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RESEARCH ARTICLE

ASSESSMENT OF GEO-HYDRAULIC PROPERTIES OF AQUIFER REPOSITORIES, IN PARTS OF NSUKKA REGION, ENUGU STATE, NIGERIA

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ABSTRACT

A geoelectric investigation was conducted using the vertical electrical sounding (VES) method across 21 locations in the Nsukka region of Enugu State, Nigeria. The study aimed to characterize the hydraulic properties of the subsurface aquifer units. The results delineated a stratigraphic sequence of five to six geoelectric layers within the surveyed depth. Key aquifer parameters were derived, with resistivity ranging from 156.8 to 32,698.2 Ωm and thickness varying between 15.3 and 159.7 m. These primary parameters were used to compute essential geohydraulic properties. The calculated values include: porosity (26.45–31.21%), hydraulic conductivity (0.0237–3.478 m/day), transmissivity (1.6056–153.6256 m^2/day), and formation factor (0.0029–0.037). Additionally, the Dar Zarrouk parameters - longitudinal conductance (0.0023–0.2783 Ω^{-1}) and transverse resistance (2712.64–3,841,839.0 Ωm^2) were determined. Spatial contour maps of these properties revealed their variation across the study area, enabling the identification of zones with the most prolific aquifer potential. This study successfully characterizes the geo-hydraulic framework of the local aquifer system. The findings provide a critical foundation for sustainable groundwater management and development in the region, with applicability to other areas of similar geology.

KEYWORDS

aquifer, geoelectric layers, VES, transmissivity, porosity

1. INTRODUCTION

Groundwater serves as a vital and relatively safe water source, benefiting from natural protection against contamination by overlying layers and typically requiring minimal treatment (George et al., 2015). Although groundwater represents the largest freshwater resource globally, its exploitation remains uneven—underutilized in some regions and over-extracted in others. In Nsukka, Enugu State, communities experience persistent water shortages and challenges in accessing groundwater through drilling (Ossai et al., 2020; Omeje et al., 2022). Residents face acute scarcity, particularly during dry seasons, exacerbated by the absence of perennial surface water bodies such as streams, rivers, ponds, or lakes. Consequently, the population relies almost entirely on borehole water for domestic, agricultural, and industrial needs (Ezeh and Ugwu, 2010; Ugwuanyi et al., 2015; Obiora and Ibuot, 2020). However, boreholes in the area are scarce, with many non-functional from installation or failing after limited use (Omeje et al., 2021). A key constraint to sustainable groundwater development is the limited understanding of local hydrogeological conditions, which is essential for effective abstraction and management.

Understanding aquifer geohydraulic properties is critical for assessing aquifer behavior, sustainability, and recharge dynamics. Such knowledge supports effective groundwater management, promotes sustainable supply, and helps mitigate risks like over-extraction, contamination, and land subsidence. Rainfall infiltration and aquifer recharge vary spatially due to differences in geological materials, significantly influencing aquifer storage, discharge, and geohydraulic parameters. Groundwater moves through fractures and pore spaces within aquifers, where it can be

abstracted for use (Akpan et al., 2006; Martinez et al., 2008; Ibuot et al., 2019; Obiora et al., 2020). The availability of groundwater is influenced by surface and subsurface geology, climate, and the porosity and permeability of geological formations, which govern storage and transmission capacity (George et al., 2022; Daniel et al., 2022).

Aquifer recharge and discharge vary due to climatic factors, especially in sedimentary regions with high rainfall (Hashemi et al., 2015). Spatial variability is further influenced by soil type, groundwater depth, porosity, hydrogeology, and precipitation patterns. Recharge is affected by rainfall variability and human activities, including unsustainable groundwater abstraction. Variations in aquifer characteristics—linked to anthropogenic factors, aquifer thickness, and material properties—can contribute to borehole failures, with negative environmental consequences. Changes in temperature and precipitation directly impact the hydrological cycle. Fluctuations in groundwater levels reflect the effects of rainfall variability and may lead to declines in groundwater quantity and quality. Since aquifers are primarily recharged by precipitation or interaction with surface water, seasonal rainfall variations directly affect groundwater reserves (Brouyere et al., 2007; Holman, 2006). Variability in subsurface materials also influences aquifer storage and transmissivity (Ibuot et al., 2019; George et al., 2015).

In geophysical surveys, measurements taken at or near the surface reflect the distribution of subsurface physical properties. The electrical resistivity method is particularly suited for studying aquifers, as it performs well in rugged terrain—unlike seismic methods—and provides distinct subsurface geological insights valuable for groundwater exploration (Telford et al., 1990; Lowrie, 1997; George et al., 2017). Key geohydraulic properties—such as aquifer resistivity, transmissivity, hydraulic

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conductivity, porosity, and longitudinal conductance—govern an aquifer’s transmission capability. These parameters vary seasonally and spatially, aiding in identifying zones of uneven groundwater distribution. This study aims to delineate aquifer layers, assess their properties, and map variations in geohydraulic characteristics and groundwater potential across Nsukka. The findings will provide guidance for sustainable borehole siting in rural communities and inform future groundwater abstraction, development, and management strategies.

1.1 Location and Geology of the study area

The study area is situated within latitudes 6.0°N to 7.0°N and longitudes 7.10°E to 7.50°E, encompassing parts of the Nsukka, Igbo-Eze North, and Igbo-Eze South Local Government Areas in Enugu State (Figure 1). Topographically, the region is characterized by undulating terrain with elevations exceeding 250 meters above sea level. Accessibility is provided by a network of major and minor roads, as well as numerous footpaths. Two predominant landforms define the area: a high-relief zone featuring undulating residual hills and valleys, and lowland areas. These geomorphic features result from the weathering and differential erosion of clastic materials, which are remnants of the Nsukka Formation and

constitute the surface layers (Ofomata, 1967).

Geologically, the area lies within the Anambra sedimentary basin, which contains Upper Cretaceous-age rocks. The primary formations are the upper Nsukka Formation and the underlying Ajali Sandstone (Figure 1). The Ajali Sandstone, composed of medium- to coarse-grained, typically white sandstone (sometimes iron-stained), is highly permeable. This permeability facilitates effective water percolation to the groundwater table during the rainy season, particularly within its outcrop belt along the Idah-Nsukka-Enugu escarpment (Agagu et al., 1985).

The Nsukka Formation possesses significant groundwater potential, hosting numerous low- to moderate-yield wells in the region. It also gives rise to several perched aquifers, which supply a number of low-yield wells (Ezeigbo and Ozioko, 1987). The area’s laterite capping is aquiferous due to its vesicular, porous, and permeable nature. In some locations, these lateritic caps overlie less permeable clay beds, forming perched aquifers. However, in many areas, erosion has removed the laterite cap and the underlying clay layer, preventing the development of such perched aquifers.

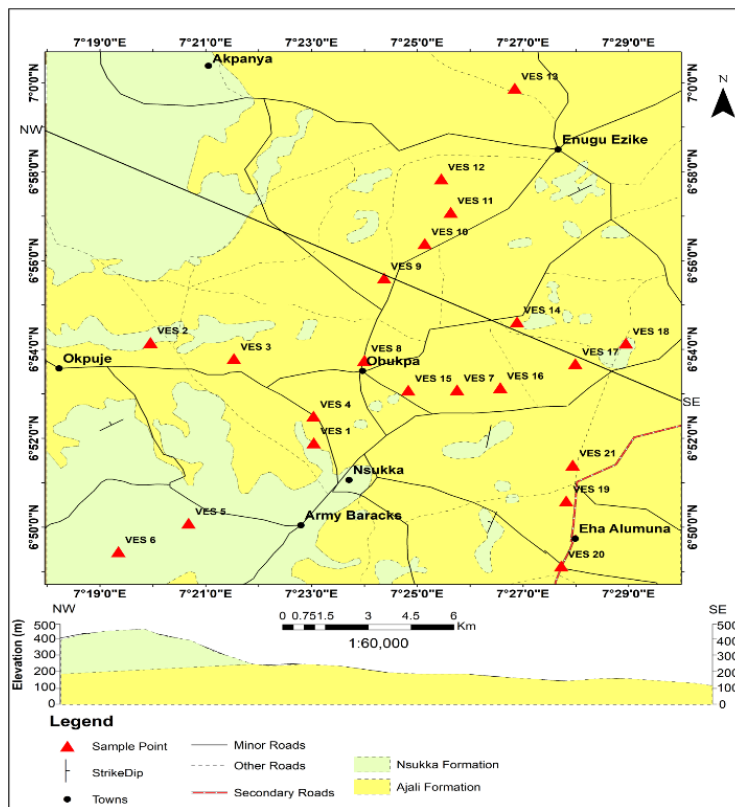


Figure 1: Geologic map of the study area

2. MATERIALS AND METHODS

This study employed the Vertical Electrical Sounding (VES) technique using the Schlumberger electrode configuration. Data were collected along relatively straight profiles. A total of twenty-one VES points were surveyed, ensuring broad spatial coverage of the designated study area. The total profile length for each sounding determined the maximum current electrode separation (AB) for that specific measurement.

Subsurface potential differences were measured between two inner potential electrodes (M and N). The initial configuration used a potential electrode separation (MN) of 0.5 meters, with each electrode placed 0.25 meters from the central point. The corresponding current electrode separation (AB) was set at 2.0 meters, meaning each current electrode was positioned 1 meter from the center. All four electrodes were connected to the resistivity meter via copper cables: the potential electrodes to terminals P1 and P2, and the current electrodes to terminals C1 and C2.

The study employs Schlumberger electrode configuration with vertical electrical sounding (VES) for twenty-one soundings using the IGIS Resistivity meter model SSR-MP-ATS. The half current electrodes spread $\left(\frac{AB}{2}\right)$ and half potential electrodes spread $\left(\frac{MN}{2}\right)$ ranged from 1.0 – 450.0m and 0.25 – 20.0m respectively. Equation 1 was used to calculate the apparent resistivity (ρ_a).

$$\rho_a = G \cdot R_a \tag{1}$$

where G is the geometric factor $:\pi \cdot \left[\frac{(AB)^2 - (MN)^2}{MN}\right]$ and R_a is the apparent resistance.

The data were processed to create one-dimensional geological models using both manual techniques and computer-assisted modeling (Zohdy, 1965; Zohdy et al., 1974). Computed apparent resistivity values were plotted against half the current electrode spacing (AB/2) on bi-logarithmic graphs. The resulting curves were smoothed to minimize noise and mitigate distortions from lateral heterogeneities (Chakravarthi et al., 2007; Akpan et al., 2006).

Curve matching was performed using standard master curves and charts following the method by Orellana and Mooney (1966). The apparent resistivity values were also input into the computer software WinResist for automated modeling. This software generated a set of geoelectric curves (Figures 2 and 3), from which the resistivity, thickness, and depth of each subsurface layer were derived. The resulting curves reveal significant variations in resistivity, layer thickness, and depth—both between different subsurface layers and within individual layers—indicating heterogeneous geological conditions beneath the survey points.

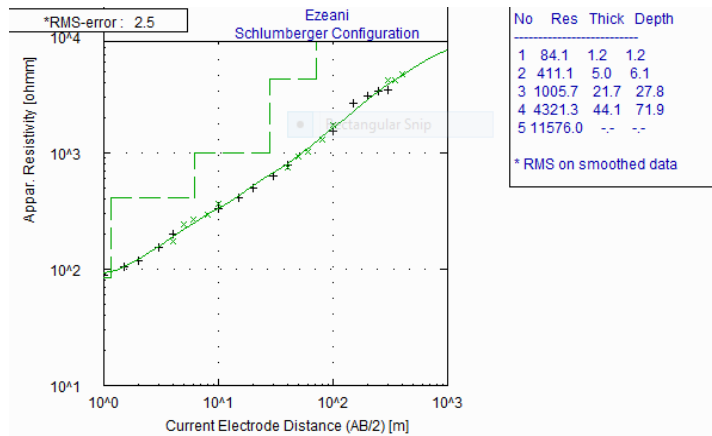


Figure 2: Goelectric curve at VES 4

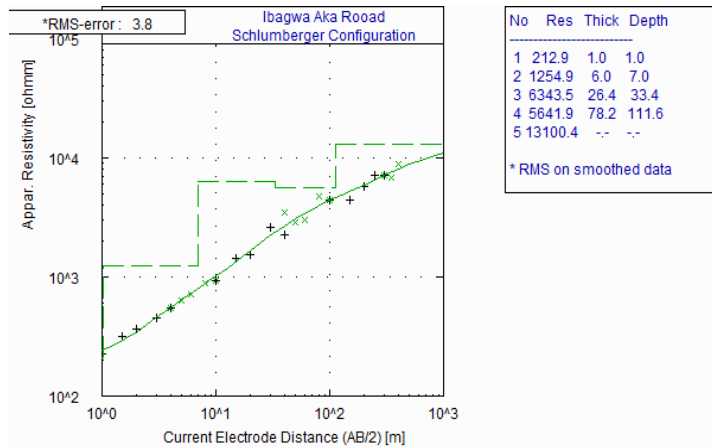


Figure 3: Goelectric curve at VES 9

Geohydraulic parameters are critical for quantifying and characterizing aquifer units. These parameters enable the assessment of groundwater potential, vulnerability, and the natural flow of water through an aquifer. In this study, the analyzed parameters include hydraulic conductivity (K), transmissivity (Tr), porosity (Φ), the formation factor, and Dar Zarrowk parameters - specifically longitudinal conductance and transverse resistance.

Hydraulic Conductivity (K) is a key property that defines an aquifer's dynamic behavior and controls the ease of groundwater movement. It significantly influences borehole yields and the velocity of contaminant transport. For this study, hydraulic conductivity was estimated using Equation 2 (Ibuot et al., 2019), which incorporates porosity and other site-specific variables.

$$K = 386.42\rho_a^{-0.933} \tag{2}$$

where ρ_a is the aquifer resistivity.

Porosity (ϕ) is the volume of open space (pore space) in rocks in relation to the total rock volume. As the drainable pore space, it can be estimated using equation 3 according to Ibuot et al. (2019). It is a rock property that determines aquifer productivity and depends not only on the grain composition of rocks, but also on the way the rocks are formed and the pressure to which rocks are exposed.

$$\phi = 36.51\rho_a^{-0.031} \tag{3}$$

where ρ_a is the aquifer resistivity, and ϕ in %.

The formation factor (F) quantifies the influence of pore structure on the electrical resistance of an aquifer material. It serves as a valuable parameter for predicting pore geometry, permeability, and the extent of mineralogical effects such as cementation and compaction. This factor can be estimated using Equation 4, which involves the resistivity of the bulk aquifer material (ρ_b) and the resistivity of the pore water (ρ_w). The flow of electrical current through a geologic formation is governed by aquifer properties including porosity (ϕ), pore shape, and diagenetic cementation. According to Archie's law (Archie, 1942), this relationship is expressed in Equation 5.

$$F = \frac{\rho_b}{\rho_w} \tag{4}$$

$$F = a \cdot \phi^{-m} \tag{5}$$

where a is the pore geometry factor and m is the cementation factor with their average values given as 0.5 and 1.5 respectively. The geometry factor indicates the influence of mineral grains on current flow and takes into account the contribution of mineral grains to electrical conductivity.

Transmissivity (Tr) is the rate at which groundwater flows through a saturated aquifer unit under a standard hydraulic gradient. It is an intrinsic property of both the fluid and the aquifer material, and is directly dependent on hydraulic conductivity. The relationship between transmissivity and the Dar-Zarrowk parameters, as established by Niwas and Singhal (1981), is given in Equation 6. Transmissivity is calculated as the product of the estimated hydraulic conductivity (K) and the aquifer thickness (h), as shown in this equation.

$$Tr = K\sigma T = \frac{KS}{\sigma} = Kh \tag{7}$$

where T and S are the transverse resistance and longitudinal conductance respectively and are calculated using equations 8 and 9.

$$S = \frac{h}{\rho} \tag{8}$$

$$T = h\rho \tag{9}$$

where h and ρ are the values of aquifer thickness and resistivity respectively.

Longitudinal Conductance (S) is utilized to assess aquifer vulnerability. The protective capacity of aquifer layers, as indicated by their longitudinal conductance values, is classified into categories ranging from poor, weak, and moderate to good (Henriet et al., 1976; Oladapo et al., 2004). Transverse Resistance (T), a geophysical parameter, is defined as the product of aquifer resistivity (ρ) and thickness (h), as shown in Equation 9. Within the saturated zone of the aquifer, transverse resistance helps delineate the most favorable and productive areas, thereby serving as a key criterion for hydrogeological exploration.

3. RESULTS AND DISCUSSION

The quantitative analysis of twenty-one (21) vertical electrical sounding (VES) stations provided subsurface data on resistivity, thickness, and depth for the lithofacies encountered within the maximum electrode

spacing (Table 1). Interpreted results from these soundings established a stratigraphic sequence of five to six distinct geoelectric layers across the study area. The top layer, with a resistivity range of 83.4 to 1277.4 Ωm , is interpreted as lateritic sand, typically unsaturated and consisting of sand with variable clay content. This unit facilitates rainwater percolation into underlying strata. Its thickness varies from 0.4 to 2.3 m, with a corresponding depth range of 0.4 to 2.3 m. The second geoelectric layer exhibits a wide resistivity range of 17.4 to 9395.9 Ωm , indicative of medium to high resistivity materials. This suggests a lithology of medium-to-coarse brownish sand intercalated with clay, which is generally less conductive than the overlying layer. Layer thickness varies from 1.5 to

14.6 m, and depth ranges from 2.5 to 15.0 m. Underlying this is a third layer characterized by high resistivity (111.3 to 6343.5 Ωm) and interpreted as unsaturated coarse sand to coarse pebbly blackish sand, exhibiting lower conductivity than overlying units. Its thickness ranges from 2.7 to 54.6 m, with depths between 5.2 and 59.1 m. The fourth layer, hosting most identified aquifers, displays very high resistivity values from 204.8 to 24,519.8 Ωm . It ranges in thickness from 15.3 to 571.0 m and occurs at depths between 9.6 and 576.2 m. The fifth layer shows resistivity values from 990.5 to 34,863.15 Ωm , with thickness and depth generally undefined except at VES 18 and VES 19, where a sixth layer was identified.

Table 1: Summary of interpreted VES data

VES	Location	Longitude (°E)	Latitude (°N)	Layer Resistivity (Ωm)						Thickness (m)					Depth (m)					Elevation(m)
				ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5	d_1	d_2	d_3	d_4	d_5	
1	Isuija Nsukka	7.3843	6.8634	279.1	387.6	2348.9	4623.4	990.5	-	1.6	3.5	5.3	83.8	-	1.6	5.1	8.2	14.0	-	405
2	Ibagwa Aka	7.3323	6.9005	163.2	871.0	928.6	8823.4	1039.9	-	1.8	7.9	1.5	80.4	-	1.8	9.7	2.2	10.6	-	285
3	Isuija Nsukka Amaobo	7.3586	6.8948	306.5	68.9	145.8	1703.8	34863.1	-	1.8	6.8	9.1	15.3	-	1.8	8.7	1.7	33.1	-	315
4	Ezeani	7.3863	6.8676	84.1	411.1	1005.7	4321.3	11576.0	-	1.2	5.0	2.7	44.1	-	1.2	6.1	2.8	71.9	-	389
5	Ezeani 2	7.3443	6.8327	127.4	884.5	1531.1	156.8	2100.7	-	0.7	3.9	4.4	17.3	-	0.7	4.6	9.0	26.3	-	440
6	Ezeani Road	7.3227	6.8231	950.0	9395.9	1071.3	204.8	6471.6	-	0.9	3.4	4.4	57.0	-	0.9	4.2	5.6	11.6	-	438
7	Owerre Obukpa	7.4295	6.8843	128.7	521.2	3452.1	15672.2	21784.9	-	0.7	8.6	1.5	57.9	-	0.7	9.3	2.5	82.4	-	407
8	Onuama Umuorua Obukpa	7.4003	6.8949	513.0	760.5	5073.7	32698.2	5408.8	-	1.7	6.7	1.8	78.2	-	1.7	8.4	2.3	10.5	-	386
9	Ibagwa Aka Road	7.4065	6.9247	212.9	1254.9	6343.5	5641.9	13100.4	-	1.0	6.0	2.4	78.5	-	1.0	7.0	3.4	11.6	-	355
10	Ibagwa Aka Road 2	7.4193	6.9371	697.9	1575.2	5759.0	3821.0	3138.7	-	1.2	1.0	4.1	80.1	-	1.2	1.3	5.4	13.3	-	306
11	Ibagwa Aka Road 3	7.4275	6.9493	389.4	3428.0	6078.6	13612.9	7569.9	-	1.0	8.7	3.8	72.4	-	1.0	9.6	4.4	11.7	-	342
12	Comp. Sec. Sch.	7.4345	6.9603	100.8	496.5	4426.9	7865.5	3656.3	-	0.4	1.6	2.5	53.0	-	0.4	1.0	4.0	93.0	-	351
13	Opp.Edu Benz	7.4482	6.9964	205.8	996.7	4217.9	22170.7	14115.0	-	0.8	1.1	1.9	60.3	-	0.8	1.9	2.8	84.0	-	338
14	Umuagama	7.4484	7.0093	972.4	1918.9	4310.0	13842.7	1766.5	-	2.3	2.8	6.1	11.1	-	2.3	5.1	1.3	12.4	-	337
15	Umu-akenyi Owerre Obukpa	7.4141	6.8831	160.3	388.0	4296.6	24056.6	8490.5	-	0.9	6.1	1.3	15.7	-	0.9	7.1	2.3	18.1	-	397
16	Amadim Hall Ovoko	7.4426	6.8846	123.4	17.4	1547.6	1021.0	6505.2	-	1.0	1.5	2.7	57.0	-	1.0	2.5	5.2	57.2	-	404

Table 1 (cont): Summary of interpreted VES data																				
17	Adani	7.4668	6.8936	83.4	500.5	772.0	24519.8	8220.1	-	0.6	2.7	4.9	95.8	-	0.6	3.3	8.2	104.0	-	425
18	Adani Iheakpu Obollo	7.4822	6.9008	305.2	877.3	785.2	2184.5	9801.1	5754.9	1.2	3.8	14.8	9.6	22.0	1.2	5.0	19.7	29.3	51.3	437
19	Timber market Orba	7.4634	6.8416	390.6	23028.2	1733.7	445.6	3221.4	654.5	0.4	2.7	4.0	21.7	120.7	0.4	3.1	7.1	28.8	149.5	452
20	Orba Road	7.3459	6.8170	873.4	2676.8	3464.1	6234.0	7596.6	-	0.7	5.0	29.5	71.0	-	0.7	5.7	35.2	106.2	-	369
21	CDU	7.4665	6.9556	127.0	77.5	111.3	985.3	5672.6	-	1.0	3.5	54.6	38.9	-	1.0	4.6	59.1	98.0	-	449

The aquifer resistivity and thickness, derived from Table 1, served as primary inputs for computing the geohydraulic parameters presented in Table 2. Aquifer resistivity ranges from 156.8 Ωm (VES 5) to 32,698.2 Ωm (VES 8), while aquifer thickness varies from 15.3 m (VES 3) to 159.7 m (VES 15). This wide variability in resistivity can be influenced by factors such as pore geometry, sediment density, porosity, pore size, water quality, and degree of saturation. The significant resistivity range is likely due to subsurface heterogeneity and the compact geological nature of the area. These results indicate that the aquifer system is primarily composed of medium- to high-resistivity sandy materials.

The spatial distribution of aquifer resistivity is illustrated in the contour map (Figure 4), which shows the highest values concentrated in the central portion of the study area, decreasing radially toward the northern and southern extents. These variations are attributed to differences in pore-water distribution resulting from the structural and textural properties of the aquifer units (Ibuot et al., 2019; Ossai et al., 2020). Lower

resistivity values at certain VES points are likely associated with higher clay content, which may correspond to zones of lower permeability and reduced groundwater potential. Aquifer thickness variations are displayed in Figure 5. The thickest aquifers are located in the southeastern and northwestern regions. This suggests that areas with greater aquifer thickness are likely to host more prolific aquifers with substantial groundwater storage capacity (Ezema et al., 2020).

Porosity, representing the drainable pore space within the aquifer, ranges from 26.45% to 31.21%. These values are characteristic of sandstone and gravel-dominated lithologies, consistent with established classifications (Roscoe, 1990; Driscoll, 1986). The porosity distribution map (Figure 6) shows higher values in the southwestern part of the study area. Notably, regions with lower resistivity exhibit correspondingly lower porosity. This inverse relationship suggests that porosity decreases as clay content increases within the sand-clay matrix (George et al., 2015).

Table 2: Computed aquifer geo-hydraulic parameters from measured resistivity and thickness													
S/N	VES Stations	Longitude (°E)	Latitude (°N)	ρ_a (Ωm)	h_a (m)	d_a (m)	ϕ (%)	K (m/day)	Tr (m ² /day)	F	S(Ω ⁻¹)	T(Ωm ²)	Elevation (m)
1	Isuija Nsukka	7.3843	6.8634	4623.4	83.8	142.0	28.11	0.1471	12.3280	0.0034	0.0181	387440.9	405
2	Ibagwa Aka	7.3323	6.9005	8823.4	80.4	101.6	27.55	0.0805	6.4720	0.0035	0.0091	709401.4	285
3	Isuija Nsukka Amaobo	7.3586	6.8948	1703.8	15.3	33.1	28.99	0.3734	5.7127	0.0032	0.0090	26068.14	315
4	Ezeani	7.3863	6.8676	4321.3	44.1	71.9	28.17	0.1567	6.9099	0.0034	0.0102	190569.3	389
5	Ezeani 2	7.3443	6.8327	156.8	17.3	26.3	31.21	3.4578	59.8202	0.0029	0.1103	2712.64	440
6	Ezeani Road	7.3227	6.8231	204.8	57.0	110.6	30.96	2.6952	153.6256	0.0029	0.2783	11673.6	438
7	Owerre Obukpa	7.4295	6.8843	15672.2	57.9	82.4	27.06	0.0471	2.7270	0.0036	0.0037	907420.4	407
8	Onuama Umuorua Obukpa	7.4003	6.8949	32698.2	78.2	101.5	26.45	0.0237	1.8545	0.0037	0.0024	2556999	386
9	Ibagwa Aka Road	7.4065	6.9247	5641.9	78.2	111.6	27.93	0.1222	9.5540	0.0034	0.0139	441196.6	355
10	Ibagwa Aka Road 2	7.4193	6.9371	3821.0	80.1	134.3	28.27	0.1758	14.0774	0.0033	0.0210	306062.1	306
11	Ibagwa Aka Road 3	7.4275	6.9493	13612.9	72.4	114.7	27.18	0.0537	3.8889	0.0035	0.0053	985574	342

Table 2 (cont): Computed aquifer geo-hydraulic parameters from measured resistivity and thickness													
12	Comp. Sec. Sch.	7.4345	6.9603	7865.5	53.0	93.0	27.6 5	0.0896	4.7492	0.003 4	0.006 7	416871. 5	351
13	Opp.Edu Benz	7.4482	6.9964	22170. 7	60.3	84.0	26.7 7	0.0341	2.0548	0.003 6	0.002 7	1336893	338
14	Umuagam a	7.4484	7.0093	13842. 7	112. 1	123. 4	27.1 7	0.0529	5.9280	0.003 5	0.008 1	1551767	337
15	Umu- akenyi Owerre Obukpa	7.4141	6.8831	24056. 6	159. 7	180. 1	26.7 1	0.0316	5.0428	0.003 6	0.006 6	3841839	397
16	Amadim Hall Ovoko	7.4426	6.8846	1021.0	71.0	176. 2	29.4 5	0.6021	42.7461	0.003 1	0.069 5	72491	404
17	Adani	7.4668	6.8936	24519. 8	95.8	104. 0	26.6 9	0.0310	2.9717	0.003 6	0.003 9	2348997	425
18	Adani Iheakpu Obollo	7.4822	6.9008	9801.1	22.0	51.3	27.4 6	0.0730	1.6056	0.003 5	0.002 3	215624. 2	437
19	Timber market Orba	7.4634	6.8416	3221.4	120. 7	149. 5	28.4 2	0.2061	24.8749	0.003 3	0.037 5	388823	452
20	Orba Road	7.3459	6.8170	6234.0	71.0	106. 2	27.8 5	0.1113	7.9032	0.003 4	0.011 4	442614	369
21	CDU	7.4665	6.9556	985.3	38.9	98.0	29.4 9	0.6224	24.2108	0.003 1	0.039 5	38328.1 7	449

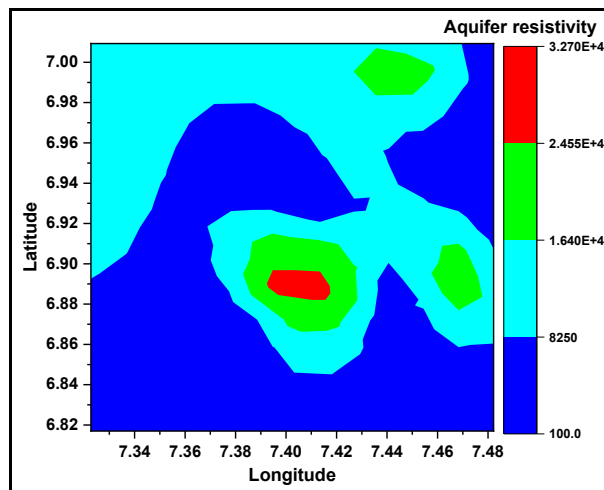


Figure 4: Contour map showing the variation of aquifer resistivity

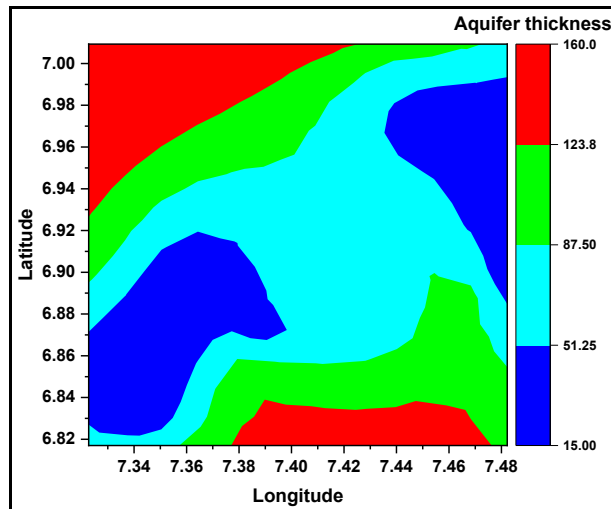


Figure 5: Contour map showing the variation of aquifer thickness

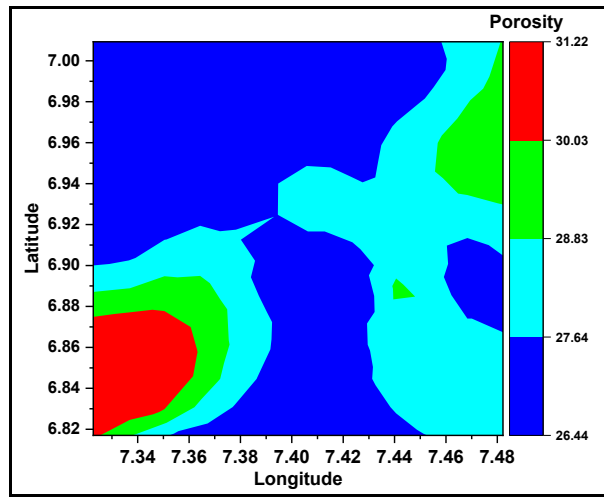


Figure 6: Contour map showing the variation of porosity

The estimated hydraulic conductivity (K) values range from 0.0237 m/day at VES 8 to 3.478 m/day at VES 5. A spatial correlation was observed where zones of low and high hydraulic conductivity align with areas of correspondingly low and high porosity. As illustrated in Figure 7, the distribution of hydraulic conductivity follows a similar pattern to that of porosity (Figure 6), with the highest values concentrated in the southwestern region. The lower hydraulic conductivity observed in other areas may be attributed to poor interconnectivity and unfavorable geometry of the pore spaces, factors which, according to Aleke et al. (2018) and George et al. (2018), can impede groundwater flow.

Aquifer transmissivity also exhibits considerable variation across the

study area, with values ranging from 1.6056 to 153.6256 m²/day. The transmissivity contour map (Figure 8) indicates the highest values are similarly located in the southwestern part. The results demonstrate a consistent relationship where areas of high transmissivity correspond to zones of high aquifer porosity and hydraulic conductivity, suggesting that the aquifer's transmission capacity is strongly influenced by these two parameters. Based on the classification by Offodile (1983), the findings indicate that the study area possesses low to moderate groundwater potential. The subsurface is predominantly composed of materials with moderate transmissivity, corresponding to a moderate water-bearing capacity.

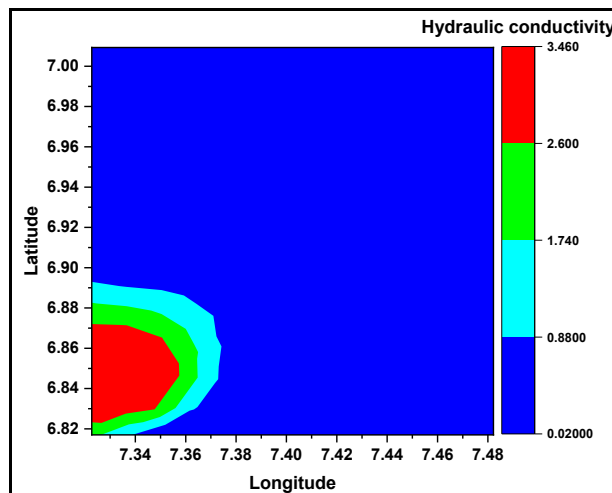


Figure 7: Contour map showing the variation of hydraulic conductivity

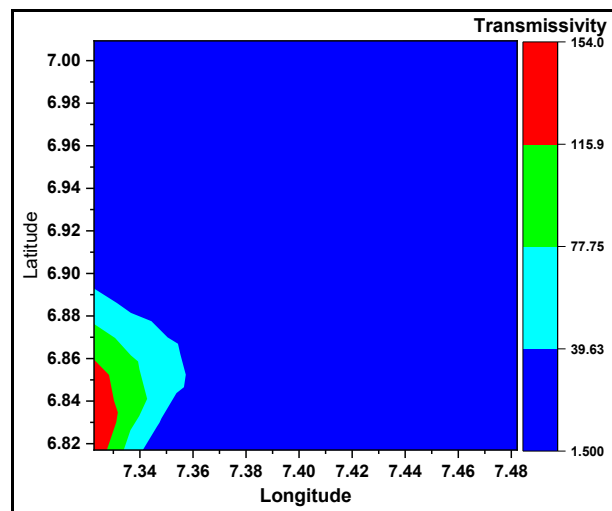


Figure 8: Contour map showing the variation of transmissivity

The formation factor has values ranging from 0.0029 to 0.0037. The contour map of Figure 9 shows high formation factor in the northwestern

and southern parts of the study area. The variation of this parameter corresponds to that of aquifer resistivity, which implies that formation

factor may likely be controlled by resistivity and reflects the heterogeneity of the subsurface and also the subsurface dynamics which control the

storage and transmissibility of the aquifer layers (Oguama et al., 2020).

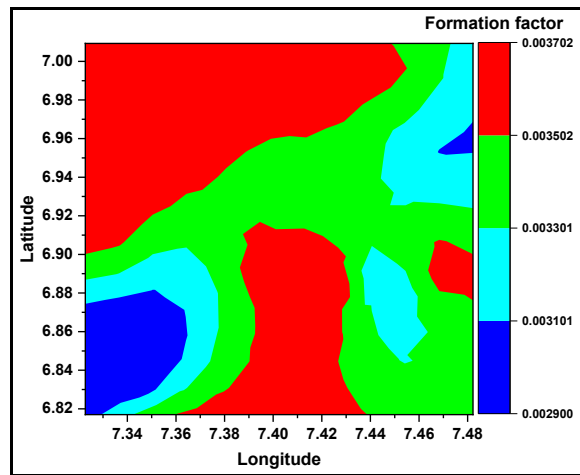


Figure 9: Contour map showing the variation of Formation factor

The longitudinal conductance values which indicate the protective capacity of the aquifer layer has values ranging from 0.0023 to 0.2783 Ω^{-1} . The ability of earth medium to retard fluid infiltrating into the subsurface is a measure of its protective capacity, since the earth medium act as a natural filter to the percolating fluids; the protective capacity of the aquifer layers in the study area is generally poor, except in VES 5 and 6 that are moderate. Figure 10 is a contour map showing the variation of

longitudinal conductance. High longitudinal conductance is observed in the southwest region of the study area. The regions with high longitudinal conductance can be delineated as zone having low permeability with high clay volume and are less vulnerable to contamination while parts of the study area characterized by poor protective capacity are vulnerable to contamination from surface contaminants (Obiora et al., 2015; Ibuot et al., 2017).

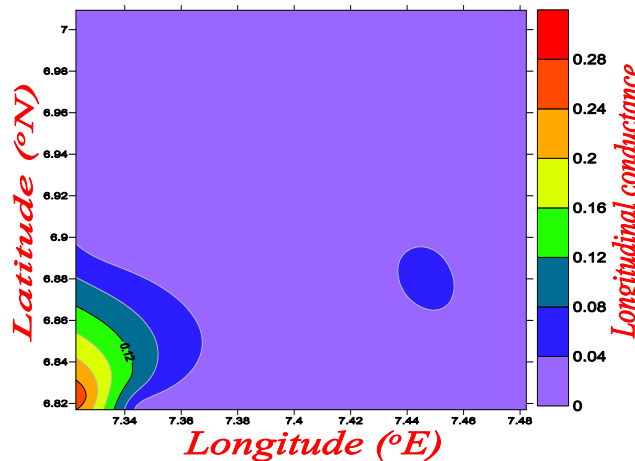


Figure 10: Contour map showing the variation of longitudinal conductance

The transverse resistance ranges from 2712.64 to 3841839.0 Ωm^2 . Its variation is shown in the contour map of Figure 11. The central part of the study area is observed to have high transverse resistance values. The high

transverse resistance is an indication of high resistivity and high thickness; thus, these zones may likely have good aquifer transmissivity with good groundwater potentials.

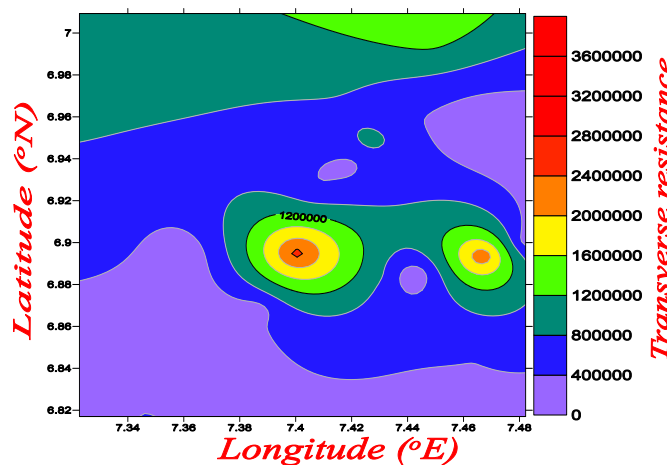


Figure 11: Contour map showing the variation of transverse resistance

4. CONCLUSION

This study was carried out to investigate the variations of aquifer geo-hydraulic parameters in parts of Nsukka, Igbo-Eze-north, Igbo-Eze south

and part of Udenu local government areas in Enugu State, southeastern Nigeria, using electrical resistivity method. The vertical electrical sounding (VES) using Schlumberger electrode configuration was employed in the geophysical investigation of the subsurface. The

subsurface was classified into five to six geoelectric layers and the results show the variations of resistivity, thickness and depth at each geoelectric layers within the maximum current electrode separation. The variations of resistivity increase with depth across most VES points. The variations of aquifer resistivity may be attributed to the heterogeneity of the subsurface layer and the compact nature of the study area. The primary parameters (resistivity and thickness) were used in computing the geohydraulic parameters which help in appraising the aquifer repositories. The spatial variations of these parameters across the study area are displayed in the contour maps generated. The observed variations may be influenced by the shape, size, density, porosity, pore sizes, water quality and degree of saturation of the aquifer layer. The values of the estimated parameters were close to the values obtained by other researchers who worked in the region. The results which are unique, are promising for further research in the study area and in the areas with similar geologic materials.

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