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Interpretation of Aquifer Lithology and Depth in Abuja Campus, University of Port Harcourt

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Abstract: **Groundwater remains the primary source of potable water in the Abuja Campus of the University of Port Harcourt. This study aimed to interpret the aquifer lithology and depth using integrated geological and geophysical methods, with a focus on the Benin Formation. Vertical Electrical Sounding (VES) employing the Schlumberger configuration was conducted across the campus to obtain apparent resistivity data, which were subsequently processed and interpreted. The resulting resistivity curve exhibited an H-type configuration, revealing five subsurface layers: sandy topsoil (79.43 Ωm, 1.25 m), dry sand/lateritic sand (120.2 Ωm, 2.45 m), saturated sand (48.75 Ωm, 9.85 m), coarse dry sand/gravel (648.7 Ωm, 51.31 m), and compact sands (436.5 Ωm). The principal aquifer occurs within the third layer, at depths between 3.7 m and 13.6 m, characterized by high porosity and water saturation. Hydrogeological analysis indicates that while the aquifer offers high yield potential, its sandy nature increases susceptibility to contamination. The study highlights the importance of combining geophysical data with geological understanding to improve groundwater exploration in the Niger Delta. Recommendations include proper borehole siting within the saturated sandy horizon, use of protective clay seals, and incorporation of advanced 2D/3D resistivity imaging for future investigations. The findings provide a scientific basis for sustainable groundwater development on the Abuja Campus and can be applied to similar settings across the Niger Delta region.**

Keywords: **Resistivity, Groundwater, Electrical, Geophysical, Heterogeneity.**

1. Introduction

Groundwater is one of the most valuable natural resources and serves as a critical source of freshwater for domestic, industrial, and agricultural needs worldwide. It is estimated that groundwater accounts for approximately 30% of the world's freshwater resources and supports nearly half of the global population for their drinking water needs (UNESCO, 2022). In sub-Saharan Africa, including Nigeria, groundwater plays an even more pivotal role due to the erratic nature of surface water availability, poor infrastructure for water supply, and rapidly growing urban populations (MacDonald et al., 2012; Oteri & Atolagbe, 2015). The increasing demand for safe and sustainable water sources has necessitated a more thorough understanding of groundwater systems, including the lithological and structural controls that govern aquifer characteristics such as depth, thickness, and productivity.

The Abuja Campus of the University of Port Harcourt, located within Rivers State in the Niger Delta region, is a rapidly expanding academic and residential area. As the student and staff populations continue to grow, the demand for potable water within the campus has increased significantly. Currently, water supply is primarily sourced from shallow boreholes and hand-dug wells, which often suffer from seasonal fluctuations and contamination issues (Nwachukwu et al., 2014). Understanding the nature of the subsurface geology, particularly the aquifer lithology and depth, is therefore critical for designing effective and sustainable groundwater development strategies in the area.

Hydrogeological investigations in such areas typically rely on a combination of borehole data and geophysical methods to interpret the subsurface features. Among the geophysical techniques, electrical resistivity methods including Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) are widely used due to their cost-effectiveness, non-invasiveness, and ability to provide continuous subsurface information (Olayinka & Osinowo, 2009; Adeoti et al., 2010). These methods are particularly useful in delineating aquiferous zones, mapping bedrock structures, and identifying potential contamination pathways. In regions with complex lithology, such as the Niger Delta basin, resistivity methods offer a reliable means of characterizing the heterogeneity of aquifer systems (Ako et al., 2014).

The interpretation of resistivity data, when integrated with borehole lithologic logs, provides a more comprehensive understanding of the subsurface conditions. Borehole logs give direct information about the types of sediments, grain size, and stratigraphic succession, while geophysical data offers lateral and vertical continuity. When these data sources are combined, it becomes possible to delineate the lithological composition of aquifers, determine their depth, and estimate their potential for sustainable water yield (Oladapo et al., 2013). This integrated approach is vital in environments like the Abuja Campus, where surface geological exposure is minimal, and subsurface data is limited.

Over the past decades, the Niger Delta has witnessed an increase in groundwater exploration due to rapid urbanization and industrial development. However, most groundwater development projects have focused on regional-scale assessments, leaving many local areas, including university campuses, understudied. The lack of detailed hydrogeological

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mapping at the campus level has resulted in indiscriminate drilling and poor siting of boreholes, often leading to dry wells, poor yield, or contamination problems (Afolayan et al., 2012). Therefore, a localized study focusing on the aquifer lithology and depth within the Abuja Campus is timely and essential for guiding future groundwater development projects.

The Abuja Campus lies within the sedimentary sequences of the Niger Delta Basin, which consists of three major lithostratigraphic units: the Akata Formation, the Agbada Formation, and the Benin Formation (Doust & Omatsola, 1990). The Benin Formation, which underlies much of the Port Harcourt area, is a predominantly sandy unit with minor clay intercalations and is known to host prolific aquifers. However, the heterogeneity within the formation, such as the lateral variation in sand and clay content, poses a challenge to aquifer delineation (Etu-Efeotor & Akpokodje, 1990). This study aims to address this challenge by using geophysical and geological tools to interpret the aquifer units beneath the Abuja Campus.

Recent advances in resistivity imaging techniques, such as 2D and 3D ERT, have further improved the resolution and accuracy of subsurface imaging. These methods allow for the mapping of subtle changes in lithology and groundwater saturation, which are critical for identifying productive aquifer zones and assessing their vulnerability to contamination (Aizebeokhai & Oyeyemi, 2014). Additionally, the application of Geographic Information Systems (GIS) in hydrogeological studies has enhanced the spatial visualization and integration of diverse data sets, including resistivity, lithology, topography, and land use patterns (Ogunlela et al., 2021).

Another critical aspect of aquifer studies is the assessment of aquifer vulnerability, particularly in urban and peri-urban settings like university campuses. With increasing infrastructural development and anthropogenic activities, there is a growing risk of groundwater contamination from surface pollutants, leachates, and poor sanitation practices (Ololade et al., 2019). Accurate delineation of aquifer depth and lithology is crucial for designing effective protection zones and minimizing the risk of contamination. Clay-rich zones, for instance, serve as natural protective layers, while sandy zones are more susceptible to infiltration of contaminants.

Furthermore, understanding the lithology and depth of aquifers is essential for groundwater modeling, recharge estimation, and sustainable water resource management. In regions where groundwater is the sole source of water supply, over-extraction can lead to aquifer depletion, land subsidence, and degradation of water quality (Famuyibo et al., 2018). Therefore, detailed hydrogeological investigations at local scales are indispensable for achieving water security goals, especially in academic institutions that are expected to be models of sustainability.

Despite the growing body of research on groundwater in the Niger Delta, studies focused on intra-campus hydrogeological investigations remain limited. The Abuja Campus of the University of Port Harcourt presents a unique opportunity to bridge this gap by serving as a microcosm of the larger hydrogeological challenges faced in the region. The insights gained from this study could inform groundwater development policies not only within the university but also in similar institutions across Nigeria.

The need for a sustainable and scientifically informed groundwater development strategy in the Abuja Campus cannot be overstated. With the increasing frequency of borehole failure and contamination incidents reported in the area, it has become imperative to adopt a systematic approach to subsurface investigation. This research is therefore designed to provide a detailed interpretation of the aquifer lithology and depth using integrated geological and geophysical methods, with the ultimate goal of improving groundwater exploration, development, and management practices within the campus.

This study is grounded in the recognition that groundwater, while abundant in some parts of Nigeria, is a finite and vulnerable resource that requires careful management. By focusing on the interpretation of aquifer lithology and depth in the Abuja Campus, the research seeks to contribute to a more nuanced understanding of the subsurface conditions that control groundwater occurrence and movement. The findings of this study are expected to enhance decision-making in borehole siting, water quality protection, and long-term sustainability of groundwater resources in the University of Port Harcourt and similar settings.

The primary aim of this study is to interpret the aquifer lithology and depth within the Abuja Campus of the University of Port Harcourt using an integrated approach involving geological and geophysical methods. This interpretation will provide valuable data for sustainable groundwater development, proper borehole siting, and long-term water resource management in the campus area. This study is limited to the Abuja Campus of the University of Port Harcourt. The investigation will involve:

The focus will be strictly on subsurface characterization related to groundwater — not on groundwater quality, recharge dynamics, or hydrological modeling.

To achieve the aim of this research, the following specific objectives are to identify and characterize the different lithologic layers underlying the Abuja Campus, determine the depth and thickness of aquiferous zones using resistivity methods and borehole log analysis, to evaluate the lateral continuity and heterogeneity of the aquifer systems in the study area, integrate lithological and geophysical data for accurate subsurface interpretation, and provide recommendations for improved groundwater exploitation and management on the campus.

The limitation of the study is that there is no access to borehole logs may be limited to only a few drilled wells on campus, advanced geophysical techniques like 3D ERT or drilling of test boreholes may not be feasible, the resistivity values may overlap for different lithologies, leading to interpretational challenges, and the study is bound within an academic schedule and may not capture long-term hydrological variations.

This research is significant for several reasons, such as:

Scientific Relevance: It contributes to the geophysical and hydrogeological understanding of aquifer systems in coastal sedimentary environments.

Institutional Planning: The findings will aid the University of Port Harcourt in making informed decisions about groundwater development, borehole drilling, and water supply planning.

Practical Application: The integrated methodology serves as a model for similar investigations in other campuses or small communities across Nigeria.

Sustainability: Proper delineation of aquifers will reduce the risk of borehole failure and promote sustainable exploitation of groundwater resources.

Academic Contribution: It fills a literature gap regarding campus-scale hydrogeological investigations in the Niger Delta.

2. Geology of the Area

The University of Port Harcourt is situated within the Niger Delta Basin, a prolific sedimentary basin in southern Nigeria. The study area, Abuja Campus, falls within the southeastern fringe of this basin, underlain by the highly porous and permeable Benin Formation, which serves as a major aquifer in the region (Etu-Efeotor & Akpokodje, 1990; Chukwu et al., 2020) as illustrated below in Figure 1. Understanding the geological framework, including the stratigraphy, tectonic setting, hydrostratigraphy, and local lithologic variation, is essential for interpreting aquifer lithology and depth.

The Niger Delta is one of Africa’s largest and most geologically complex delta systems. It developed in the Late Cretaceous to Recent as a result of rifting and subsequent sedimentation along the West African continental margin (Doust & Omatsola, 1990; Whiteman, 1982). The delta has accumulated over 12 km of sediments and contains extensive fluvial, deltaic, and shallow marine depositional sequences.

The delta's evolution is closely linked to the opening of the South Atlantic Ocean during the Late Jurassic–Early Cretaceous period. The tectonic and sedimentary history led to the formation of three main lithostratigraphic units that define the Niger Delta stratigraphy: the Akata, Agbada, and Benin Formations (Nton et al., 2021).

The Stratigraphy of the Study Area:

The Akata Formation is the oldest of the three and serves as the basal unit. It is composed primarily of marine shales with minor sandstone and siltstone intercalations. The formation was deposited under prodelta conditions and typically lies at depths of 3,000 m or more in the subsurface (Reijers, 2011).

Agbada Formation, overlying the Akata is the Agbada Formation, which consists of interbedded sandstones and shales deposited in paralic (coastal) environments. This formation ranges from 300 to 4,500 m thick and is the primary oil-bearing unit in the Niger Delta (Doust & Omatsola, 1990).

The Benin Formation, the youngest unit, is of Miocene to Recent age and consists predominantly of coarse-grained, unconsolidated sandstones with occasional clay lenses. It reaches up to 2,000 m in thickness and forms the main aquiferous unit throughout much of the delta (Okereke et al., 2017). It is this formation that underlies the Abuja Campus and provides the primary focus for groundwater exploration in the study.

The Niger Delta Basin is a passive margin basin formed by the separation of the African and South American plates. The region is characterized by extensional tectonics, gravity-induced faulting, and growth fault systems, which significantly influence groundwater flow patterns (Corredor et al., 2005; Essien et al., 2019). These structural features can enhance or restrict aquifer connectivity, depending on their orientation and fill material.

The delta is also subject to minor seismic activity and subsidence, which further complicate hydrogeological interpretations (Adepelumi et al., 2017). In the Port Harcourt area, these structures are less pronounced but may still influence local groundwater distribution, especially where buried channels or fault lines occur.

The Benin Formation is the principal hydrostratigraphic unit in the study area. It is a continental deposit made up of loosely compacted, coarse to medium-grained sands, often interbedded with lateritic soils and clayey lenses. These sands exhibit high porosity (20–35%) and permeability, making them excellent aquifer materials (Ehirim & Ebeniro, 2013).

Aquifers within the Benin Formation are typically unconfined to semi-confined, depending on the presence and thickness of overlying clay units. The aquifer thickness varies significantly due to lithologic heterogeneity but generally ranges from 10 to 70 meters in the Port Harcourt area (Etu-Efeotor & Akpokodje, 1990; Chukwudi et al., 2023).

Abuja Campus is situated in Choba, Obio-Akpor LGA, Rivers State. The local geology is reflective of the broader Benin Formation characteristics, dominated by sandy sediments, laterites, and minor clay horizons (Nwachukwu & Uzoije, 2014). The terrain is relatively flat, with gentle undulations that encourage surface runoff and moderate infiltration.

The heterogeneity of the Benin Formation introduces variability in aquifer productivity. Thick, clean sand beds represent the most productive zones, while interbedded clay layers can act as aquitards, restricting vertical flow and influencing water quality (Aizebeokhai et al., 2016).

The presence of clay-rich layers, although less dominant, has twofold significance: they may restrict contaminant migration, acting as protective barriers, or they may reduce recharge if overly thick and impermeable (Famuyibo et al., 2018).

Groundwater in the study area occurs under unconfined to semi-confined conditions. Recharge primarily comes from rainfall infiltration, facilitated by the high permeability of the sandy layers. The average annual rainfall in Port Harcourt exceeds 2,300 mm, making recharge potentially abundant, though often limited by urbanization and compaction (Akankpo & Igboekwe, 2011).

Groundwater movement is generally from north to south, following the regional slope and topography. However, local flow patterns may be distorted by human development, buried channels, and lithologic variability (Chinyem et al., 2020).

Despite the high groundwater potential, aquifer delineation is often challenging due to:

Lithological Similarity: Coarse sands and gravels yield similar resistivity signatures.

Discontinuous Aquifers: Some aquifers are laterally limited by clay barriers or paleochannels.

Borehole Siting Errors: Drillers often rely on surface information or guesswork, leading to dry or poorly productive boreholes.

Contamination Risk: Shallow aquifers in sandy formations are vulnerable to surface contamination due to lack of protective clay cover (Ololade et al., 2019).

These challenges underscore the importance of combining geophysical methods with borehole log data for a reliable interpretation of aquifer geometry and depth.

Recent studies have emphasized the integration of Geographic Information Systems (GIS) with geophysical data to improve groundwater targeting and aquifer management (Akinlalu et al., 2021). In the Abuja Campus context, GIS can be used to create spatial maps of aquifer depth, resistivity, lithologic boundaries, and potential recharge zones.

Additionally, advances in 2D and 3D electrical resistivity tomography (ERT) allow better visualization of subsurface heterogeneity, essential for locating high-yield aquifer zones and avoiding drilling failures (Aizebeokhai & Oyeyemi, 2014; Okere et al., 2020).

The geology of the Abuja Campus is controlled by the Benin Formation, which hosts the region's major aquifers. Its high porosity, permeability, and sand dominance make it ideal for groundwater development. However, variability in lithology, especially the presence of interbedded clay, requires detailed subsurface characterization to avoid drilling failure and to ensure sustainable exploitation.

Understanding the local geology through an integrated interpretation of geophysical and borehole data will enable better mapping of aquifer boundaries, determination of thickness, and assessment of groundwater potential.

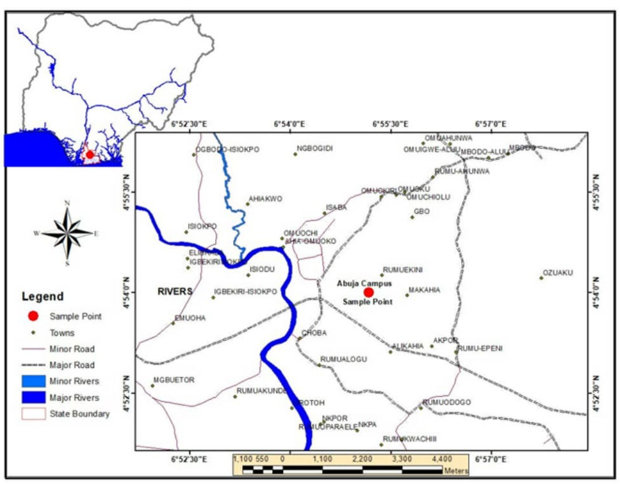

Fig. 1. The geologic map of the area

Groundwater is a critical natural resource that supports the livelihood of billions worldwide, particularly in regions where surface water is either seasonal or contaminated. Globally, it accounts for over 50% of domestic water supply and over 40% of irrigation needs (Custodio & Llamas, 1983; UNESCO, 2022). In developing nations, especially sub-Saharan Africa, groundwater plays a central role in meeting rural and urban water demands due to its relative protection from immediate surface pollution, abundance, and year-round availability (MacDonald et al., 2012; Ololade et al., 2019). Nigeria's increasing urbanization and the unreliability of municipal water supply have intensified reliance on groundwater across residential, industrial, and institutional settings (Oteri & Atolagbe, 2015).

The conceptual foundation for aquifer studies hinges on the understanding of subsurface lithology, porosity, permeability, and hydrostratigraphy, which determine groundwater occurrence and movement. The theoretical frameworks informing groundwater studies often draw from Darcy's law, flow-net analysis, and hydrogeological modeling (Todd & Mays, 2005). These frameworks emphasize that aquifer productivity is influenced not only by rock type but also by the configuration and continuity of porous media, recharge mechanisms, and anthropogenic factors.

In Nigeria, the Benin Formation has been identified as one of the most productive aquifers, particularly in the Niger Delta region where it underlies much of Rivers, Bayelsa, and Delta States (Etu-Efeotor & Akpokodje, 1990; Nwachukwu et al., 2014). This formation, consisting mainly of coarse sandstones and minor clays, offers favorable conditions for groundwater abstraction. However, the presence of clay lenses, buried channels, and lithologic heterogeneity makes aquifer delineation complex (Chukwu et al., 2020).

Traditionally, borehole data has served as the primary source of subsurface geological information. Borehole lithologic logs offer direct insights into the composition, depth, and sequence of subsurface materials. However, borehole data are often sparse, spatially discontinuous, and expensive to acquire. These limitations have led to increased adoption of geophysical methods, particularly electrical resistivity techniques, as complementary tools in aquifer investigations (Olayinka & Osinowo, 2009; Ako et al., 2014).

Electrical resistivity methods, especially Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), have proven highly effective in hydrogeological mapping. These methods rely on the principle that different subsurface materials conduct electricity differently based on their porosity, saturation, and mineral content (Parasnis, 1997). Sandy formations typically have high resistivity due to low conductivity, whereas clayey or saturated zones show lower resistivity values. Studies by Adeoti et al. (2010) and Ehirim and Ebeniro (2013) demonstrated that resistivity methods can delineate aquiferous zones, map basement topography, and even detect potential contamination plumes.

Recent improvements in inversion algorithms and data visualization have made 2D and 3D resistivity imaging popular for detailed subsurface studies. For instance, Aizebeokhai and Oyeyemi (2014) used 2D ERT to map aquifer distribution in parts of Ogun State and successfully identified multilayered aquifers. Similar works by Famuyibo et al. (2018) and Akankpo and Igboekwe (2011) revealed that resistivity data can be correlated with borehole logs to improve accuracy and reliability of interpretations.

Integrative approaches that combine geophysical and geological datasets are increasingly being advocated. Oladapo et al. (2013) emphasized that relying solely on resistivity data can be misleading, especially in areas where lithologic units have overlapping resistivity ranges. Thus, combining resistivity surveys with borehole logs allows for cross-validation and more reliable delineation of aquifers. Chinyem et al. (2020) applied this integrated approach in Port Harcourt and observed significant improvements in the prediction of aquifer depth and thickness.

Despite the considerable progress, several literature gaps remain. First, most groundwater studies in Nigeria are conducted at regional or state levels, with fewer micro-scale studies tailored to small environments like university campuses. Second, few studies integrate multiple data types such as resistivity, borehole, and GIS in a structured, systematic way. Third, the influence of buried structural features such as paleo-channels and faults on aquifer geometry is rarely addressed, even though such features can drastically affect local water availability.

The University of Port Harcourt, particularly the Abuja Campus, has been understudied in terms of aquifer characterization. Most prior investigations have focused on the main campus or broader Obio-Akpor region. The specific hydrogeological profile of the Abuja Campus remains largely undocumented, yet borehole failure and water shortage issues are commonly reported (Nwachukwu & Uzoije, 2014). This presents a significant research opportunity to fill knowledge gaps and enhance water resource management on the campus.

The reviewed literature strongly supports the use of integrated geological and geophysical methods for aquifer characterization. It demonstrates that resistivity techniques, when combined with borehole logs and interpreted within a geological framework, provide a reliable basis for determining aquifer lithology and depth. Moreover, the adoption of advanced data processing tools, GIS applications, and vulnerability assessment techniques has enriched the field. However, the lack of focused studies on university campuses like the Abuja Campus suggests the need for localized investigations to support sustainable groundwater management in such settings.

3. Methodology

An integrated geophysical and geological approach was adopted to characterize aquifer lithology and depth. The primary method used was Vertical Electrical Sounding (VES) employing the Schlumberger array configuration. This method measures variations in subsurface electrical resistivity, which correspond to different lithologies and groundwater conditions.

Multiple VES stations were occupied within the campus to capture lateral and vertical variations in subsurface resistivity. Current electrodes were progressively expanded to increase depth of investigation, while potential electrode spacing was adjusted for signal strength.

The electrode spacing is 200m and the half spacing AB/2 is 100m.

Apparent resistivity data were plotted against electrode spacing on a log–log scale to produce resistivity curves. These curves were matched with theoretical master curves to derive true resistivity values, layer thicknesses, and depths.

The curve obtained for Abuja Campus displayed an H-type configuration, characterized by alternating high–low–high resistivity patterns indicative of sandy, saturated, and compact sand/gravel layers.

The materials used at the course of this research are:

1. Resistivity meter and accessories (cables, electrodes, hammers)
2. Measuring tapes for electrode spacing
3. GPS device for coordinate logging
4. Field notebooks and data sheets
5. Computer software for curve matching and geoelectric section plotting

4. Results and Discussion

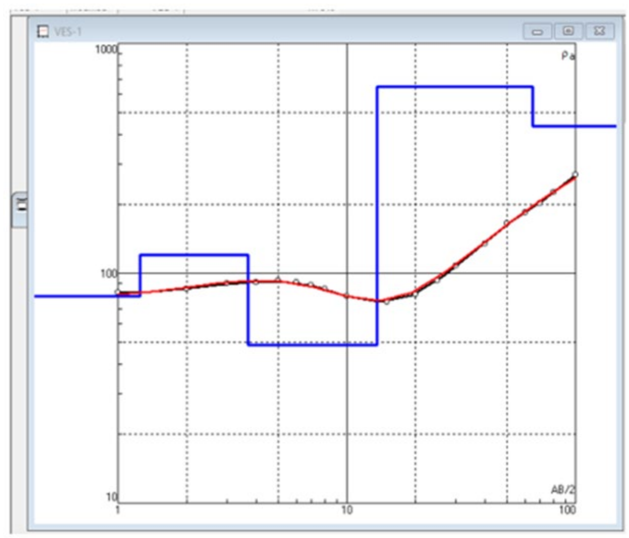

Fig. 2. The resistivity curve for Abuja campus

Table 1
The apparent resistivity, depth and thickness of the curve

S/n	Resistivity (Ωm)	Depth (m)	Thickness (m)
1	79.43	1.25	1.25
2	120.2	3.698	2.448
3	48.75	13.55	9.854
4	648.7	64.87	51.31
5	436.5		

A. Discussion

The resistivity curve in Figure 2 and Table 1 shown to have a five (5) subsurface layers with four (4) thicknesses.

Layer 1: 79.43Ωm, ~1.25m thick — likely sandy topsoil with moderate moisture content.

Layer 2: 120.2Ωm, ~2.45m thick — indicative of dry to slightly moist sand or lateritic sand.

Layer 3: 48.75Ωm, ~9.85m thick — significantly lower resistivity, interpreted as saturated fine-to-medium sand forming part of the main aquifer zone.

Layer 4: 648.7Ωm, ~51.31m thick — high resistivity suggesting coarse dry sand, gravelly sand, or compacted sediments, possibly a deeper unconfined aquifer with less saturation.

Layer 5: 436.5Ωm — interpreted as deeper compact sands or semi-consolidated deposits.

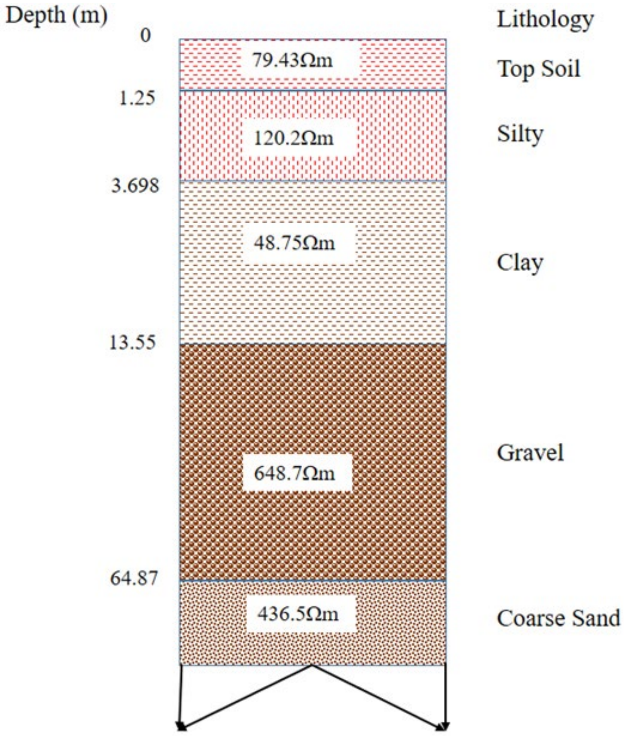

Fig. 3. The geoelectric section for resistivity curve

The configuration of the subsurface ranges from low-high-low-high scenario which indicates its resistivity trends, and the resistivity trend of the curve, $\ell_1<\ell_2>\ell_3<\ell_4>\ell_5$, which is characteristic of an H-type resistivity curve type as seen in Figure 2, this pattern reveals increasing resistive layers, and also reveals a sequence where deeper layers have increasingly higher resistivity, which typically indicates progression from surface sandy soil through saturated zones to deeper, relatively drier or more compact sand/gravel units.

The H-type curve configuration reflects a sequence where an unsaturated zone overlies a water-bearing layer, which is in turn underlain by more resistive materials. This aligns with typical Benin Formation aquifer patterns where clay content is minimal and aquifer productivity is controlled by sand thickness and grain size.

The third layer represents the principal aquifer horizon due to its saturation and thickness.

The deeper resistive layers could store water but may require deeper drilling to access, potentially increasing costs.

The high permeability of these sandy layers facilitates recharge but also increases vulnerability to contamination, especially in areas with poor sanitation

5. Summary

The study successfully applied electrical resistivity methods to delineate aquifer lithology and depth beneath Abuja Campus. Five subsurface layers were identified, with the main aquifer located at ~3.7–13.6m depth. The lithology is dominated by sandy sediments of the Benin Formation, characterized by high porosity and permeability. The resistivity pattern corresponds to an H-type curve typical of Niger Delta aquifers.

6. Conclusion

The main productive aquifer occurs within saturated sandy units between 13m to 64.87m depth.

The Benin Formation's sandy nature ensures high yield potential but increases vulnerability to contamination.

An integrated approach combining geophysics and geological knowledge enhances reliability of aquifer characterization.

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