are few boreholes located at Amaimo, Iho, Ngugo and Uzoagba (Fig. 1). Although some of these boreholes are no longer very functional, the pumping test data were very reliable and enhanced the interpretation of the VES data. It was also discovered that most of the communities still depend on water tankers for water supply especially during the dry seasons. However, the sources and potability of the water remain doubtful. Further investigations revealed that no pre-drilling geophysical surveys were carried out before drilling the private/commercial water wells that exist in the communities and some of them are either abortive or nonfunctional.

A total of twenty (20) vertical electrical soundings (VES) were carried out in the area with five of them sited near existing boreholes for proper interpretation (Fig.1). The Schlumberger electrode configuration was used with maximum spread of 700m. The Allied Ohmega Ω earth resistance meter was employed for the field measurement with four stainless, non-polarizable electrodes comprising two current electrodes and two potential electrodes. A 12V D.C. battery powered the instruments while necessary precautions for carrying out VES were adopted. The current electrodes spacing was increased systematically about the centre, keeping the potential electrode spacing constant until it became necessary to increase it when the strength of recorded signal diminished.

The field data acquired were first subjected to manual computation in which the apparent resistivity values were computed using equation 1.

$$P_a = K R \quad (1)$$

where K = geoelectric factor

R = field resistance

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The apparent resistivity values were then subjected to computer modeling using the Advanced Geosciences Incorporation (AGI) 1D Software Package. The modeling result gave a twelve (12) geoelectric layers which were constrained to six or seven layers depending on the resistivity values of the layers.

By integrating the borehole information from pumping test analysis of Table 2 such as static water level, and borehole lithologic log (Fig. 9), the aquiferous layers and the lithologic units at each sounding station were delineated.

Table 2: Pumping test data for some boreholes in the study area

Location	Total Drilled Depth(M)	Static Water Level(m)	Screen Length(m)	Maximum Draw Down(m)	Well Discharge Q(m^3/day)
Ngugo	116.00	47.30	18.30	3.40	1571
Iho	85.00	53.00	15.20	3.10	6110
Amaimo 1	86.00	45.40	18.30	3.70	6110
Amaimo 2	183.00	40.00	21.30	9.80	2291
Uzoagba	110.00	33.50	15.20	12.20	3928

The aquifer characteristics of hydraulic conductivity (K), Transmissivity (T), as well as Transverse Resistance (R) are useful in assessing groundwater resources potential of a place and are best determined on the basis of pumping test analysis. Ekine and Iheonunekwu (2007); Nwosu et al. (2013) and Odoh et al. (2009) observed that these parameters are needed for proper water planning and management and also useful in investigating the water flow through an aquifer and its response to fluid abstraction.

Based on the pumping test data of Table 2, these parameters were determined using equations 2 to 5.

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

Where Q = well discharge

S_{mw} = maximum draw down

h = Screen length

The Transmissivity is obtained using equation 3

$$T = Kh \qquad (3)$$

For VES data, the hydraulic conductivity is determined from equation 3

$$K = \frac{T}{h} \qquad (3)$$

Where T = average transmissivity from pumping test analysis

h = aquifer thickness

The Transmissivity of the auriferous layers is calculated from the analytical relationship of Niwas and Singhal (1981) given by equation 5

Equation 5 should read:

$$T = K\sigma R \qquad (5)$$

Where σ = Electrical conductivity of the aquiferous layer

R = transverse resistance of the aquiferous layer.

Results and Discussions

Typical model results obtained for this study are shown in (Fig. 3). The modeled result displayed geoelectric section with 12 layers constrained to 6 or 7 layers with the inferred lithologic units shown. The lithologic units and aquiferous layers were delineated (Table 3) by correlating with borehole information and standard resistivity values (Tables 1 and 2). Figure 4 shows the variation of resistivity of the aquiferous zone. Low resistivity values are discovered in areas around Iho (VES 4) and Akabo (VES 5) with values of 500Ωm and below. This could be attributed to aquifer materials being clay/sand deposit. There is variation in aquifer thickness ranging from 5.71m to 116m recorded at Inyishi (VES 17) and Avuvu (VES 18) respectively. Table 3 is the summary of the modeling result for all the VES stations.

The hydraulic conductivity values ranges from 15.90m/day to 191.80m/day while the transmissivity values are fairly uniform and quite high characteristic of Coastal Plain Sands Formation (Fig. 5). It ranges from 1093m^2/day measured at Amaimo and Umuoziri to 1097m^2/day observed at Amachi and Ikembara (Table 4). Areas of relatively high transmissivity value have corresponding high aquifer thickness. This agreed with the expected result as transmissivity is a function of aquifer thickness (Ekine and Osobonye, 1996; Nwosu et al., 2013).

Two interpretative geoelectric cross-sections (IGCS) constructed for the area were also used to map the aquifer horizon. Figure 6 shows the IGCS along profile line AB. It runs almost parallel to the Mbaa River and covers 28.0km while profile line CD covers 38.0km. In the cross-sections, 5 to 6 layers were mapped out with their average resistivity values indicated. Aquifer horizon was mapped out in the 5^{th} layer and is thick enough for drilling and development of standard water boreholes especially in areas at Amaimo, Uzoagba, Inyishi, Ikembara and Umuofo to a depth of about 90m to 100m (270ft to 300ft). To achieve this, the design of standard water well by Nwachukwu et al. (2012) is recommended (Fig. 8). Akaolisa and Selemo (2009) have also used IGCS to determine the depth and thickness of gravel deposits around Owerri near the present study area.

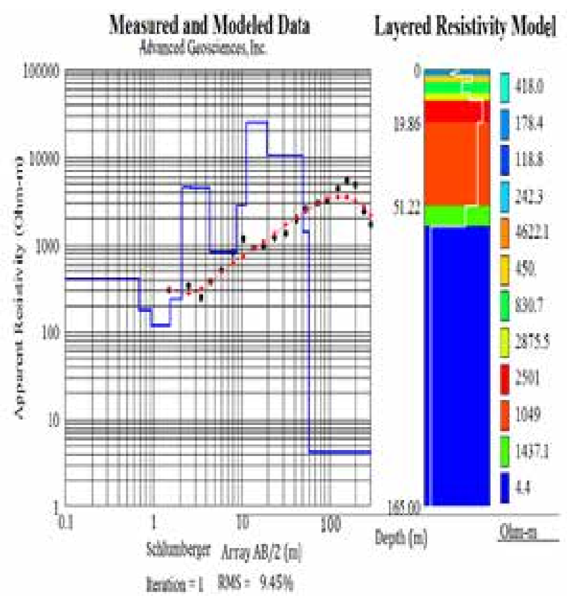

Fig. 3: Typical Model Result for Amaimo (VES 10)

Table 3: Analysis of Amaimo VES 10:

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	4.40	418.00	Top soil lateritic	Yellow
2	8.80	830.70	Sand	Green
3	11.20	2875.50	Medium coarse sand	Orange
4	19.80	2501.00	Sand	Red
5	51.80	1049.00	Sand	Off Red
6	59.00	1437.00	Sand	Green
7	165.00	4.40	Clay	Blue

Table 4: Summary of the Modeling Result for VES Stations

VES Numbers	Depth to water table (m)	Resistivity of aquifer layers ρ (ohm-m)	Thickness of aquifer *h*(m)	Hydraulic Conductivity K (m/day)	Transverse Resistance (ohm)	Transmissivity T (m^2/day)
1	62.70	9695.00	16.70	65.57	161906.50	1095.00
2	66.30	7774.10	34.90	31.40	271316.10	1096.30
3	53.27	4465.50	24.00	45.63	107172.00	1095.10
4	51.71	252.00	17.22	63.59	4339.40	1095.00
5	59.16	266.00	34.00	32.20	9054.60	1096.00
6	90.73	1456.10	58.10	18.85	8892.60	1202.00
7	144.00	613.00	69.00	15.90	42297.00	1097.10
8	77.70	8706.80	48.70	22.50	424021.20	1096.90
9	75.00	2495.00	23.52	46.50	58682.40	1095.10
10	59.00	1437.00	7.20	151.80	10346.40	1093.30
11	89.00	1463.00	24.60	44.51	35990.00	1095.00
12	75.00	2385.00	5.70	191.80	13594.50	1093.20
13	90.00	5529.00	102.00	145.40	149083.50	1094.90
14	90.25	4524.80	45.10	24.30	204068.50	1097.00
15	70.00	2700.00	60.50	115.30	258.40	1094.50
16	89.00	1463.00	24.600	44.51	359898.00	1095.00
17	70.51	13422.30	26.24	41.73	352201.20	1095.30
18	49.35	5836.20	116.00	67.30	94955.00	1095.00
19	94.40	2890.00	25.60	42.77	73984.00	1094.90
20	39.00	3208.00	7.50	146.00	24060.00	1095.00

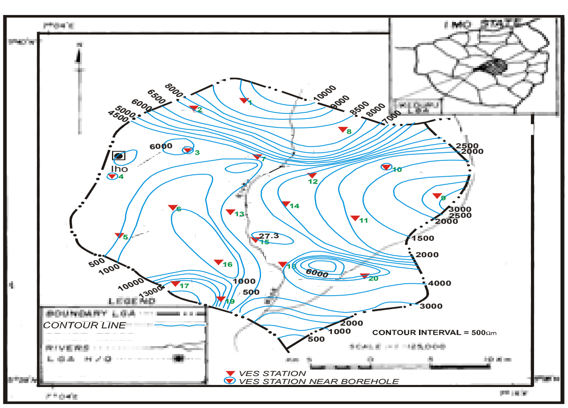

Fig. 4: Resistivity Contour Map of the Aquiferous Zones in the Study Area

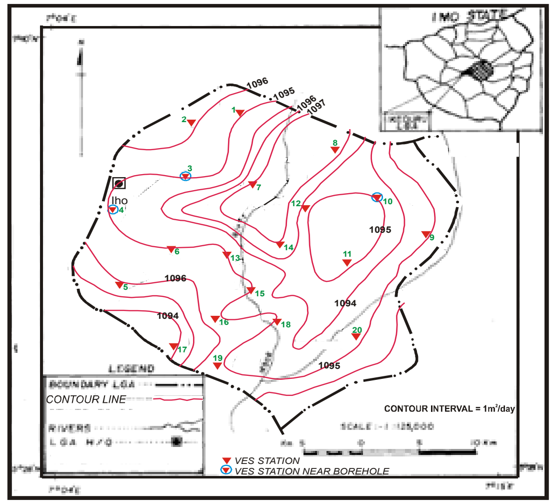

Fig. 5: Transmissivity Map of the Aquiferous Zones in the Study Area

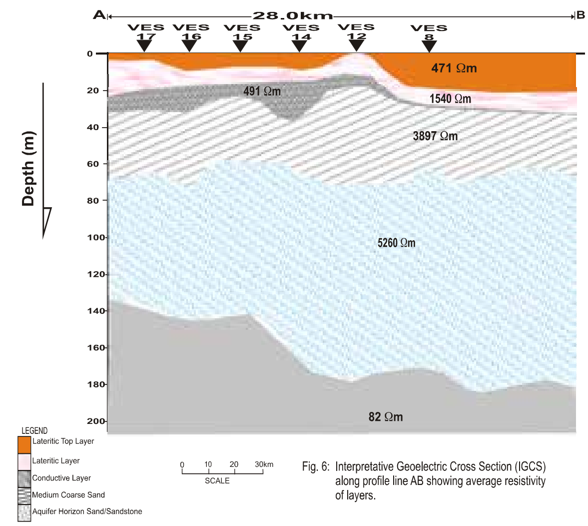

Fig. 6: Interpretative Geoelectric Cross Section (IGCS) along profile line AB showing average resistivity of layers.

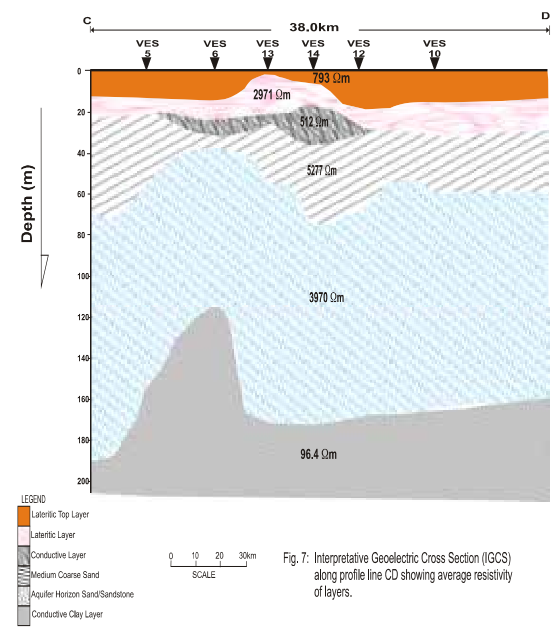

Fig. 7: Interpretative Geoelectric Cross Section (IGCS) along profile line CD showing average resistivity of layers.

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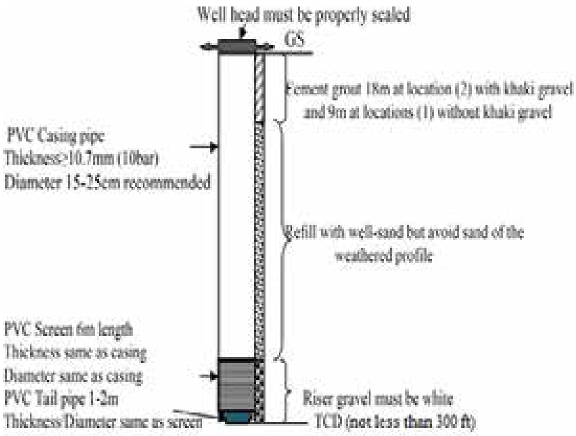

Fig. 8: Design for Standard Water well (Nwachukwu et al., 2012)

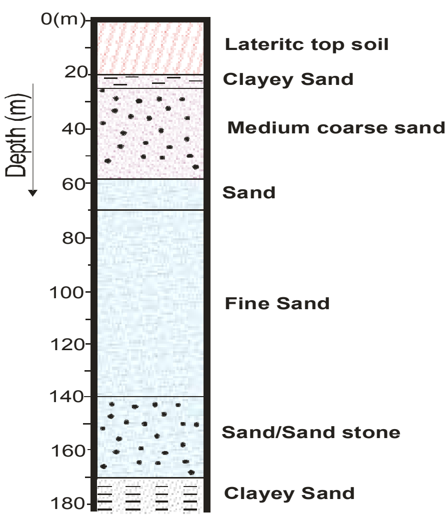

Fig. 9: Lithologic Log of Amaimo Borehole

Conclusion

Aquifer horizon has been delineated in this study. It is therefore recommended that to solve the water problem, both State and Local Government authorities should embark on public water supply development project by drilling standard water well in the prospective areas identified. It is economically cheaper for the residents to pay public water rate than spending much in patronizing commercial water tanker and private commercial water well operators which is associated with public health hazards arising from drinking water from polluted sources.

Acknowledgment

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