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Geoelectric Investigation for Groundwater in Imo State University Campus and Environs using Direct Current Electrical Resistivity Method

***[1]Agbodike, I. I. C., [1]Chinaka, J. C. and [2]Onuoha, N. O.**

[1]Department of Physics, Faculty of Physical Sciences, Imo State University Owerri
[2]Department of Mathematics, Faculty of Physical Sciences, Imo State University Owerri

*Corresponding author's email: ifygift_2009@yahoo.com

ABSTRACT
Eighteen, vertical electrical soundings (VES), were carried out in Imo State University and Environs to delineate the potential site for groundwater. Data were acquired using ABEM SAS 300 resistivity meter. Schlumberger array and maximum electrode spread of 700m were adopted. Data were interpreted with IP2WIN software. Contour maps were done using Sulfer 20 software. Geoelectric cross-sections constructed along three profile lines delineated subsurface stratification. Sediments consist of sequence of sandstone/gravel, silty sand/sand and clay with geology representing the Benin Formation. Groundwater was delineated within the zone interpreted to be sand with quartz making up more than 95% of all grains. Resistivity of aquifer varies across study area and ranges from 159Ωm, observed around Library and Information Department (VES 11) to 100000Ωm recorded at IMSU Plaza (VES 10). Depth to water table also varied across study area with higher values of 150m and 130m observed at College of Health Science (VES 3) and Behind Old ETF (VES 4). A relatively shallow aquifer is delineated behind Senate Building and Okwu-Uratta with water table at depths of 23.5m and 26.5m. The transmissivity values are moderately high except at some locations. The variation in longitudinal conductance and transverse resistance values show that part of the study area such as Aso Rock, Female Hostel, Law Faculty and IMSU Plaza are underlain by relatively resistive (low longitudinal conductance) aquifer material. Distribution of hydraulic conductivity and electrical conductivity values indicates that in some of the VES points, the values are fairly constant. This could be seen as areas with similar geologic settings and water quality. Storativity of study area ranges from 0.00003 at VES 1 and 12 to 0.00028 at VES 4. Study area shows a good prospect for groundwater development, except at Library and Information Department, where the zone delineated is an aquitard.

Keywords:
Stratification,
Groundwater,
Aquifer,
Geology,
VES.

INTRODUCTION

Groundwater is water stored beneath the earth's surface in aquifers, which are layers of permeable rock, sand, or soil. It is a vital component of the earth's hydrologic cycle and a crucial source of freshwater for various uses. Increased demands for water due to population growth and agricultural development have stimulated development of groundwater resources. More stress is being placed on available prolific aquifers, techniques for investigating the occurrence and movement of groundwater have been improved, better equipment for extracting has been developed, concepts for resource management have been established, and the research has contributed to a better understanding of the project. Because of the growing worldwide population, there is an increasing need to develop groundwater resources, which makes resource protection crucial (Nwosu and Chinaka, 2021).

Groundwater exploration is the process of searching for and identifying potential sources of groundwater, such as aquifers, to meet water supply needs. It involves a combination of geological, geophysical, and hydrological techniques to identify potential aquifer locations, determine aquifer properties (such as depth, thickness, permeability and so on) and assess groundwater quality and quantity. Groundwater exploration avoids the risk of drilling less productive or unproductive boreholes (usually through highly expensive drilling method) by conducting cost-effective geophysical investigations.

These days the use of geophysical techniques for groundwater exploration and water quality evaluations has increased due to rapid advances in computer software and other numerical modeling techniques. The use of vertical electrical Sounding (VES) has become very popular with groundwater prospecting due to simplicity of the technique (Abdullahi *et al.*, 2015). The geoelectrical sounding or vertical electrical sounding technique measures the distribution of electrical resistivity in the subsurface. This technique is widely used for aquifer delineation as it can penetrate deeper into the subsurface (Oyeyemi *et al.*, 2019). In addition, the technique is quite non-destructive, very sensitive and offers a very attractive tool for describing the subsurface properties without digging. Using this method, depth and thickness of various subsurface layers and their water yielding capabilities can be inferred. However, a hydrogeologic method called the Geoelectric Layer Susceptibility Index (GLSI) assesses the geoelectric parameters produced by the electrical resistivity contrast between subsurface lithological sequences and reveals useful data for groundwater exploration (Nwosu and Chinaka, 2021).

Water supply problems are not new to many areas of Nigeria but the situation is more acute in some localities. Many boreholes have been drilled in the study area based on the fact that the area belong to a sedimentary environment and should have a good water bearing rocks. Some of these boreholes are yielding water; some yielding capacity fluctuate between the wet and dry season while some yielded for a short time and went dry. Part of the problem was due to the fact that no prior geophysical and hydrogeological investigations were conducted before drilling was done. This research therefore focuses on the use of the geoelectrical resistivity method to locate the productive subsurface aquifer and estimate its geophysical properties with a view to evaluating its potential for sustainable groundwater exploration. If the groundwater conditions of an area is properly understood, it could be used as an effective tool in the planning of reliable water borehole in such area (Sunmonu *et al.*, 2012).

Location and Hydrogeology of the Study Area

The study area is Imo State University cakpus and environs defined by latitude 5.50043˚N to 5.50886˚N and longitude 7.03768˚E to 7.04817˚E. The study area is located in Owerri, the capital city of Imo State, South eastern part of Nigeria. The area is characterized by a tropical savanna climate. It is dominantly of two seasons: rainy (April - October) and dry (November - March). Rain falls for most months of the year with a brief dry season. The harmattan affects the area in the early periods of the dry season and it is noticeably less pronounced than in other cities in Nigeria. Vegetation in the area is typically of tropical rainforest and grasslands environment and produces many agricultural products, such as yam, cassava, taro, corn, rubber and palm products. The study area is bordered by the Otamiri River to the east and the Nworie River to the south. The Otamiri river's average flow varies from about 3.4 m^3/s in the dry season to a maximum of 10.7 m^3/s in the rainy season (September to October) (November to February). Around 1.7 x 10^8 m^3 of the Otamiri's total annual discharge (3.74 x $l0^7$ m^3 of which is direct runoff from rains, making up the river's safe yield) is discharged annually (Okechukwu Mbaeze, 2023). The study area is accessible with a network of tarred roads. Some of the major roads that go through the study area are Okigwe road, IMSU/Samek road, Wethedral road, Ikenegbu road and Mcc/Uratta road.

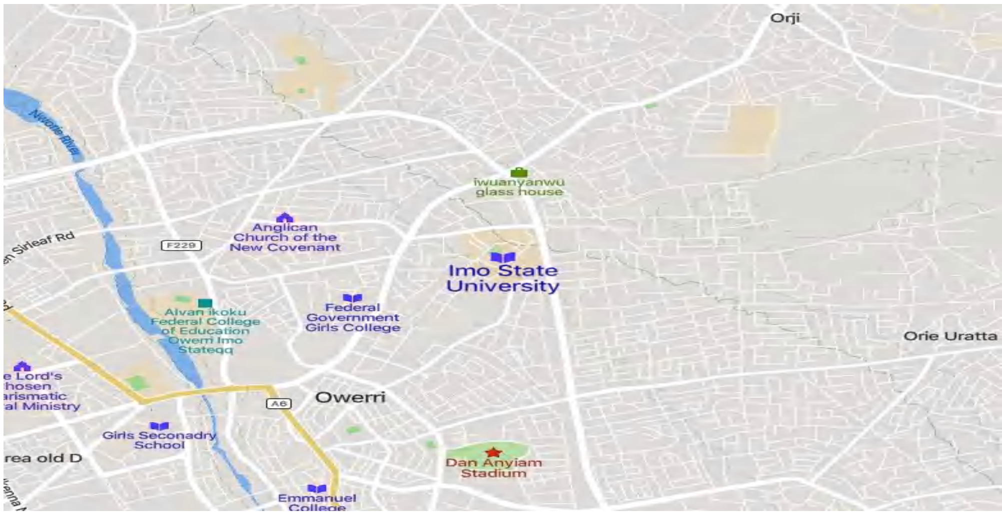


Figure 1: Map showing the study area

Geologic Setting

The study area is situated in the Coastal Plain sands otherwise known as the Benin Formation. The Benin Formation (Miocene to Recent) accounts for more than half of the Imo River Basin. It is mainly made-up gravel, sandstones and sands with some clay and sandy clay intermingled. It contains improperly sorted fine, medium, and coarse-grained sands. A petrographic study of numerous thin sections revealed that quartz makes up more than 95% of all grains; nevertheless, there are indications that feldspar and other skeletal elements may also make up a significant fraction of the grains. This formation exhibits a very small dip to the south and southwest. The Imo River's floodplains and the area around its estuary in the Atlantic Ocean are where most alluvium of recent age, the youngest deposit type in the basin, is to be found (Okech ukwu Mbaeze, 2023). The environment of deposition of the Benin Formation is partly lagoonal and fluvio lacustrine/deltaic (Reyment, 1965). The stratigraphic succession of rocks in the study area consists of Nsukka Formation, being the oldest formation and followed by Imo-Shale, Ameki Formation, Ogwashi-Asaba Formation while the youngest is the Benin Formation (Uma and Egboka, 1985). The coastal plain sand belonging to the Benin Formation extends to a considerable depth in the area and with a good hydraulic properties for groundwater development (Amadi, 2009). The Benin Formation is a good aquifer with an average annual replenishment of about 2.5 billion cubic meters per year (Onyeagocha, 1980).

Figure 2: Geologic map of the study area

MATERIALS AND METHODS

Eighteen VES were conducted at different points within the study area using the Schlumberger electrode configuration. The maximum spacing for the current electrodes (AB/2) used in this study is 350 m. The apparent resistivity was measured using the ABEM SAS 300 resistivity meter. The spacing of AB/2 started at 1.0 m and increased while potential spacing (MN/2) was fixed at a point until AB/2 became large that an increase in potential became necessary.

The fundamental principle behind collection and interpretation of electrical resistivity measurements is the Ohm's law. Ohm's law states that the product of the electrical current, I, through a conductor and the resistance of the conductor, R, for which the current passes, is equivalent to the potential difference, V, across the conductor (Loke, 2000). This is expressed in equation (1).

$$V = IR \quad (1)$$

In principle, it is relatively simple to measure the resistance of a strand of wire. Connect a battery to a wire of known voltage and then measure the current flowing through the wire. The voltage divided by the current yields the resistance of the wire. In essence, this is how the resistivity measures resistance as shown in equation (2).

$R = \frac{V}{I}$ (2)

To further explain and have better understanding of the principle of electricity, let us consider current I flowing through a wire of length L and cross-sectional area A. The resistance R, of the wire can be expressed in terms of A and L as shown in equation (3).

$R \propto \frac{L}{A}$ (3)

The constant of proportionality is resistivity given as (ρ). Therefore, the total resistance of the wire element, R, is the product of the material resistivity, ρ, and the ratio of the wire length and cross-sectional area as illustrated in equation (4).

$R = \rho \left[\frac{L}{A}\right]$ (4)

Considering the physical relationship between the geometry of the conductor and the material property, equation (4) can be manipulated to determine the material resistivity of the conductor element as expressed in equation (5).

$\rho = R\left[\frac{A}{L}\right]$ (5)

The quantity inside the brackets is a function only of the various electrode spacing. The quantity is denoted as k, which allows rewriting the equation as:

$\rho = kR$ (6)

where, k = geometric factor, which depends on the arrangement of the four electrodes and R= measured resistance

The resistivity measurements were made by injecting current into the ground through two current electrodes (C_1 and C_2), and measuring the resulting voltage difference at two potential electrodes (P_1 and P_2). From the current (I) and potential (ΔV) values, the resistivity (ρ) value was calculated using Equation (6). The measured resistivity value is not the true resistivity of the subsurface, but an 'apparent' value, which is the resistivity of a homogeneous ground, which will give the same voltage and current values for the same electrode arrangement. The measured apparent resistivity values were plotted against their respective current electrode spacing (AB/2) on a bi-log graph and were presented as sounding curves. From these plots, qualitative deductions such as the resistivity of the first or top layer, the depth of each layer, and the curve signatures or types were made. Quantitative interpretations of the VES curves were carried out using partial curve matching technique and computer-aided 1-D forward modeling using IP2Win software.

Niwas and Singhal (1981) gave us the relationship between hydraulic parameters and electrical parameters in a porous medium as:

$T = K\sigma R = KL\rho = Kh$ (7)

Where, T is the transmissivity, K is the hydraulic conductivity, σ the aquifer conductivity, R the transverse resistance, L the longitudinal conductance, ρ the aquifer resistivity and h the aquifer thickness respectively. Thus knowing the K values from existing boreholes and σ values extracted from the sounding interpretation for the aquifer at borehole locations, the determination of transmissivity and its variations from place to place is made possible, including those areas without boreholes. This provides a general idea of the water producing capabilities of the aquifer. Using hydraulic conductivity of 10.02 m/day from an existing borehole within the study area, transmissivity of the aquifer in the study area was calculated using equation (7).

The Dar-zarrouk parameters of longitudinal conductance and transverse resistance of the overburden unit at each VES were obtained using equations (8) and (9)

$R = h\rho$ (8)

$L = h/\rho$ (9)

Where, R = transverse resistance, h = aquifer aquifer thickness, ρ = aquifer resistivity, and L = longitudinal conductance

The storativity S of the confined aquifer system and the deep and thick unconfined aquifer which may be hydraulically similar to it was estimated from the rule of thumb equation given by Lohman (1972) and Todd (1980) as:

$S = 3 \times 10^{-6} b$ (10)

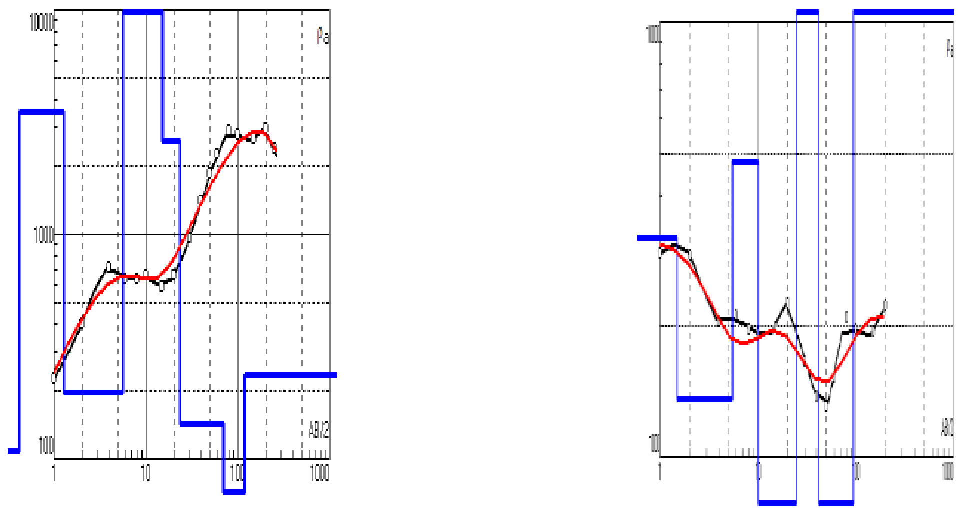
where b is the saturated thickness of the aquifer

RESULTS AND DISCUSSION

Typical modelled VES results are shown in Figure 3 to Figure 5. Table 1 gives the summary of the modelled VES results for the study area. The VES analysis reveals that the area is characterized by 2 to 5 geoelectric subsurface layers with 4 and 5 - layer types occurring more. The 4 - layer geoelectric section is characterized by HA, KH, KA and HK. The 5 - layer geoelectric section is characterized by HKH, KHK, KHA and HKA. The single - layer geoelectric section is characterized by K and A.

Table 1: Summary of the modelled VES results for the study area

VES NO	LOCATION	Latitude N (Degree)	Longitude E (Degree)	Elevation (m)	Curve Type	Aquifer Depth (m)	Aquifer Thickness (m)	Aquifer Resistivity (Ωm)
1	Behind Science Building, IMSU	5.50618	7.04707	107	KHK	23.5	8.34	2594
2	Aso Rock, IMSU	5.50617	7.04604	102	HKH	41.9	17.20	14325
3	College of Health Science, IMSU	5.50815	7.04065	112	KHA	150	43.10	5032
4	Behind Old ETF, IMSU	5.50412	7.04583	75	KH	130	94.20	30401
5	In Front of Catholic Church, IMSU	5.50430	7.04214	81	HA	117	54.60	1099
6	IMSU Staff School	5.50114	7.03986	62	KA	72.2	26.20	3995
7	Female Hostel, IMSU	5.50043	7.04186	65	KH	116	69.70	65896
8	Law Faculty (MOOT Court), IMSU	5.50300	7.04384	83	KH	51.2	28.00	32603
9	Faculty of Environ. Science, IMSU	5.50856	7.04522	109	KH	63.9	35.60	16158
10	IMSU Plaza	5.50788	7.04148	97	HKA	89.1	34.60	100000
11	Dept of Lib. & Information, IMSU	5.50559	7.03893	85	K	39.9	28.10	159
12	Love Garden, IMSU	5.50583	7.04320	67	KHA	44.1	10.40	3977
13	Behind Coca-Cola Spot, IMSU	5.50525	7.04213	96	KH	69.4	32.70	8536
14	Bishop's Court, Owerri	5.50886	7.04817	115	KHK	37	13.90	2308
15	IMSU Junct./Okigwe Road, Owerri	5.50683	7.03768	68	KHK	51.4	35.60	8713
16	Ikenegbu, Owerri	5.50486	7.04795	89	A	77.6	48.10	2680
17	Okwu-Uratta, Owerri	5.50812	7.04671	106	KH	26.5	44.2	30809
18	Aladinma Shopping Mall, Owerri	5.50274	7.04747	93	HA	90	42.00	11044



(a) (b)

Figure 3: Geo-electric Sample Curves interpreted from the study area: (a) KHK Geo-electric curve types Behind Science Building, IMSU (VES 1) & (b) HKH Geoelectric curve type at Aso Rock, IMSU (VES 2)

Table 2: Summary of aquifer characteristics for all the sounding points in the study area

VES NO	Aquifer Depth (m)	Aquifer Thickness (m)	Aquifer Resistivity (Ωm)	Aquifer Conductivity $(\Omega m)^{-1}$	Transverse Resistance (Ωm^2)	Longitudinal Conductance (Ω)	Storativity	Diagnostic Constant Kδ	Transmissivity (m^2/day)	Hydraulic Conductivity N & S Model (m/day)
1	23.5	8.34	2594	0.00039	21633.96	0.003	0.00003	0.00091	19.63	2.35
2	41.9	17.20	14325	0.00007	246390.00	0.001	0.00005	0.00091	223.54	13.00
3	150.0	43.10	5032	0.00020	216879.20	0.009	0.00013	0.00091	196.77	4.57
4	130.0	94.20	30401	0.00003	2863774.20	0.003	0.00028	0.00091	2598.24	27.58
5	117.0	54.60	1099	0.00091	60005.40	0.050	0.00016	0.00091	54.44	1.00
6	72.2	26.20	3995	0.00025	104669.00	0.007	0.00008	0.00091	94.96	3.62
7	116.0	69.70	65896	0.00002	4592951.20	0.001	0.00021	0.00091	4167.09	59.79
8	51.2	28.00	32603	0.00003	912884.00	0.001	0.00008	0.00091	828.24	29.58

9	63.9	35.60	16158	0.00006	575224.80	0.002	0.00011	0.00091	521.89	14.66
10	89.1	34.60	100000	0.00001	3460000.00	0.000	0.00010	0.00091	3139.19	90.73
11	39.9	28.10	159	0.00629	4467.90	0.177	0.00008	0.00091	4.05	0.14
12	44.1	10.40	3977	0.00025	41360.80	0.003	0.00003	0.00091	37.53	3.61
13	69.4	32.70	8536	0.00012	279127.20	0.004	0.00010	0.00091	253.25	7.74
14	37.0	13.90	2308	0.00043	32081.20	0.006	0.00004	0.00091	29.11	2.09
15	51.4	35.60	8713	0.00011	310182.80	0.004	0.00011	0.00091	281.42	7.91
16	77.6	48.10	2680	0.00037	128908.00	0.018	0.00014	0.00091	116.96	2.43
17	26.5	44.2	30809	0.00003	1361757.80	0.001	0.00013	0.00901	1239.20	28.04
18	90.0	42.00	11044	0.00009	463848.00	0.004	0.00013	0.00091	420.84	10.02

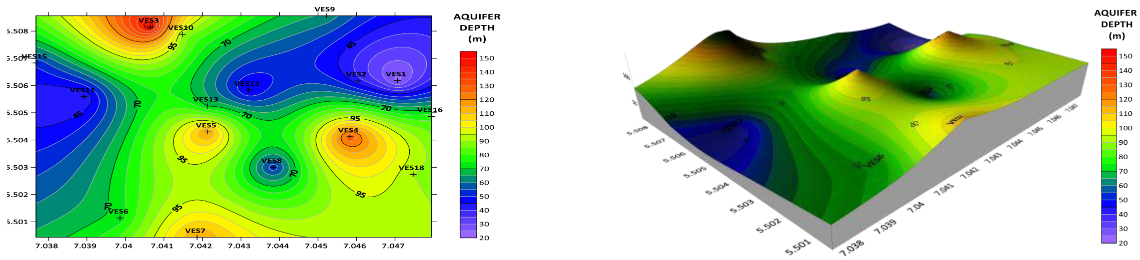


Figure 4: 2D & 3D spatial variation plots of aquifer depth of the study area

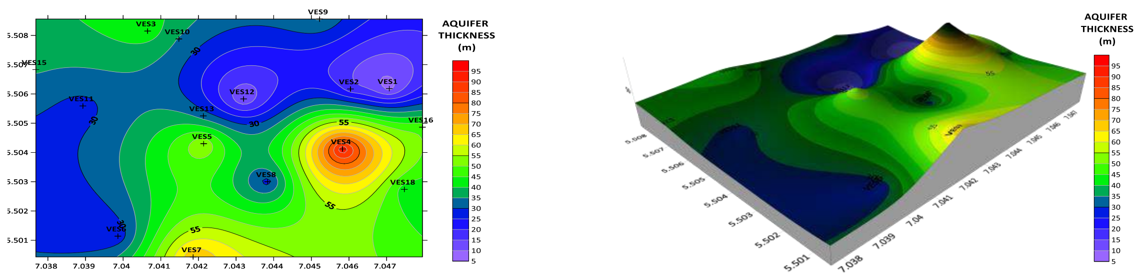


Figure 5: 2D & 3D spatial variation plots of aquifer thickness of the study area

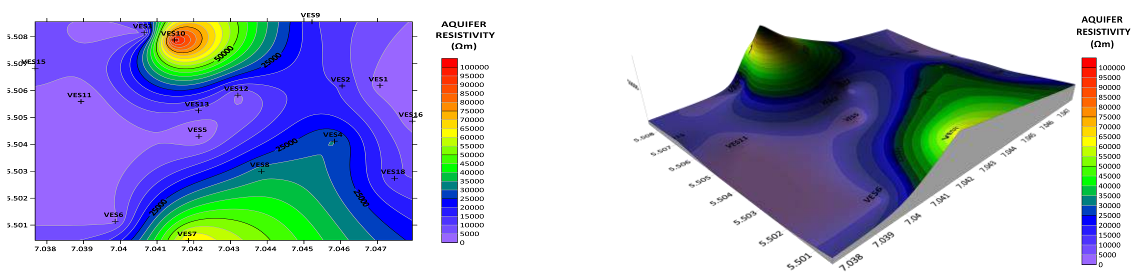


Figure 6: 2D & 3D spatial variation plots of aquifer resistivity of the study area

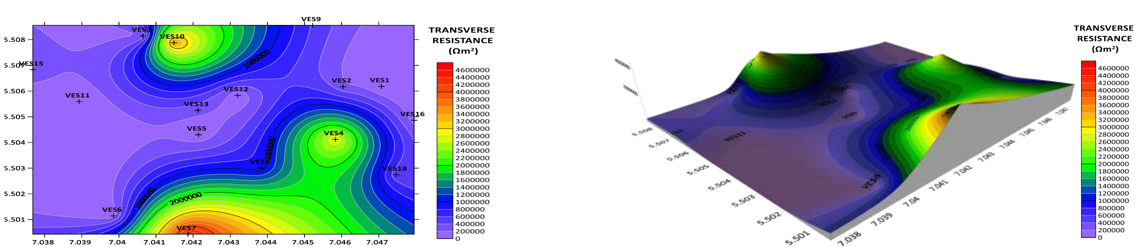


Figure 7: 2D & 3D spatial variation plots of transverse resistance of the study area

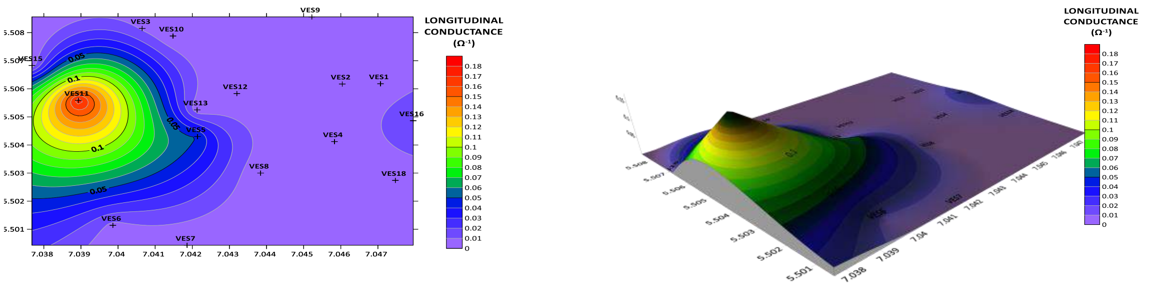


Figure 8: 2D & 3D spatial variation plots of longitudinal conductance of the study area

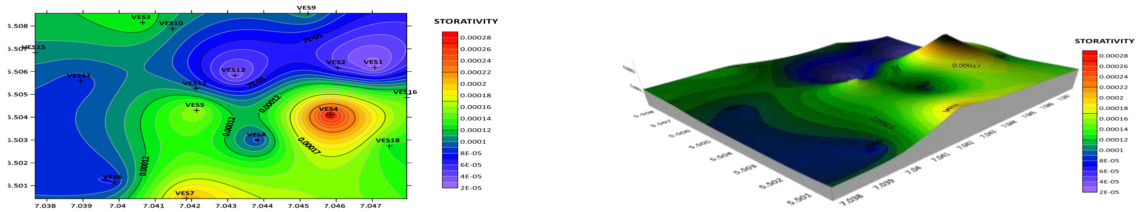


Figure 9: 2D & 3D spatial variation plots of storativity of the study area

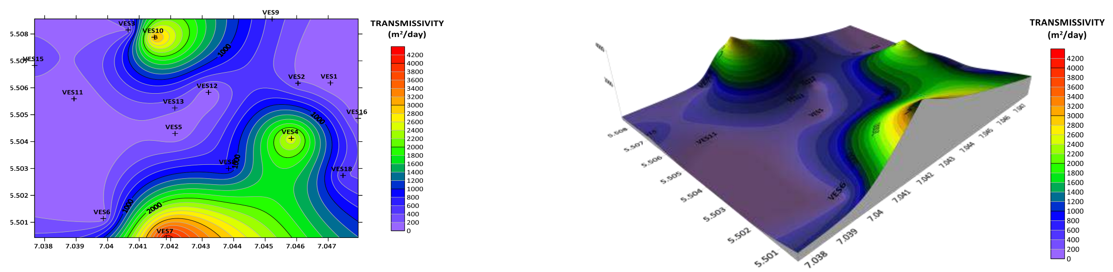


Figure 10: 2D & 3D spatial variation plots of transmissivity of the area

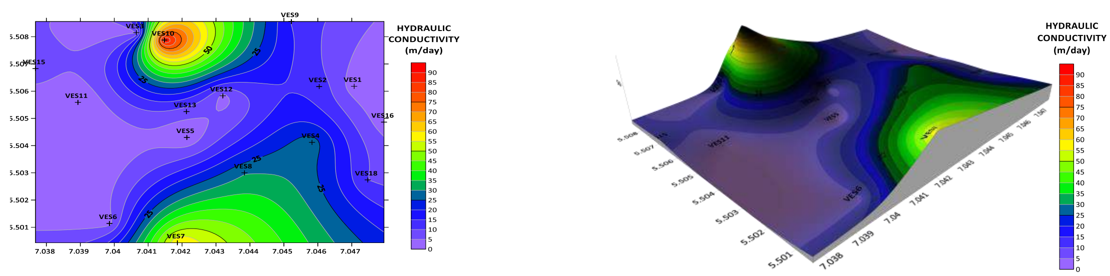


Figure 11: 2D & 3D spatial variation plots of hydraulic conductivity of the area

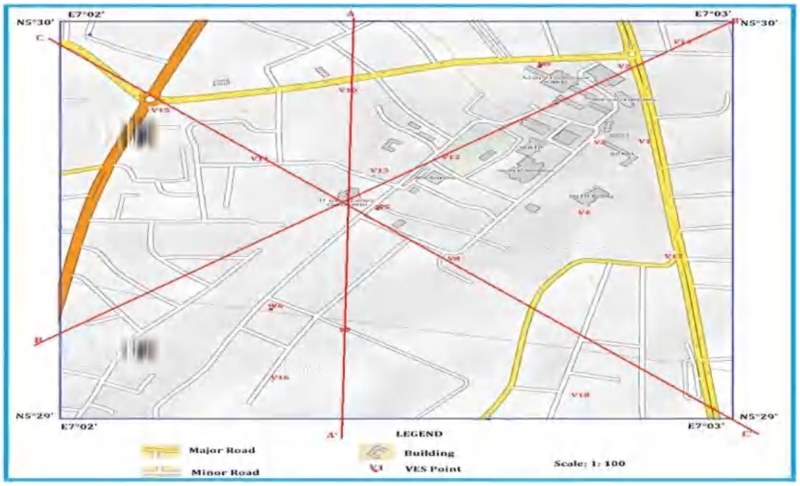


Figure 12: VES points, locations and profiles across the study area

The results of subsurface stratification of the study area are shown by Figures 13, 14 and 15 corresponding to the geoelectric interpretative cross-section along profile lines A-A', B-B', and C-C' (Figure 12). These show that the subsurface stratification is underlain by alternation of sandstone/gravel, silty sand/sand and clay with geology representing the Benin Formation signature. The cross-sections revealed the irregular nature of the depth to the top of the aquifer in the area. The cross-sections also show that boreholes drilled at different points in the area will encounter the main aquifer at different depths in the subsurface. Groundwater was delineated within the zone interpreted to be sand with quartz making up more than 95% of all grains.

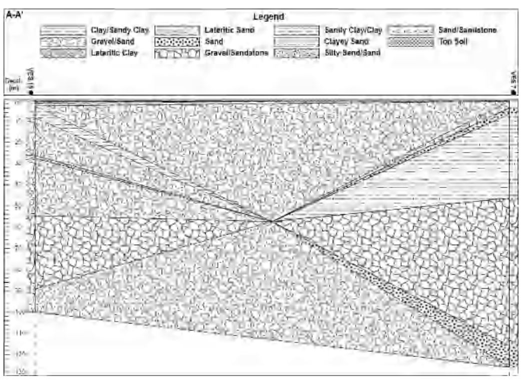


Figure 13: Interpretative Cross Section across profile A-A'

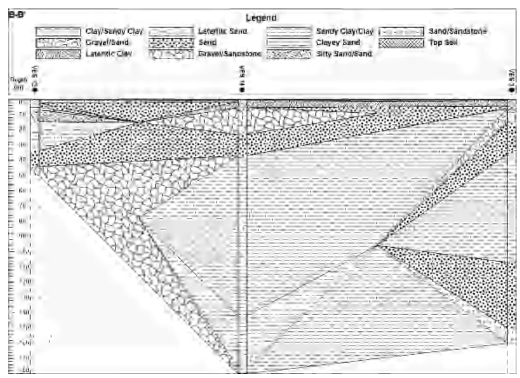


Figure 14: Interpretative Cross Section across profile B-B'

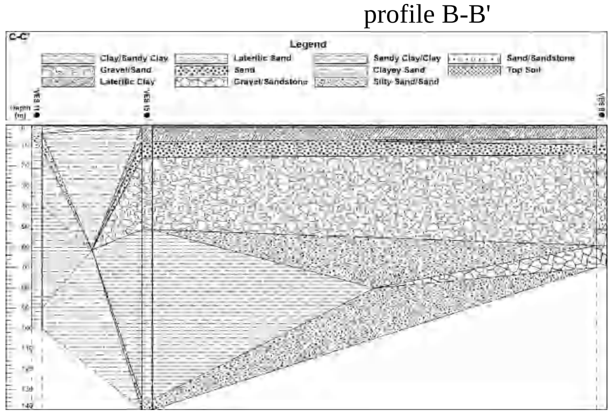


Figure 15: Interpretative Cross Section across profile C-C'

The modelled VES results show that the study area is underlain by gravel, sandstones and sands with some clay and sandy clay intermingled. Table 2 is the summary of aquifer characteristics for all the sounding points. The aquifer is delineated within the sand/sandstone formation. The resistivity of the aquifer varies across the study area and ranges from 159Ωm observed around Department of Library and Information (VES11) to 100000Ωm recorded at IMSU Plaza (VES 100). The low resistivity (high conductivity) observed at Department of Library and Information could be due to the presence of highly conductive clayey material or highly saturated aquifer.

The depth to water table also varied across the study area (Figure 6) with higher values of 150m and 130m observed at College of Health Science (VES 3) and Behind Old ETF (VES 4) respectively. Thus high drill depths are required for standard water well in such area (Nwosu and Ndubueze, 2017). A relatively shallow aquifer is delineated behind Senate Building and Okwu-Uratta with water table at depths of 23.5m and 26.5m respectively. Figure 7 shows the variation of aquifer thickness in the study area. Figure 12 reveals the variation of transmissivity within the study area. Areas with high aquifer thickness have corresponding high transmissivity values as transmissivity is a function of aquifer thickness (Nwosu and Ndubueze, 2016). Such areas have good prospect for groundwater exploitation (Nwosu and Nwosu, 2017; Nwosu and Nwankwo, 2016). The transmissivity values are moderately high except at some locations in the study area.

The Dar-Zarrouk parameters of transverse resistance and longitudinal conductance determined for the study area showed variation across the study area (Table 2). These parameters have shown to be very powerful interpretational aid in groundwater survey (Zhody, 1965; Niwas and Singhal, 1981). The variation in longitudinal conductance values show that part of the study area such as Aso Rock, Female Hostel, Law Faculty and IMSU Plaza are underlain by relatively resistive (low longitudinal conductance) aquifer material. These areas may not be good prospects for drilling of boreholes with high yield expectations (Mbonu *et al.*, 1991).

The distribution of hydraulic conductivity and electrical conductivity values also displayed in Table 2 indicates that in some of the VES points, the values are fairly constant. These locations include VES 6 and 12, VES 13 and 15, VES 4, 8 and 17, and VES 1, 14 and 16. This could be interpreted as areas with similar geologic setting and water quality (Niwas and Singhal, 1981).

The storativity of the study area ranges from 0.00003 at VES 1 and 12 to 0.00028 at VES 4. This defines the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

CONCLUSION

The groundwater potential of the study area has been investigated recently using geoelectrical sounding. The subsurface stratification of the study has been delineated and the aquifer horizon mapped out. The study was carried out to avoid drilling unproductive borehole and low yield borehole in the area. The results revealed subsurface stratigraphy with geoelectrical units, including the topsoil (clay), gravel, confining bed (clay) and the main aquifer (sand). The study area shows a good prospect for borehole drilling except at Department of Library and Information which is not a good aquifer. Total drill depth for standard well required for groundwater development should not be less than 170m around College of Health Science, Behind Old ETF, In front of Catholic church and Female Hostel while the total drill depth should not be less than 110m at other locations. The knowledge of the total drill depth for standard water well determined in this study will in no doubt help to reduce the time, cost and materials wasted in drilling private water wells without pre-drilling geophysical survey, which might prove abortive. The results of this study will reduce the difficulty in groundwater development in the study area.

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REFERENCES

Abdullahi, M.G., Toriman, M.E., Gasim, M.B. (2015). The Application of Vertical Electrical Sounding (VES) for Groundwater Exploration in Tudun Wada Kano State, Nigeria. *J. Geol. Geosci.*, **4**: 186.

Amadi, A.N. (2009). Physicochemical and bacteriological evaluation of groundwater in parts of Aba, Abia State, southeastern, Nigeria. *International Journal of Applied Biological Research*, **1**(1): 63-71.

Lohman, S.W. (1972). Groundwater hydraulics. U.S. Geological Survey Professional Paper. http://doi.org/10.3133//pp.708.

Loke, M. H. (2000). "Topographic modeling in resistivity imaging inversion". 62nd EAGE Conference & Technical Exhibition Extended Abstracts, D-2.

Mbonu, D.D.C., Ebeniro, J.O., Ofoegbu, C.O and Ekine, A.S. (1991). Geoelectrical sounding for determination of aquifer characteristics in Umuahia area of Nigeria .Geophysics.

Niwas, S. and Singhal, D.I. (1981). Estimation of aquifer transmissivity from Dar-Zarouk parameters in porous media. *Journal of Hydrology*, pp. 394-400.

Nwosu I. E. and Chinaka J. C. (2021). Evaluation of Aquifer Potential and Vulnerability of Mbaitoli/Ikeduru Area, Southeastern Nigeria, Using Direct Current Electricity Data. *Journal of Research in Environmental and Earth Sciences*, **7**(12):01-11, ISSN (Online):2348-2532

Nwosu, L.I. and Ndubueze, D.N. (2016). Groundwater prospect for siting productive water borehole using transmissivity values determined from pumping test and surface geoelectric sounding data in parts of the Sedimentary Area of Southeastern Nigeria. *Indian Journal of Applied Research* **6(**11):113-118.

Nwosu, L.I. and Ndubueze, D.N. (2017). Geoelectric investigation of water table variation with surface elevation for mapping drill depths for groundwater exploitation in Owerri metropolis, Imo State, Nigeria. I*nternational Journal of Science and Research Methodology*, **5**(4):40-54.

Nwosu, L.I. and Nwankwo, C. N. (2016). Surface geoelectric survey for delineating aquifer horizon for siting standard water wells in water petroleum area of Imo State, southeastern Nigeria. *Indian Journal of Applied Research*, **6**(10):271-275.

Nwosu, L.I. and Nwosu, B.O. (2017). Groundwater exploration for sustainable water supply development in the rural communities of Imo State in the Imo River Basin, Nigeria. *Indian Journal of Applied research*, pp. 791-795. http://dx.doi.org/10.1190/1.1443042. 30-290.

Okechukwu Mbaeze (2023). Groundwater resources in Owerri: Quality assessment and management consideration. Orvium Community.

Onyeagocha, A.C. (1980). Petrography and depositional environment of the Benin Formation, Nigeria. *Journ. Min. Geol.*, 17, pp.147-151.

Oyeyemi, K.D., Aizebeokhai, A.P., Sanuade, O.A. (2019). Geological-geophysical investigations for hydrological studies in a basement complex terrain, southwestern Nigeria. In: Chamine, H.I., et al. (Eds.), Advances in Sustainable and Environmental Hydrology, Hydrogeology, Hydrochemistry and Water Resources, Advances in Science, Technology and Innovation. Springer. https://doi.org/10.1007/978-3-0-1572-5_58.

Reyment, R.A. (1965). Aspects of the geology of Nigeria, Ibadan University Press, pp. 147.

Sunmonu L.A., Adagunodo, T.A., Olafisoye, E.R .and Oladejo, O.P. (2012). The groundwater potential evaluation at industrial estate Ogbomoso, Southwestern Nigeria. *Materials and Geoenvironment*, **59**(4):363–390.

Todd, D.K. (1980). Groundwater hydrology (2nd ed.). New York, NY: Wiley.

Uma, K.O. and Egboka, B.C.E (1985). Water resources of Owerri and its environs, Imo State, Nigeria. *Journ. Min. Geol.*, **22**(1-2):57-64.

Zhody, A.A.R. (1965). The auxiliary point method of electrical sounding interpretation and its relationship to the Dar-Zarrouk parameters. *Geophysics*, pp. 645-665.