

MODELLLED RESISTIVITY INTERPRETATION FOR ASSESSING AQUIFER PROTECTION AND POLLUTION VULNERABILITY AT ALVAN IKOKU FEDERAL UNIVERSITY OF EDUCATION, OWERRI, NIGERIA

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ABSTRACT

This study employed Vertical Electrical Sounding (VES) to assess aquifer protection and pollution vulnerability at Alvan Ikoku Federal University of Education, Owerri, Nigeria. Eleven VES points revealed resistivity values ranging from 0.0137 Mho to 0.2862 Mho, with the majority indicating poor protective capacity ($S < 0.1$ Mho) and high vulnerability indices (GOD index values between 0.168 and 0.378). The depth to aquifer layers varies from 11.8 meters to 47.1 meters, with shallower depths (11.8 m and 17.5 m) showing particularly high vulnerability. The resistivity and depth data suggest most aquifers are inadequately protected against surface pollution, emphasizing the need for improved waste management and land-use policies. The findings demonstrate the efficacy of geophysical methods in delineating vulnerable groundwater zones in urban environments of Southeast Nigeria.

IndexTerms - Vertical Electrical Sounding, Aquifer Protection, Pollution Vulnerability, Resistivity, Nigeria, Geophysical Survey.

1. INTRODUCTION

Groundwater remains a critical resource for domestic, agricultural, and industrial uses across Nigeria, especially in urban centres where surface water sources are often inadequate or contaminated. Over the past few decades, Nigeria has experienced rapid urbanization, with cities like Owerri, Enugu, and Port Harcourt expanding rapidly, often outstripping infrastructural development and environmental management capacities (Oguge & Olaleye, 2012; Egboka et al., 2014). Consequently, the aquifers in these regions are increasingly vulnerable to pollution from anthropogenic activities such as improper waste disposal, industrial effluents, and land-use changes (Nwankwoala et al., 2018).

In Southeast Nigeria, the aquifers are typically shallow and highly susceptible due to the geological formations, predominantly comprising sandstones, shales, and clay-rich sediments that influence the hydrogeological characteristics. The proximity of surface activities to groundwater sources accentuates the risk of contamination, which can have serious health and environmental consequences. For example, studies in Enugu and Port Harcourt have shown that groundwater sources are often polluted by hydrocarbons, heavy metals, and microbial pathogens (Egboka et al., 2014; Nwankwoala et al., 2018).

Assessing the vulnerability of aquifers to pollution is vital for sustainable water resource management. Vulnerability assessment involves understanding the hydrogeological, hydrochemical, and land-use factors that influence the susceptibility of groundwater to contamination (Foster et al., 2019). Various methods have been developed for this purpose, with geophysical techniques like Vertical Electrical Sounding (VES) being particularly valuable due to their cost-effectiveness, non-destructive nature, and ability to delineate subsurface resistivity distributions (Olayinka & Oladapo, 2012; Akinbile & Akinbile, 2020).

This study aims to employ VES to evaluate the aquifer protection status and pollution vulnerability at Alvan Ikoku Federal University of Education, Owerri. The findings will contribute to a better understanding of subsurface hydrogeological conditions, guiding policy formulation and land-use planning to safeguard groundwater resources in the region.

2. GEOLOGY OF THE AREA

Owerri is located within South-eastern Nigeria and is predominantly underlain by the Benin Formation, which forms part of the West African sedimentary sequences dating from the Cretaceous to Paleocene periods (Ofoegbu, 1985). This formation is characterized by deposits from the late Cretaceous to Paleocene epochs, mainly comprising sands, clays, and sandstones, Figure 1. These geological features have significant implications for groundwater occurrence and movement within the region (Egboka et al., 1990).

The sediments within the Benin Formation in Owerri are generally heterogeneous, featuring alternating layers of permeable sands and less permeable clay lenses. This stratigraphy influences the patterns of groundwater flow and the storage capacity of the aquifer

system. The sandy layers are typically porous, serving as primary aquifers capable of storing substantial volumes of groundwater, while the clay layers act as confining units, restricting vertical flow and serving as barriers to recharge (Nwankwoala et al., 2012).

Hydrogeologically, the aquifers in Owerri are mainly unconfined, with recharge primarily occurring through direct infiltration of rainfall and lateral flow from adjacent areas. The high permeability of the sandy units promotes the movement of groundwater, which is commonly accessed via boreholes and hand-dug wells. However, the presence of clay lenses can compartmentalize the aquifers, leading to variations in water quality and yield across different zones (Akinbile, D.M., & Akinbile, C.O., 2020).

Additionally, resistivity variations within the Benin Formation, observed through geophysical methods such as electrical resistivity imaging, are valuable in delineating aquifer boundaries, identifying zones of high porosity, and selecting optimal sites for boreholes (Nwugha et al., 2016). An understanding of these subsurface characteristics is essential for the sustainable development of groundwater resources, particularly in urban centres like Owerri, where groundwater supplies a significant portion of domestic and industrial water needs Adelana, S. M., & MacDonald, A. M. (2018).

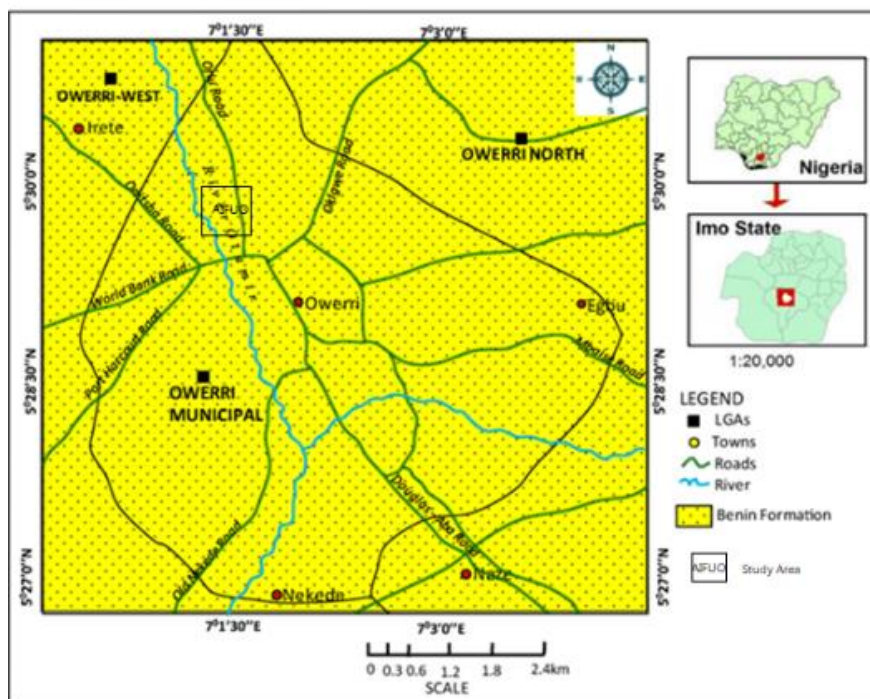


Figure 1: Geology of Owerri and the Environments

3. MATERIALS AND METHODOLOGY

3.1 Study Area

Owerri, the capital of Imo State in Southeast Nigeria, is situated within the tropical rainforest zone characterized by high rainfall, dense vegetation, and urbanization (Oke & Olowu, 2013). The area's geology predominantly comprises recent sediments, including clay, sand, and gravel, forming the primary aquifer units (Egboka et al., 2014). The shallow aquifers are often less than 50 meters deep, making them highly vulnerable to surface pollution. Rapid urban growth and land-use changes, including construction, agriculture, and waste disposal, threaten the integrity of groundwater sources (Nwankwoala et al., 2018).

3.2 Data Acquisition

Eleven Vertical Electrical Soundings (VES 1–11) were conducted using the Schlumberger array, which is widely used for aquifer studies due to its sensitivity to horizontal and vertical lithological variations (Olayinka & Oladapo, 2012, Okeke P.I. et al, 2023). The maximum current electrode spacing (AB/2) ranged of 200 m, allowing for a detailed investigation of the subsurface resistivity structure.

The principles guiding the VES method are rooted in the differences in electrical resistivity between subsurface materials. The Schlumberger array involves placing four electrodes along a straight line, with current electrodes (C1 and C2) transmitting current into the ground, while potential electrodes (P1 and P2) measure the resulting voltage difference. As the current electrodes are gradually expanded, different depths and layers are probed, enabling the construction of a resistivity profile (Topp et al., 2014).

3.3 Principles and Theories

The VES method relies on the inverse relationship between the measured electrical resistivity and the physical and chemical properties of subsurface materials. Resistivity is influenced by porosity, fluid content, mineral composition, and saturation levels. Typically, aquifer materials such as sands and gravels exhibit high resistivity, whereas clay and shale are characterized by low resistivity (Olayinka & Oladapo, 2012).

The interpretation of VES data is based on the concept that different geological layers produce distinctive resistivity responses. The data are modelled using software to generate apparent resistivity curves, which are then interpreted to identify layer interfaces, thicknesses, and resistivities. The resistivity of the aquifer and overlying layers informs the calculation of protective capacity and vulnerability indices, such as the GOD (Groundwater Occurrence and Depth) index (Foster et al., 2019).

3.4 Data Analysis

Resistivity data were interpreted using partial curve matching and computer modelling with software IP2WIN. The protective capacity of aquifers was classified based on resistivity values, with low resistivity indicating poor protection due to potential contamination pathways. The GOD index was calculated to quantify aquifer vulnerability, considering aquifer resistivity, depth, and overlying geological layers.

4. RESULTS AND DISCUSSION

4.1 Results

The electrical resistivity imaging was conducted at eleven different locations within A.I.F.U.E. Owerri to delineate subsurface aquifer characteristics and identify suitable borehole sites. The sites include the Centre of Excellence, Faculty of Architecture, Hostel D, Pavilion, University Gate, CKC Church/Opposite Mosque, Home Economics Department, Nursery School, Nwaorie River vicinity, between the Microteaching Laboratory and Nathan Ejiogu Hall, and the Centre for Entrepreneurship Education. The interpreted geophysical data revealed variations in resistivity values across these locations, indicating differences in subsurface lithology and aquifer potential, Figure 2 (a, b, c, d, e, f, g, h, i, j and l)

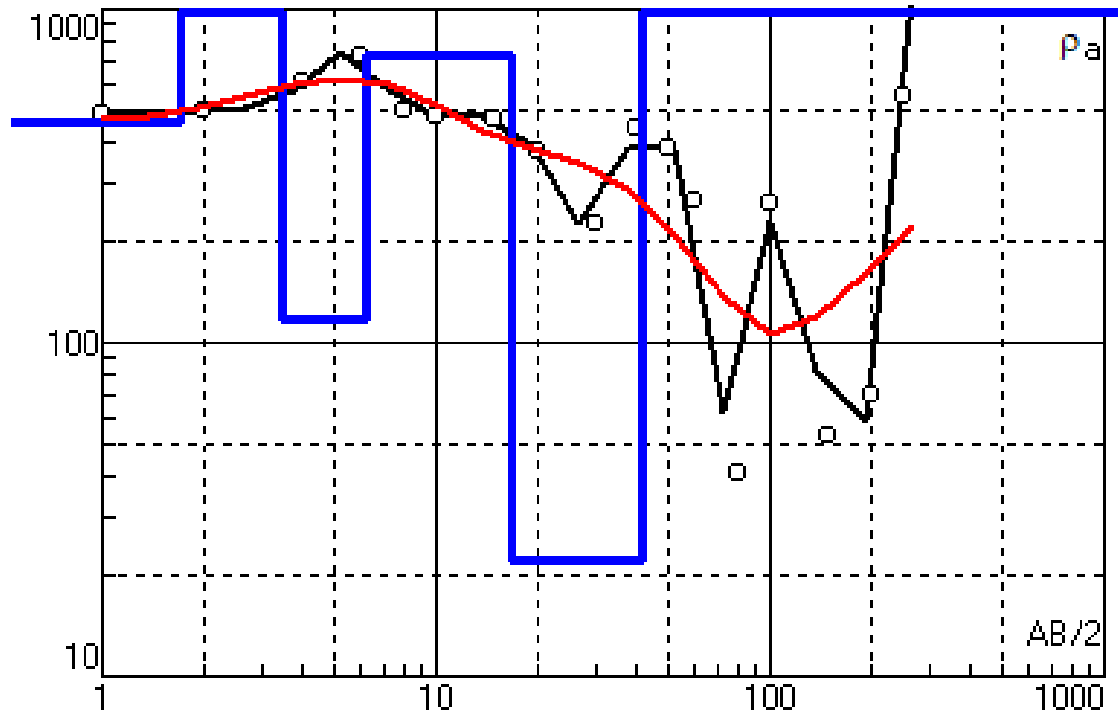


Figure 2a: The Resistivity Curve at Centre of Excellence (VES 1), A.I.F.U.E. Owerri

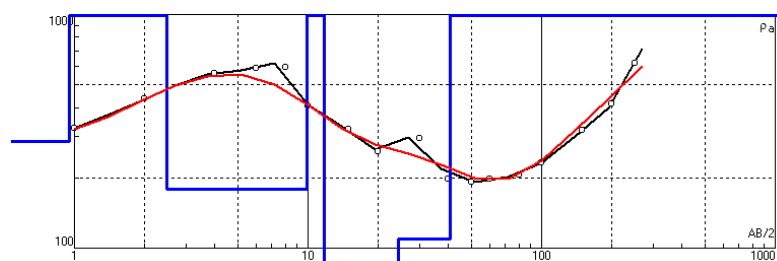


Figure 2b: The Resistivity Curve at Faculty of agriculture (VES 2), A.I.F.U.E. Owerri

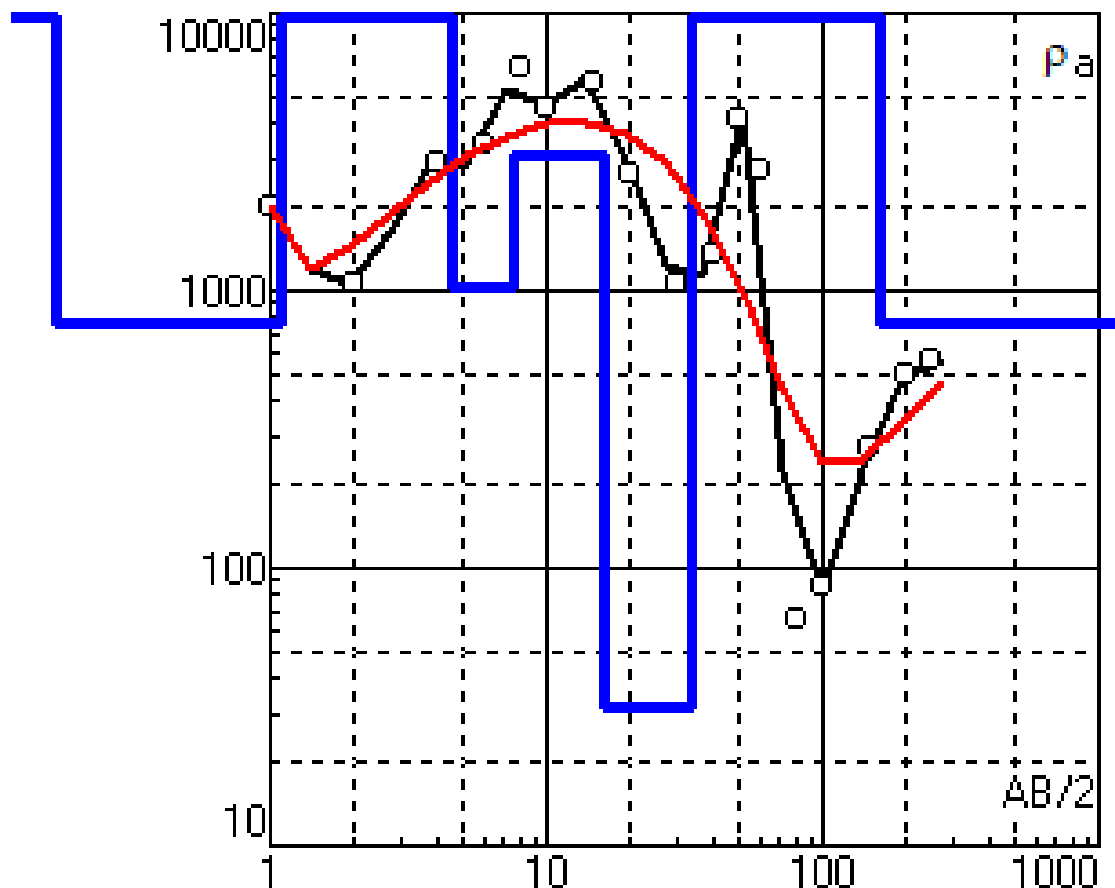


Figure 2c: The Resistivity Curve at Hostel (VES 3), A.I.F.U.E. Owerri

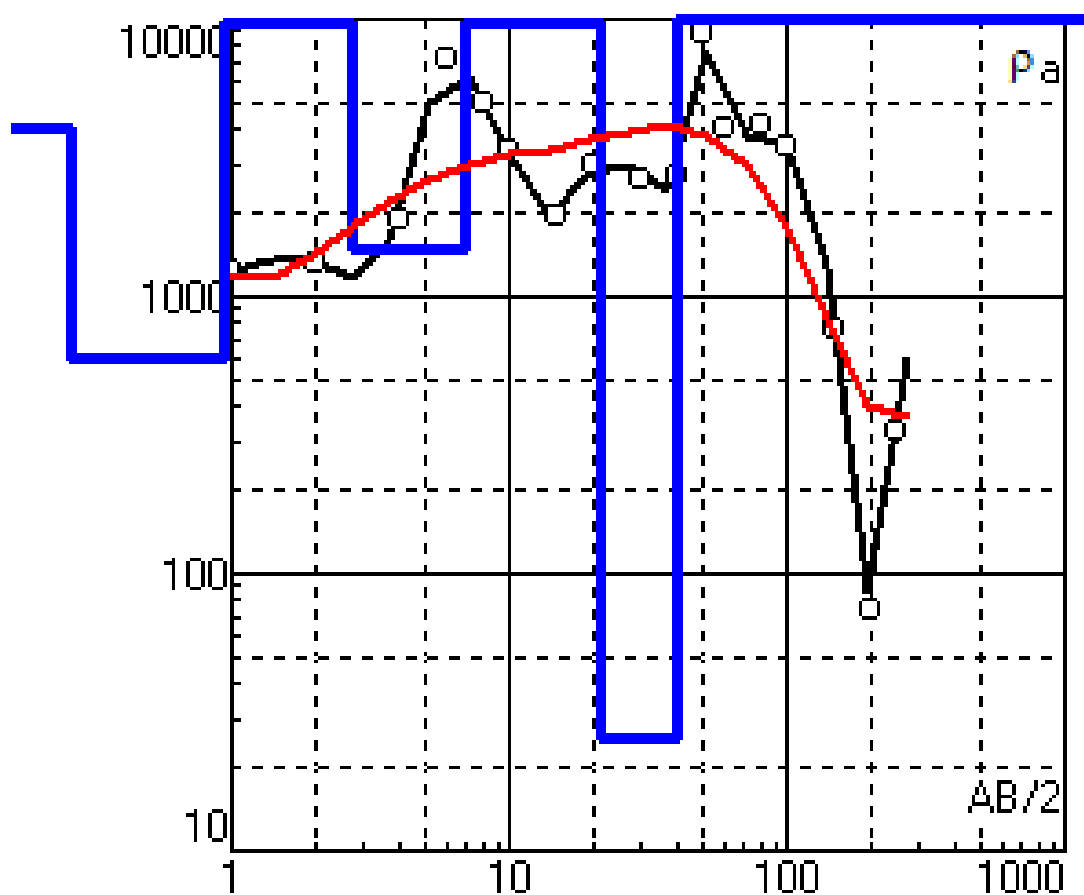


Figure 2d: The Resistivity Curve at the Pavilion (VES 4), A.I.F.U.E. Owerri

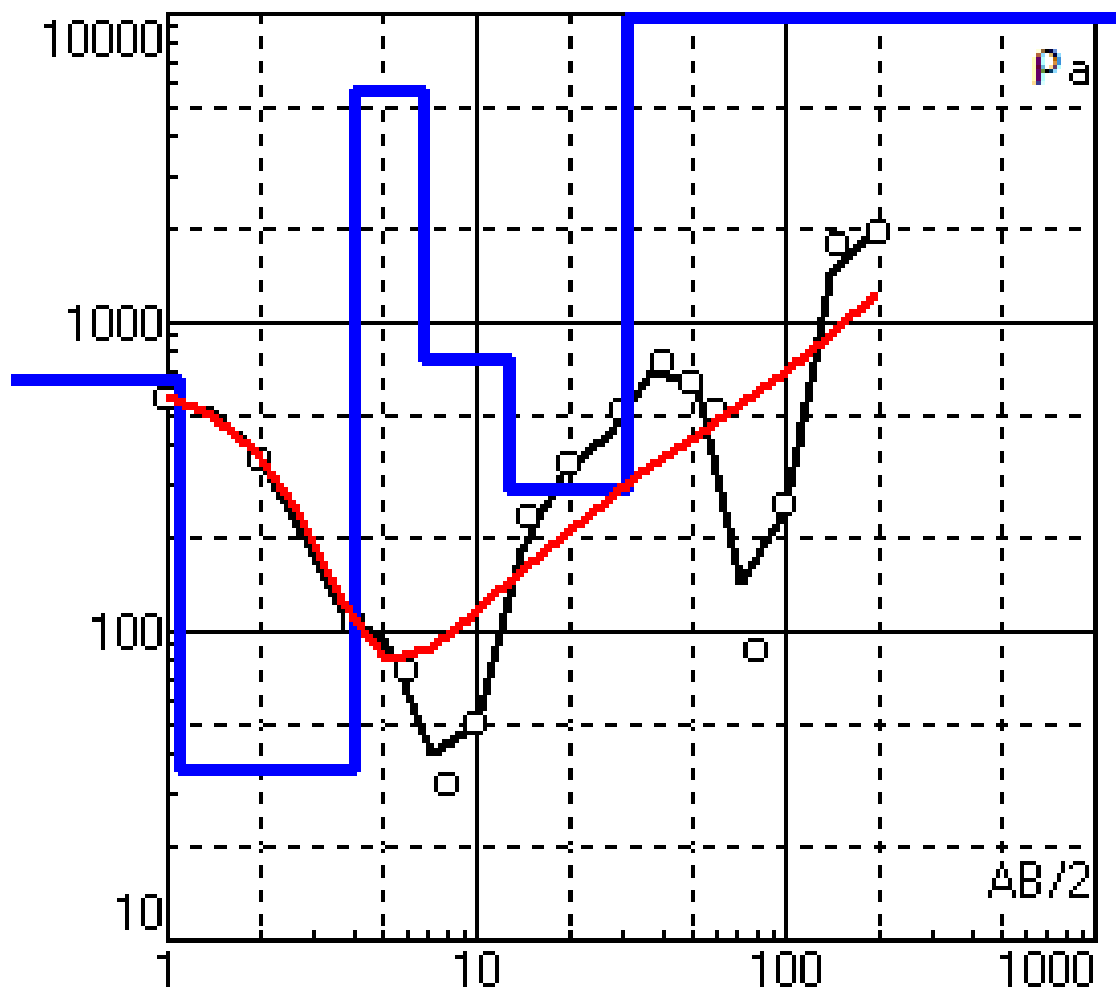


Figure 2e: The Resistivity Curve at the University Gate (VES 5), A.I.F.U.E. Owerri

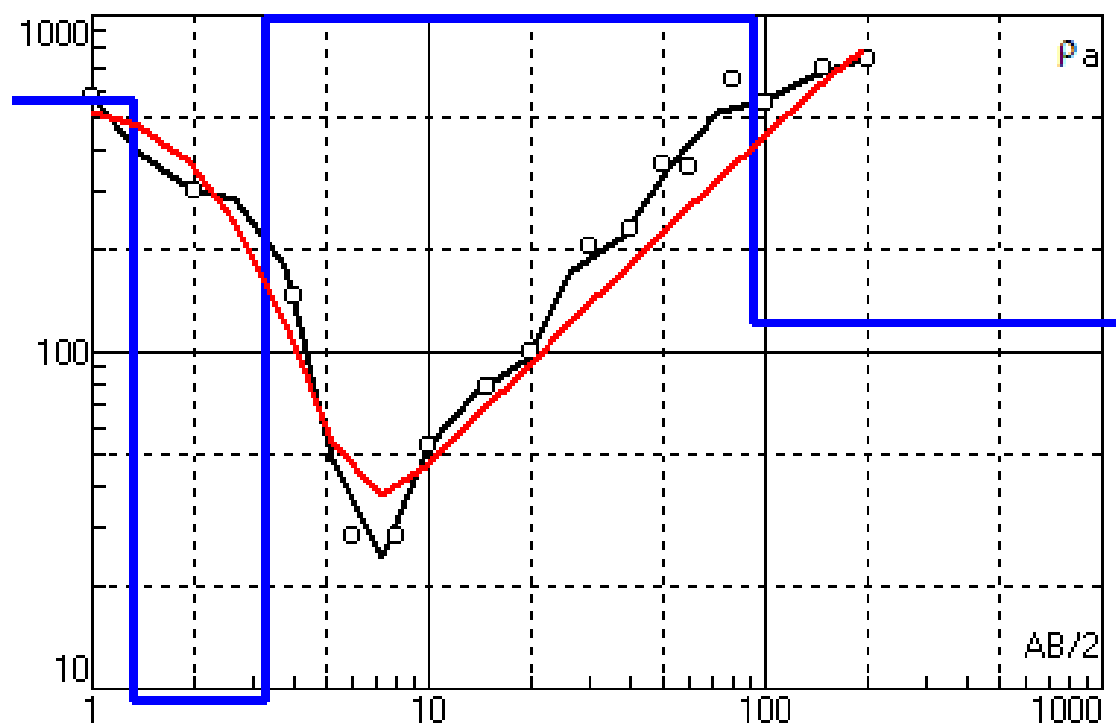


Figure 2f: The Resistivity Curve at the CKC (VES 6), A.I.F.U.E. Owerri

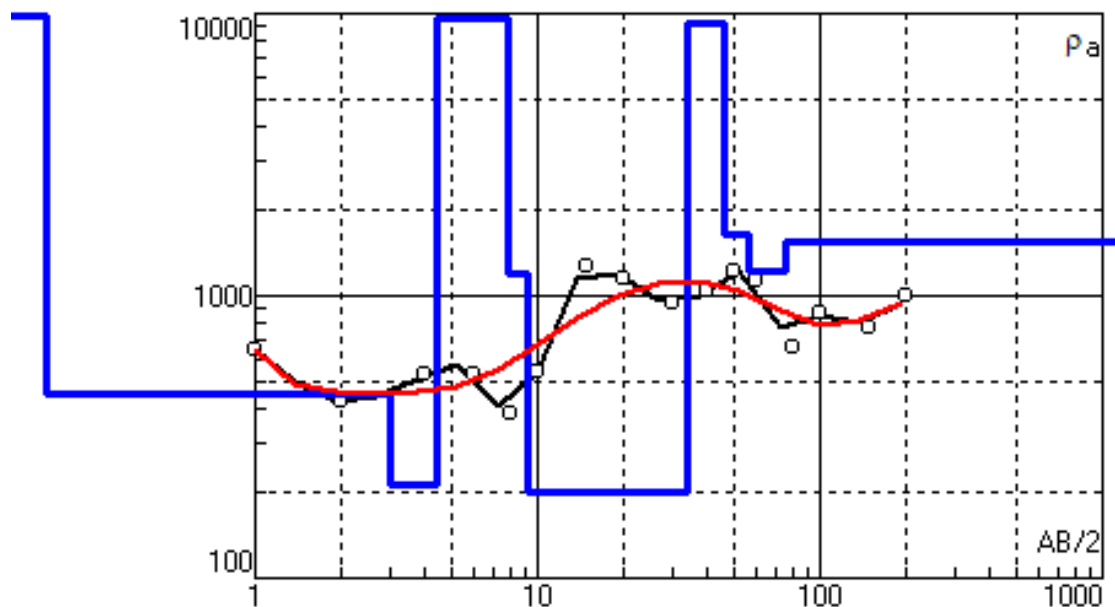


Figure 2g: The Resistivity Curve at Home Economics Department (VES7), A.I.F.U.E. Owerri

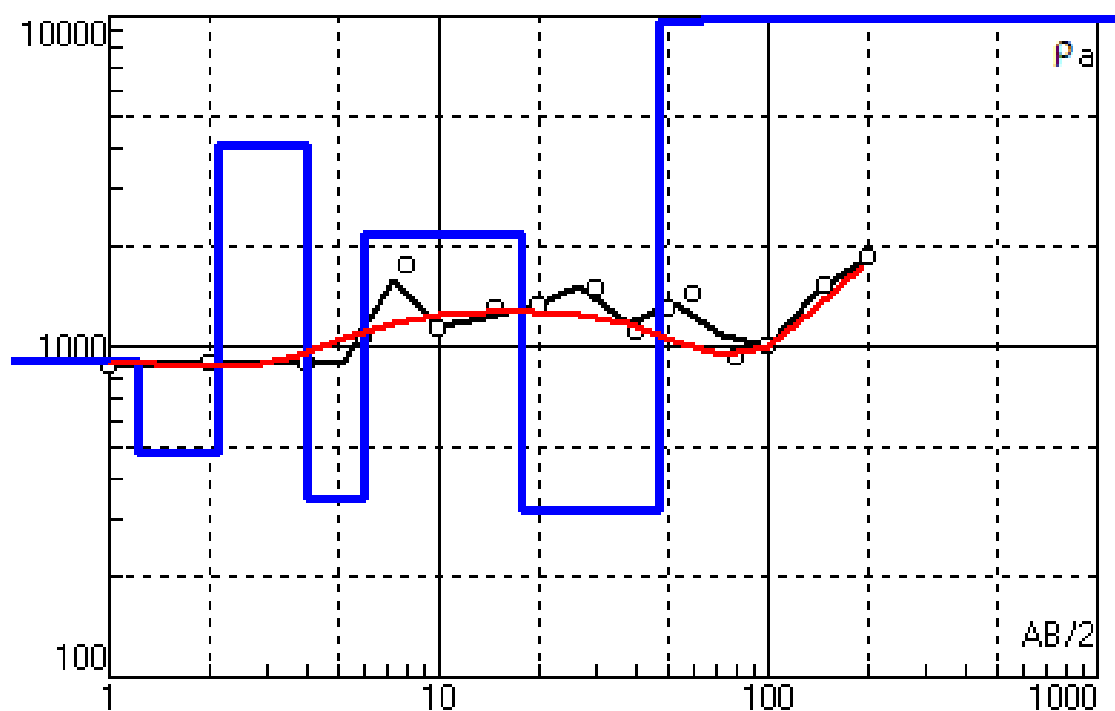


Figure 2h: The Resistivity Curve at the Nursery School (VES 8), A.I.F.U.E. Owerri

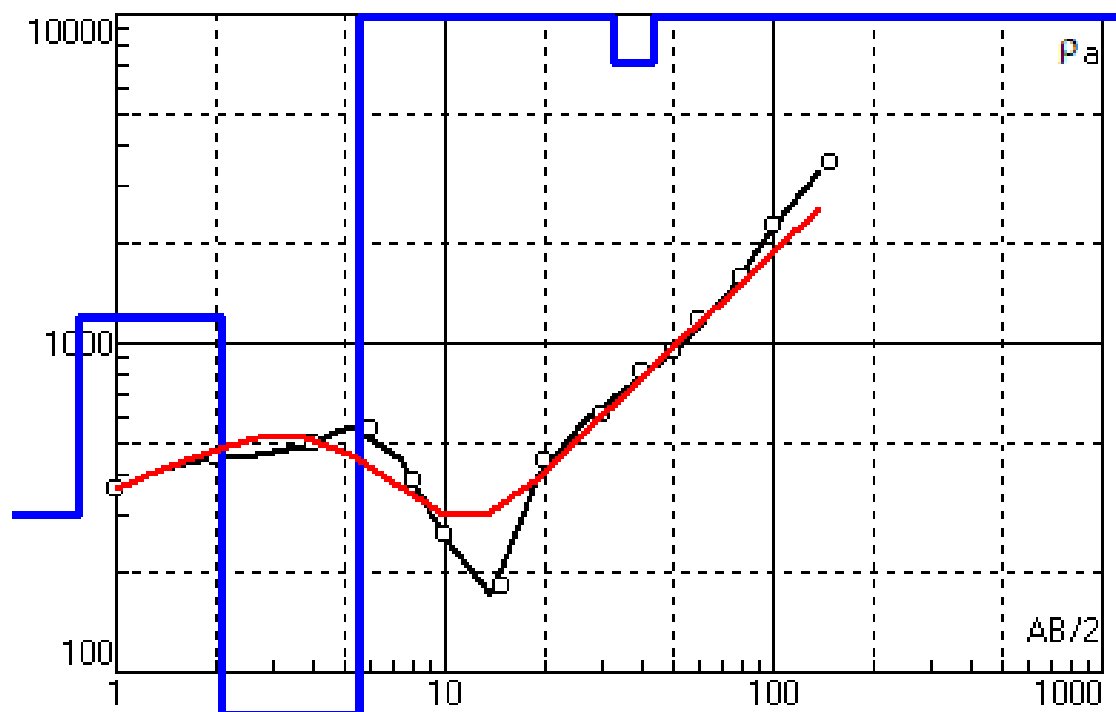


Figure 2i: The Resistivity Curve at Nworie River Bank by Sandwich Building (VES 9), A.I.F.U.E. Owerri

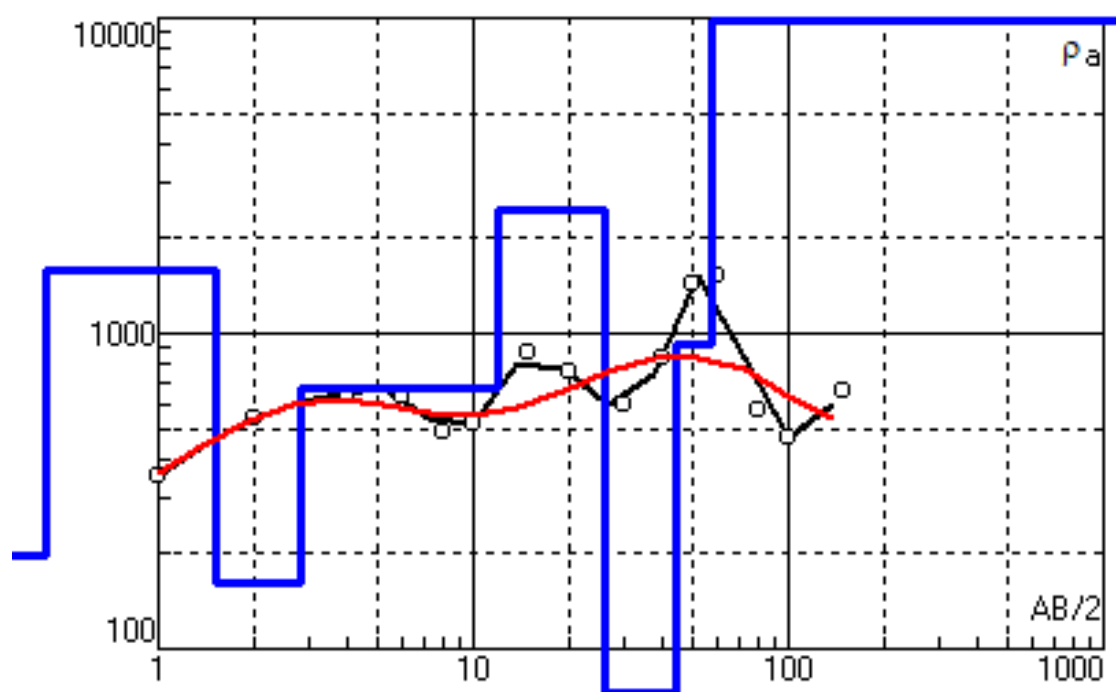


Figure 2k: The Resistivity Curve at between Microteaching Lab., and Nathan Ejiogu Hall (VES 10), A.I.F.U.E. Owerri

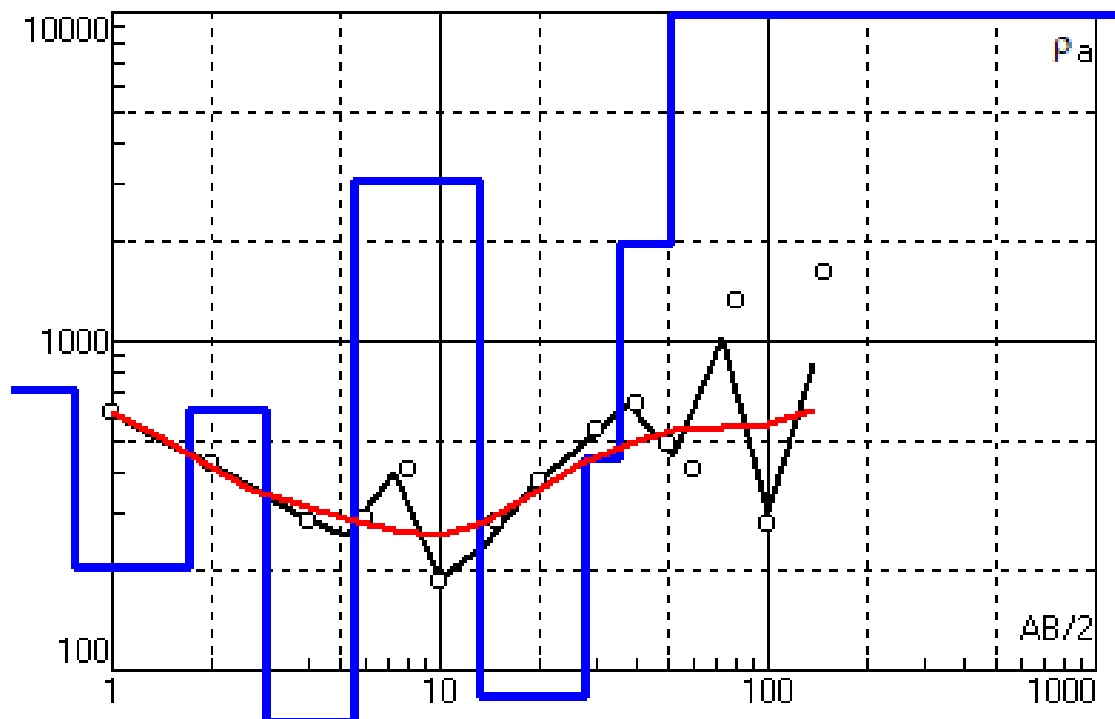


Figure 21: The Resistivity Curve at the Centre for Entrepreneurship Education (VES 11), A.I.F.U.E. Owerri

Presentation of Vulnerability Results

Table 1, summarizes key hydrogeological parameters for eleven different sites, focusing on their electrical and hydraulic properties relevant to aquifer vulnerability assessment. The parameters include the longitudinal conductance (S) in Mho, Protective capacity, transverse resistance ($\Omega \cdot m^2$), GOD index, vulnerability class, aquifer layer(s), depth to aquifer (m), and aquifer type. Longitudinal Conductance (S) ranges from 0.023 to 1.160, indicating varying degrees of aquifer protection, with higher conductance generally implying better natural shielding. The Protective Capacity values are from 'Poor' to 'Good,' indicating the extent to which the overlying layers protect the aquifer from potential contaminants. Transverse Resistance varies widely, with some sites showing very high resistance ($>10^7 \Omega \cdot m^2$), suggesting low vertical leakage, while others exhibit lower resistance. The GOD Index values range from 0.018 to 0.441, Figure 3, with lower values indicating higher vulnerability. The vulnerability ratings are classified as 'Very Low,' with a few categorized as 'High' or 'Moderate'. The sites are predominantly semi-confined aquifers, with depths ranging from 11.8 m to 47.1 m.

Table 1: The Aquifer hydrological, Protective Capacity and Vulnerability Parameters

VES Location	Point/	Longitudinal Conductance S (Mho)	Protective Capacity	Transverse Resistance (Ωm^2)	GOD Index	Vulnerability Class	Aquifer Layer(s)	Depth to Aquifer (m)	Aquifer Type
1, Centre of Excellence		1.160	Good	4.24×10^6	0.018	Very Low	6-7	41.5	Semi-Confined
2, Agric. Department		0.426	Weak	1.594×10^6	0.04216	Very Low	6-7	40.6	Semi-Confined
3, Hostel D		0.560	Moderate	4.62×10^6	0.168	Very Low	7-8	34.1	Semi-Confined
4, Pavilion		0.745	Moderate	1.221×10^6	0.03	Very Low	7	40.4	Semi-Confined
5, University Gate		0.151	Poor	5.27×10^6	0.441	High	6-7	17.5	Unconfined
6, CKC		0.216	Weak	1.10×10^5	0.168	Moderate	5-6	29.8	Semi-confined
7, Homec Department		0.135	Poor	2.86×10^5	0.216	Moderate	7-10	33.7	Semi-confined
8, Nursery School		0.107	Poor	2.55×10^7	0.054	Very Low	7-8	47.1	Semi-confined
9, Sandwich Building		0.0495	Poor	3.68×10^6	0.378	High	4-6	19.1	Semi-confined
10, Microtech Lab.		0.023	Poor	4.24×10^4	0.378	High	6	11.8	Semi-confined
11, Centre for Entrepreneurship Education		0.241	Weak	5.648×10^6	0.168	Moderate	8-9	35.4	Semi-confined

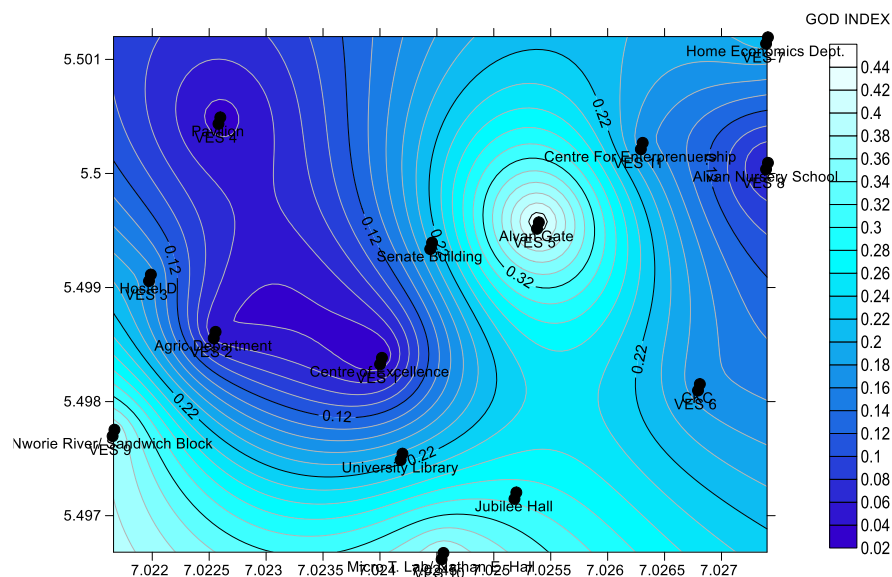


Figure 3: The GOD Index spatial distribution within the Study Area.

4. RESULTS AND DISCUSSION

The resistivity profiles (Table 1) reveal that some locations exhibit low longitudinal conductance (<0.1 Mho), indicating poor protective capacity and high vulnerability to pollution. Notably, at Microteaching Laboratory, Behind Sandwich Building and Home Economics demonstrated the highest vulnerability indices with resistivity values below 0.05 Mho and shallow aquifer depths (11.8 m to 19.1 m). These shallow aquifers are highly susceptible to surface contamination from waste disposal, agricultural runoff, and industrial activities.

The dominant geological formations comprising loose sands and gravels overlaying clay affect the resistivity responses. Sandy layers with high porosity and saturated conditions contribute to high resistivity, indicating good aquifer potential as shown at Centre of Excellence, Hostel D and Pavilion. The vulnerability is rated from very low to High at Sandwich Building especially. The aquifer type of all the locations are classified as semi-confined aquifers which actually protects the groundwater from contamination.

The calculated GOD indices support these observations, with values ranging from 0.168 to 0.378, Figure 3. High GOD indices correlate with shallow aquifer depths and low resistivity, emphasizing areas of higher pollution risk. The spatial distribution indicates that activities, including waste disposal sites and drainage channels, are situated above or near vulnerable aquifers.

The implications are significant in shallow aquifers in Owerri are at considerable risk of contamination, which can lead to waterborne diseases like cholera, dysentery, and typhoid (Nwankwoala et al., 2018). Proper land-use regulations, waste management, and community awareness are essential to mitigate these risks.

5. CONCLUSION

This investigation affirms that the aquifers beneath Alvan Ikoku Federal University of Education, Owerri, are generally poorly to moderately protected and highly vulnerable to pollution. The resistivity values and shallow depths (ranging from 11.8 to 47.1 meters) indicate a fragile hydrogeological environment susceptible to surface contamination. The application of Vertical Electrical Sounding proved effective in delineating subsurface resistivity distributions, identifying zones at risk, and highlighting the need for sustainable groundwater management.

The findings underscore the critical importance of integrating geophysical surveys into regional planning and environmental protection strategies. Urban development should incorporate safeguards such as protective zones around aquifers, improved waste disposal systems, and community education to prevent groundwater contamination. Future research should focus on hydrochemical analyses to complement geophysical data, providing a comprehensive assessment of groundwater quality and vulnerability.

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