

Geophysical assessment of groundwater potential in the Nsukka Campus of University of Nigeria, southeastern Nigeria, using vertical electrical sounding (VES)

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Abstract

The increasing reliance on groundwater for domestic and agricultural use in Africa necessitates an accurate assessment of aquifer potential, particularly in hard rock terrains where groundwater occurrence is spatially variable. This study investigates groundwater potential within the Nsukka Campus of the University of Nigeria using vertical electrical sounding (VES) with a Schlumberger array. Twenty VES stations were acquired and analyzed to delineate subsurface layers, evaluate aquifer parameters, and identify productive

groundwater zones. The study area is underlain by the Ajali and Nsukka Formations, which comprise sandstone, siltstone, and lateritized layers with varying degrees of porosity and permeability. Interpretation of the geoelectric data revealed four to five subsurface layers in most profiles. Aquifer units were mainly located within weathered and fractured zones, with resistivity values indicating moderate-to-good groundwater potential. The integration of Dar Zarrouk parameters allowed estimation of aquifer thickness, porosity, and hydraulic conductivity. Spatial variations in these parameters guided the delineation of zones suitable for borehole development. The findings demonstrate the utility of resistivity methods in guiding sustainable groundwater development in sedimentary terrains of southeastern Nigeria.

Keywords: *Groundwater, Vertical Electrical Sounding, Potential, Resistivity Method, Nsukka*

Introduction

Groundwater remains a vital resource for domestic, agricultural, and industrial purposes, particularly in regions with unreliable or inadequate surface water sources. Across much of sub-Saharan Africa, including Nigeria, climate change has intensified the dependence on groundwater due to declining rainfall, increasing evaporation, and widespread contamination of surface water sources (Raji and Abdulkadir 2020).

Groundwater, the largest source of accessible freshwater globally, plays a pivotal role in achieving several Sustainable Development Goals (SDGs), particularly those related to water security, health, agriculture, and climate resilience. The integration of groundwater governance into sustainable development frameworks is crucial, yet often underemphasized in policy and implementation strategies (UNESCO, 2022).

Groundwater is integral to achieving a wide array of SDGs, yet its role is often overlooked in policy and planning. Sustainable groundwater management requires a multidisciplinary approach that considers ecological, social, and economic dimensions. Strengthening governance, improving data systems, and promoting equitable access are fundamental steps toward realizing the 2030 Agenda for Sustainable Development.

SDG 6 aims to "ensure availability and sustainable management of water and sanitation for all". In order to achieve this, greater attention should be paid to groundwater since it provides nearly 50% of the global drinking water supply and up to 40% of water used for irrigation (UN-

Water, 2022). In regions with limited surface water, such as Sub-Saharan Africa and South Asia, groundwater is the primary source of water for both domestic and agricultural use (MacDonald et al., 2016). However, over-extraction and contamination pose significant risks to its sustainability. Nitrate pollution from agriculture and untreated sewage are major threats to groundwater quality, particularly in developing countries (Lapworth et al., 2017).

SDG 2 calls for ending hunger and promoting sustainable agriculture. In order to eradicate hunger, promoting sustainable agriculture is paramount and irrigation cannot be neglected. Groundwater plays a crucial role in supporting irrigation and food production, especially in arid and semi-arid regions. Irrigated agriculture accounts for about 70% of global freshwater withdrawals; much of which is sourced from aquifers (Siebert et al., 2010). Nevertheless, unsustainable abstraction, particularly in major agricultural basins like the Indo-Gangetic Plain, has led to groundwater depletion and salinization, threatening long-term food security (Shah, 2009).

Groundwater contributes to climate change adaptation by acting as a buffer against seasonal variability and droughts. As climate change intensifies the frequency of extreme weather events, groundwater storage offers resilience for communities vulnerable to water scarcity (Taylor et al., 2013). However, climate variability also impacts recharge rates, altering the availability of groundwater resources in the long term (Döll et al., 2012).

Equitable access to groundwater intersects with SDG 16 (Peace, Justice and Strong Institutions) and SDG 10 (Reduced Inequalities). In many contexts, groundwater is a common pool resource lacking effective governance, leading to over-extraction by more powerful users at the expense of marginalized communities (Giordano, 2009). Strengthening institutions and local participation in groundwater management is essential to promote justice and sustainability.

To align groundwater use with the SDGs, integrated water resource management (IWRM) is essential. This includes policies that recognize the interdependencies between groundwater and other resources, promote conjunctive use of surface and groundwater, and incorporate local knowledge in management strategies (Gleeson et al., 2020). Data collection and monitoring must also be improved, as groundwater is often termed the “invisible resource” due to limited information on its quantity and quality (UNESCO, 2022).

Groundwater accounts for over 95% of the world's freshwater reserves (Siklomanov 1998; Healy et al. 2007), yet its availability is uneven and influen

ced by factors such as lithology, porosity, permeability, and recharge conditions (Kosinski and Kelly 1981; Kalinski et al. 1993).

In hard rock terrains, typical of basement and some sedimentary formations, aquifers are often discontinuous, poorly connected, and highly variable in storage capacity (Warmate 2016; Vashisht and Aggarwal 2016). These aquifers depend on secondary porosity from weathering, fracturing, and faulting (Raji et al. 2019; MacDonald et al. 2012). Consequently, successful groundwater exploitation in such areas requires a careful geophysical evaluation to identify zones of enhanced permeability and storage (Niwas and Singhal 1981; Ezech 2011). Quantitative assessment of aquifer properties such as transmissivity, porosity, and hydraulic conductivity is essential not only for siting productive boreholes but also for long-term water resource planning (Scanlon and Cook 2002; Raji and Abdulkadir 2020a).

Electrical resistivity methods, particularly vertical electrical sounding (VES) using the Schlumberger configuration, have been widely employed for subsurface exploration due to their cost-effectiveness, minimal environmental impact, and ability to resolve layered structures (Oladunjoye and Jekayinfa 2015; Egbai 2013). These methods provide indirect estimates of hydrogeologic parameters through interpretation of resistivity signatures, which reflect variations in lithology, moisture content, and pore fluid conductivity (Olorunfemi et al. 2005; Ojekunle et al. 2015). The VES technique is particularly suited for sedimentary terrains, where aquifers are often layered and spatially extensive (Badmus and Olatinsu 2012).

Several researchers have demonstrated the effectiveness of geoelectrical methods in evaluating aquifer potential across various parts of Nigeria and beyond. Laouini et al. (2017) applied Dar Zarrouk parameters to delineate aquifers in Akwa Ibom, showing the vulnerability of high-yield aquifers to contamination. Aweto and Akpoborie (2015) estimated transmissivity and hydraulic conductivity in the western Niger Delta, confirming substantial groundwater reserves. Similarly, Nwachukwu et al. (2019) observed shallow aquifers in Orogun with notable pollution risk from hydrocarbons. Studies by Obiora et al. (2015) and Raji and Abdulkadir (2020b) emphasized the link between resistivity profiles and aquifer protective capacity, highlighting the role of clay overburden in reducing contamination risk.

In southeastern Nigeria, where the Nsukka Campus of the University of Nigeria is located, the subsurface is characterized by the Ajali and Nsukka Formations; units within the Anambra Basin. These formations

include sandstone, shale, and lateritic layers with variable aquifer properties (Reyment 1965 and Agagu et al. 1985). Prior geophysical assessments in related settings (e.g., Ogundana and Talabi 2014; Igboekwe and Akpan 2011) have shown that weathered and fractured basement units or coarse-grained sandstone layers often yield productive aquifers. However, groundwater conditions on university campuses remain under-studied, despite increasing water demands from institutional and residential users.

This present study aims to assess the groundwater potential of the Nsukka Campus using vertical electrical sounding. Specific objectives include delineating subsurface lithologic layers, estimating aquifer thickness and porosity, and identifying zones with favorable hydraulic conductivity. The findings are expected to aid in the sustainable development of groundwater resources and support the planning of borehole infrastructure for campus and community use.

Materials and Methods

Electrical Resistivity Method and Survey Design

This study employed the electrical resistivity method - specifically, Vertical Electrical Sounding (**VES**) - to investigate the subsurface hydrogeological characteristics of the Nsukka Campus, University of Nigeria. The technique is based on the principle that subsurface materials exhibit different electrical resistivities depending on their lithology, moisture content, and porosity. Direct current (DC) was introduced into the subsurface through a pair of current electrodes, and the resulting potential difference was measured across a separate pair of potential electrodes. The Schlumberger electrode configuration was adopted for its ability to probe deeper layers and its reduced sensitivity to near-surface inhomogeneities.

In this array, the apparent resistivity (ρ_a) was calculated using the expression:

$$\rho_a = G \times R_a, \quad 1.$$

where R_a is the measured apparent resistance and G is the geometric factor determined by:

$$G = \pi \left[\frac{\frac{AB^2}{2} - \frac{MN^2}{2}}{MN} \right]. \quad 2.$$

Then,

$$\rho_a = \pi \left[\frac{\frac{AB^2}{2} - \frac{MN^2}{2}}{MN} \right] R_a, 3.$$

where AB and MN are the current and potential electrode spacing, respectively. The resistivity values were interpreted to delineate subsurface lithologies and identify water-bearing formations.

Field Procedure and Instrumentation

VES points were conducted across the study area with a maximum current electrode spacing (AB) of 800 meters. SSR-MP-ATS resistivity meter was used for data acquisition, metallic electrodes were driven into the ground using hammers; current electrodes and potential electrodes were connected to the resistivity meter using transmission cables. GPS was used to record the coordinates of each VES point. Measurements were taken during the wet season (April), which helped ensure good electrical contact with the ground. In dry areas, the soil was manually wetted to improve conductivity. The electrode spacing was progressively increased to investigate deeper layers. All electrode positions were aligned along a straight profile, and readings were taken at increasing AB/2 spacing to generate depth-dependent resistivity data.

Data Processing and Data Interpretation

Data Processing

The field data collected included electrode spacing (AB/2 and MN/2) and the apparent resistance values for each VES point. The geometric factor (G) was calculated, and the apparent resistivity (ρ_a) values were derived using equations 2 & 3. The computed resistivity values were plotted against electrode spacings on a bi-logarithmic graph to generate sounding curves. Outliers were visually identified and removed to smooth the curves. Data inversion and interpretation were carried out using *WINRESIST* software. This allowed for automatic and manual curve matching to derive subsurface layer resistivities and thicknesses. The resulting models provided vertical profiles of geoelectric layers, which were used to infer the geological and hydrogeological setting.

Data Interpretation

Interpretation of the VES data was carried out in two phases: qualitative and quantitative.

Qualitative interpretation involved examining the shape and trend of the sounding curves to identify geoelectric layer sequences and possible aquifer zones. The types of curves observed (e.g., H-type, KH-type) were classified based on standard curve shapes, which provide insights into resistivity layering and potential water-bearing horizons.

Quantitative interpretation was performed using the resistivity values and layer thicknesses obtained from inversion. Key hydrogeological parameters were estimated:

○ *Hydraulic Conductivity (K)*: This is the measure of resistance to movement of water flowing through a porous medium. It is an important hydrological parameter that governs along with other parameters the flow of fluids and migration of contaminants in soils and aquifers. It was estimated using the empirical relation by Heigold et al. (1979):

$$K = 386.40 \rho_a^{-0.93283}, \quad 4.$$

○ *Transmissivity (T)*: This is the rate at which water passes through a unit width of the aquifer under a unit hydraulic gradient. It is also the rate at which groundwater flows horizontally through an aquifer. Transmissivity provides a general idea of the water-producing capabilities of aquifer. It was calculated using Todd et al. (1980):

$$T = K \cdot h, \quad 5.$$

where h is the thickness of the aquifer.

○ *Porosity (ϕ)*: computed using the equation by Marotz (1969):

$$\phi = 25.5 + 4.5 \ln K. \quad 6.$$

Aquifer productivity was classified according to transmissivity ranges suggested by Offodile (1983), ranging from negligible to high potential. These parameters were spatially evaluated to map zones of differing groundwater potential across the study area.

Table 1: Transmissivity range according to Offodile (1983)

Transmissivity (m ² /day)	Groundwater potential
>500	High potential
50 – 500	Moderate potential
5 – 50	Low potential
0.5 – 5	Very low potential
<0.5	Negligible potential

Results and Discussion

Analysis of Geo-Electrical Data

The interpretation of the vertical electrical sounding (VES) data was carried out using WINRESIST software. The software generated sounding curves and provided resistivity, thickness, and depth estimates for each geoelectric layer at the five VES points. Figures 4.1 to 4.5 present the field curve models for each VES location, showing the relationship between apparent resistivity and half current electrode spacing.

Tables 4.1 through 4.5 give the resistivity, thickness, and computed geohydraulic parameters of the layers at each VES site (hydraulic conductivity, transmissivity, porosity, and hydraulic resistance). Table 4.6 summarizes the geoelectric characteristics across the five points, while Table 4.7 includes spatial coordinates and averaged aquifer properties. Contour maps generated using SURFER 13 visualize the spatial distribution of aquifer resistivity, thickness, hydraulic conductivity, transmissivity, porosity, and resistance across the study area.

Geo-Electrical Characteristics

Interpretation revealed the presence of four to five geoelectric layers across the study area. VES 1–3 exhibited five layers, with KHKH-type curves at VES 1 and 2, and HKHK at VES 3. VES 4 and 5 showed four layers with HKH and KHK-type curves, respectively. The first layer's resistivity ranged from 38.1 to 2713.2 $\Omega \cdot m$, with thicknesses between 0.4 and 2.2 m. The second layer had resistivity values between 359.3 and 51339.9 $\Omega \cdot m$, and thicknesses from 1.1 to 51.6 m. The third layer ranged from 239.5 to 3656.5 $\Omega \cdot m$ in resistivity and 8.9 to 70.5 m in thickness. The fourth layer exhibited resistivities of 3674 to 38366.7 $\Omega \cdot m$, and thicknesses of 9.9 to 209.3 m. The fifth layer was observed only in VES

1–3, with resistivity values ranging from 6651.1 to 50360.2 $\Omega \cdot \text{m}$ and thicknesses between 190.6 and 1001 m.

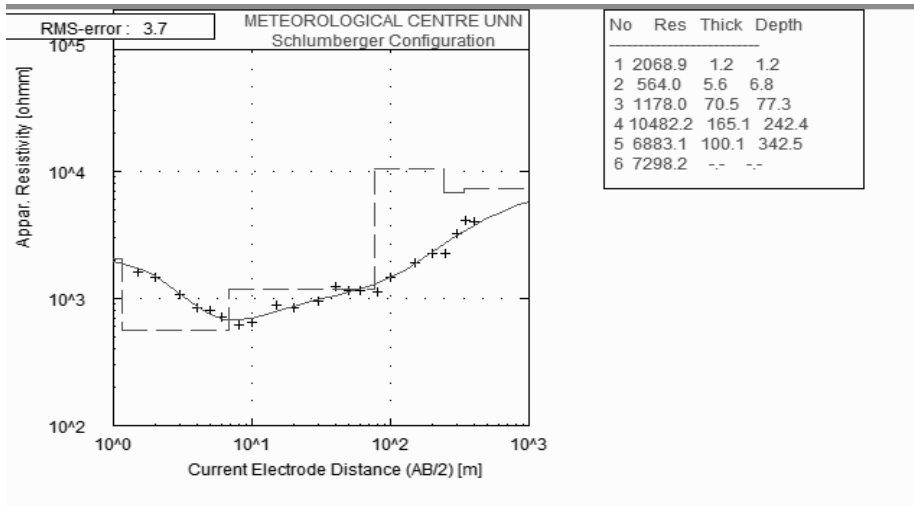


Fig. 4.1: The field curve model for VES 1

Table 4.1 Aquifer parameters of VES 1

VES 1: METROLOGICAL CENTRE AROUND GREENHOUSE AREA						
Layer	ρ_a	h	K	T	ϕ	C
1	2068.9	1.2	0.3119	0.37428	20.257	3.847383
2	564	5.6	1.0485	5.871505	25.713	5.341049
3	1178	70.5	0.5274	37.18517	22.621	133.6622
4	10482.2	165.1	0.0686	11.33406	13.442	2404.964
5	6883.1	100.1	0.1016	10.17352	15.210	984.9112

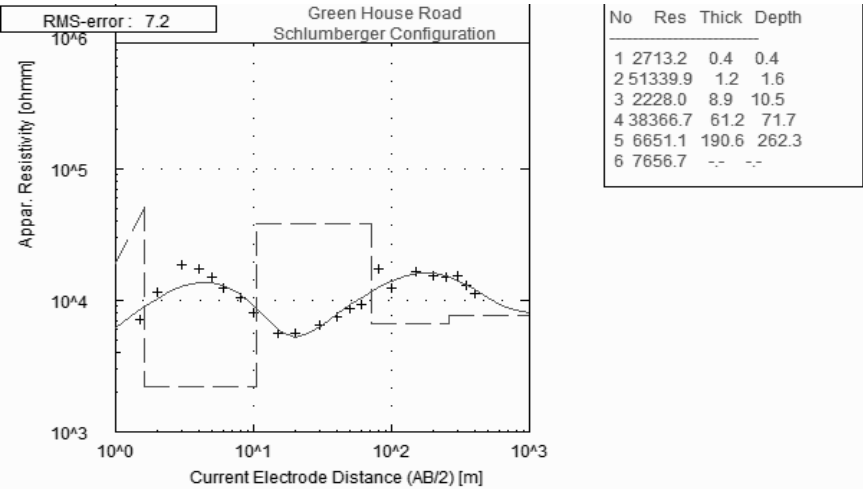


Fig. 4.2: The field curve model for VES 2

Table 4.2 Aquifer parameters of VES 2

VES 2: GREENHOUSE ROAD						
Layer	ρ_a	h	K	T	ϕ	C
1	2713.2	0.4	0.2422	0.096882	19.119	1.651497
2	51339.9	1.2	0.0156	0.018714	6.778	76.9481
3	2228	8.9	0.2911	2.590547	19.950	30.57656
4	38366.7	61.2	0.0205	1.252386	8.007	2990.643
5	6651.1	190.6	0.1049	20.00093	15.354	1816.333

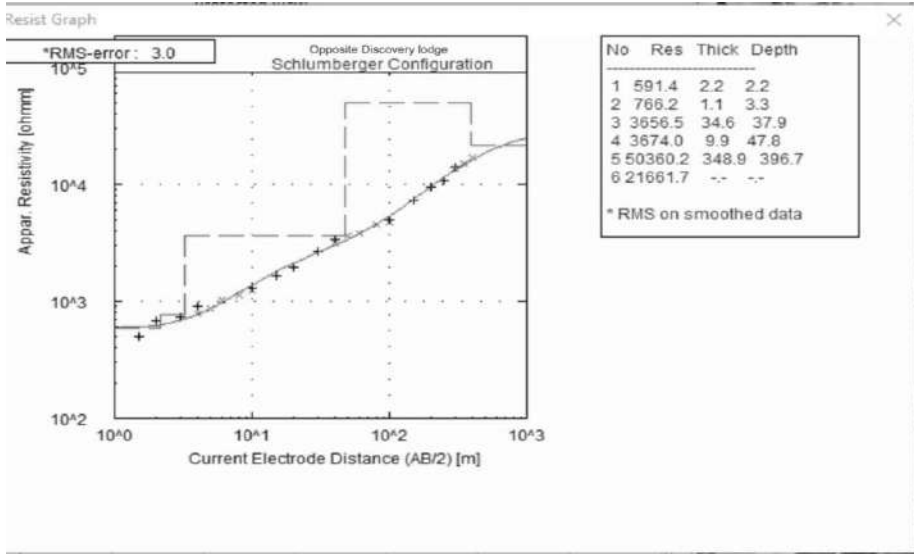


Fig. 4.3: The field curve model for VES 3

Table 4.3 Aquifer parameters of VES 3

Ves 3: Opposite Discovery Lodge						
Layer	ρ_a	h	K	T	ϕ	C
1	591.4	2.2	1.0031	2.206814	25.512	2.193207
2	766.2	1.1	0.7878	0.86662	24.427	1.396228
3	3656.5	34.6	0.1834	6.344228	17.868	188.7007
4	3674	9.9	0.1825	1.807189	17.845	54.2334
5	50360.2	348.9	0.0159	5.539746	6.864	21974.15

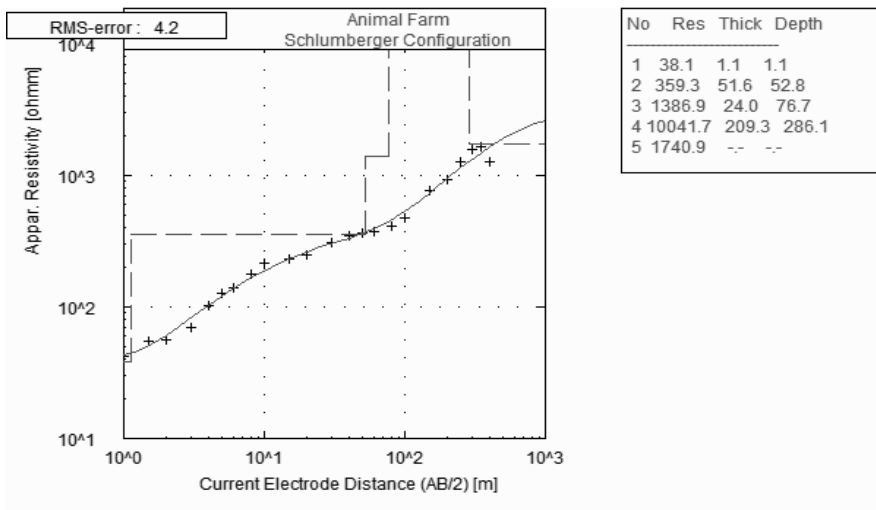


Fig. 4.4: The field curve model for VES 4

Table 4.4 Aquifer parameters of VES 4

Ves 4: Anmal Farm						
Layer	ρ_a	h	K	T	ϕ	C
1	38.1	1.1	12.9510	14.24609	37.025	0.084936
2	359.3	51.6	1.5967	82.39098	27.606	32.31616
3	1386.9	24	0.4529	10.87062	21.936	52.98685
4	10041.7	209.3	0.0715	14.95548	13.629	2929.125

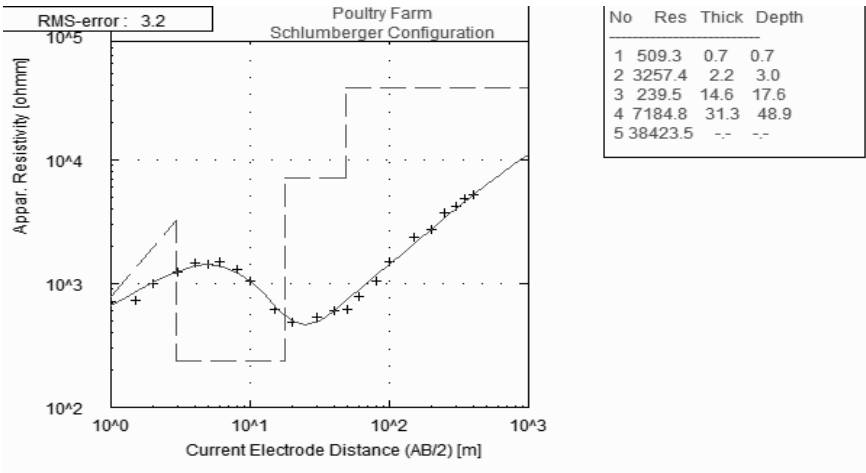


Fig. 4.5: The field curve model for VES 5

Table 4.5 Aquifer parameters of VES 5

Ves 5: Poultry House						
Layer	ρ_a	h	K	T	$\phi(\%)$	C
1	509.3	0.7	1.1532	0.807214	26.141	0.607026
2	3257.4	2.2	0.2042	0.449312	18.351	10.77202
3	239.5	14.6	2.3310	34.03317	29.308	6.263301
4	7184.8	31.3	0.0976	3.056343	15.029	320.5432

Table 4.6 summary of Result obtained from interpreted VES data 5

VES	location	ρ_1	ρ_2	ρ_3	ρ_4	ρ_{45}	h_1	h_2	h_3	h_4	h_5	Curve type
1	Metrological centre	2068.9	564	1178	10482.2	6883.1	1.2	5.6	70.5	165.1	1001	KH KH
2	Greenhouse road	2713.2	51339.9	2228	38366.7	6651.1	0.4	1.2	8.9	61.2	190.6	KH KH
3	Opposite discovery lodge	591.4	766.2	3656.5	3674	50360.2	2.2	1.1	34.6	9.9	348.9	HK HK
4	Animal farm	38.1	359.3	1386.9	10041.7	-	1.1	51.6	24	209.3	-	HK H
5	Poultry house	509.3	3257.4	239.5	7184.8	-	0.7	2.2	14.6	31.3	-	KH K

Table 4.7 Aquifer parameters of the study area

VES	location	Latitude (°N)	Longitude (°E)	$\rho_a (\Omega m)$	$h (m)$	$K (m/day)$	$T_r (m^2/day)$	$\phi (%)$	C
1	Metrological centre	6.51484	7.25106	10482.2	165.1	0.0686	11.33406	13.442	2404.964
2	Greenhouse road	6.51374	7.25304	6651.1	190.6	0.1049	20.00093	15.354	1816.333
3	Opposite discovery lodge	6.51176	7.25376	50360.2	348.9	0.0159	5.539746	6.864	21974.15
4	Animal farm	6.51032	7.25305	10041.7	209.3	0.0715	14.95548	13.629	2929.125
5	Poultry house	6.51088	7.25324	7184.8	31.3	0.0976	3.056343	15.029	320.5432
Average				16,944	189.04	0.0717	10.97732	12.8636	5889.023

Evaluation of Aquifer Potentials

Aquifer potential was evaluated using key hydraulic parameters: aquifer resistivity (ρ_a), thickness (h), hydraulic conductivity (K), transmissivity (T_r), porosity (ϕ), and hydraulic resistance (C).

Aquifer Resistivity

Aquifer resistivity ranged from 6651.1 to 50360.2 $\Omega \cdot m$, with an average of 16944 $\Omega \cdot m$. VES 2 (Greenhouse Road) recorded the lowest resistivity,

suggesting higher conductivity, while VES 3 (Opposite Discovery Lodge) had the highest resistivity. The contour map (Fig. 4.6) shows that resistivity increases westward, indicating potential lithological changes such as increased rock content or less conductive materials. These values are extremely high resistivities, such high resistivity is usually characteristic of competent crystalline basement rocks (granite, gneiss, quartzite, basalt, etc.) with little or no weathering, massive dry sandstone/limestone units with negligible porosity and water content or zones devoid of significant groundwater, unless fractured or weathered (Iserhien-Emekeme et al 2018; Driscoll 1986). We think that this result shows that the subsurface is a massive or aggregates of dry sandstone/limestone units (Todd 1980; Orellana 1972; Heigold et al. 1979; Ezech 2011; Obiora et al. 2015).

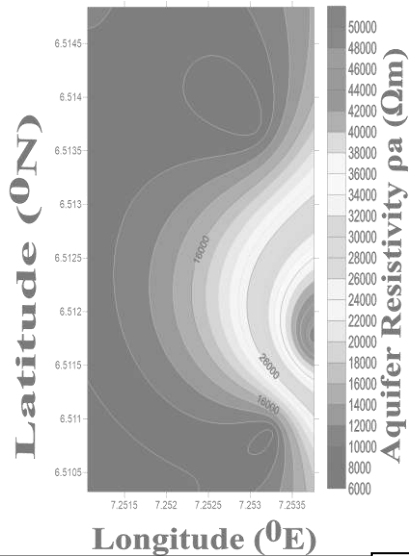


Fig. 4.6: Contour map of aquifer resistivity showing its distribution in the study area.

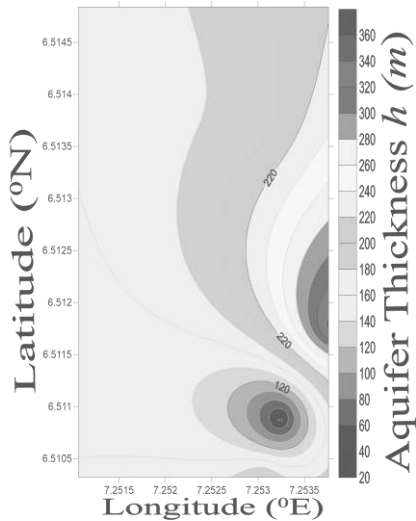


Fig. 4.7: Contour map of aquifer Thickness showing its distribution in the study area.

Aquifer Thickness

Aquifer thickness varied from 31.3 m at VES 5 to 348.9 m at VES 3, with an average thickness of 189.04 m. Figure 4.7 reveals that aquifer thickness generally increases from the southeast to the northwest, with the thickest zones in the central and northwestern parts of the study area,

indicating favorable groundwater storage potential. The 31.3-meter thickness could indicate a localized area where the water table (patched aquifer) is closer to the surface, making it potentially easier to access groundwater through shallow wells or boreholes (Todd 1980; Orellana 1972; Obiora et al. 2015).

Hydraulic Conductivity

- Hydraulic conductivity values ranged from 0.0159 to 0.1049 m/day, averaging 0.0717 m/day. Based on the classification by Driscoll (1986) and Todd (1980), the study area generally exhibits moderate to low hydraulic conductivity. The highest values are concentrated in the northwest and parts of the southeast, as shown in Figure 4.8. Water will move more slowly through the aquifer, potentially affecting the rate at which wells can be recharged and the overall capacity of the aquifer to supply water. The aquifer will definitely have a lower than expected well yields, meaning the aquifer may not be able to support high-capacity wells for municipal or large-scale water supply (Ezeh 2011; Obiora et al. 2015; Ashraf 2018).

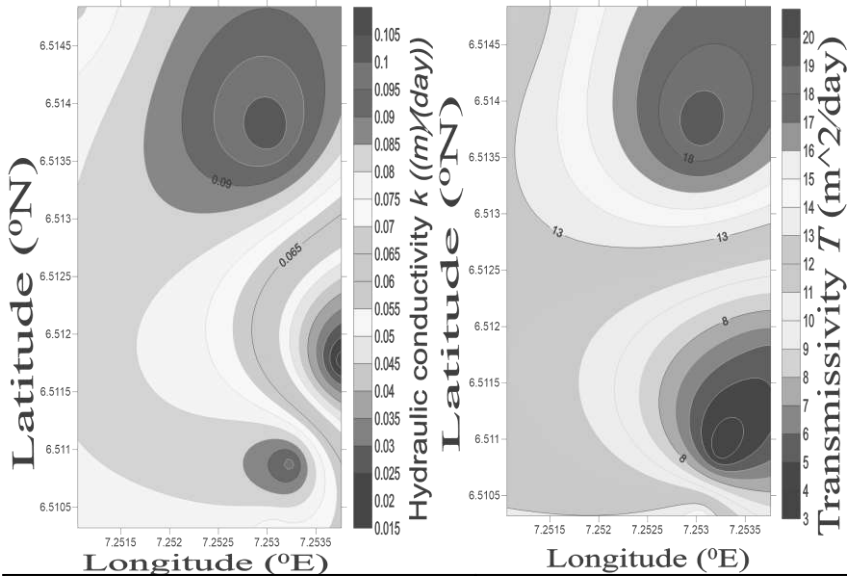


Fig. 4.8: Contour map of Hydraulic conductivity showing its distribution in the study area.

Fig. 4.9: Contour map of Transmissivity showing its distribution in the study area.

Transmissivity

Transmissivity ranged from 3.056 to 20.001 m²/day, with an average of 10.98 m²/day. VES 2 recorded the highest transmissivity, indicating a more permeable aquifer unit, while VES 5 had the lowest (Fig. 4.9). According to Ofodile's (1983) classification, transmissivity values across the study area fall within low to very low potential categories (Table 1). This range of transmissivity value implies that while water can flow through the aquifer, it might be at a slower rate compared to aquifers with higher transmissivity values. The implication is that the aquifer might not be suitable for large-scale water supply or high-demand extraction, but could still be viable for local or smaller-scale use (Todd 1980; Orellana 1972; Heigold et al. 1979).

Porosity

Porosity ranged from 6.864% at VES 3 to 15.354% at VES 2, with an average of 12.86%. Figure 4.10 shows that areas with the highest porosity are concentrated in the northwest through to the southwest, indicating better groundwater storage capacity in these zones (Fig. 4.10). An aquifer with porosity in the given range is likely to hold a moderate amount of groundwater. However, the actual yield of groundwater from such an aquifer would depend on its permeability (Bhattacharya 2012). If the permeability is also low, despite the moderate porosity, the aquifer might not be a significant source of groundwater (Todd 1980; Orellana 1972; Heigold et al. 1979; Ezech 2011; Obiora et al. 2015). On the other hand, if the permeability is high, even with a relatively lower porosity, the aquifer could still be a viable source of groundwater.

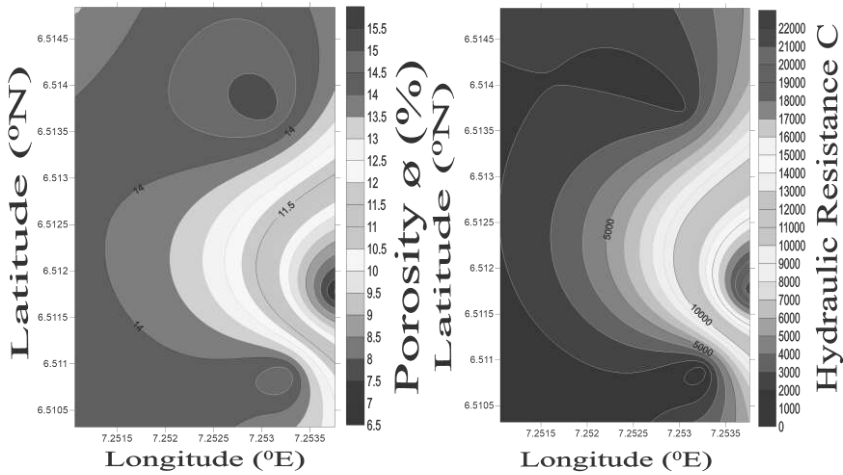


Figure 4.10: Contour map of porosity showing its distribution in the study area.

Figure 4.11: Contour map of hydraulic resistance showing its distribution in the study area

Hydraulic Resistance

Hydraulic resistance values ranged from 320 to 21974.15 C, with an average of 5889.02 C. High resistance zones correspond with deeper or more compact geologic units (Gleeson et al. 2020; Healy et al. 2007). Lower resistance in the western and central parts of the area suggests zones with higher permeability (Fig. 4.11). These values suggest a less permeable aquifer with slower flow rates, potentially lower well yields, and slower recharge, but also better protection against surface contamination (Todd 1980; Orellana 1972; Ezech 2011; Obiora et al. 2015).

Summary

The VES analysis reveals spatial variation in aquifer properties across the Nsukka Campus. The northwest generally exhibits higher aquifer thickness, conductivity, and porosity - indicating better groundwater potential. In contrast, the southeast and parts of the northeast show relatively lower values, suggesting limited aquifer productivity. However, the overall productivity or potential of the area is largely limited to subsistence use. These insights are essential for optimizing borehole citing and sustainable groundwater development in the area.

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Authors' contributions

Authors have contributed equally in preparing and writing the manuscript.

Availability of data

The data for this study are available from the corresponding author, upon official request.

Conflict of interests

The authors declare that they have no known competing financial or personal relationships that could influence the work reported in this paper.

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