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Interpretation Of Resistivity Curves for Aquifer Depth Evaluation in Parts of Alakahia, Rivers State.

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Abstract
This research focuses on evaluating aquifer depths in parts of Alakahia, Rivers State, Nigeria, through the interpretation of resistivity curves derived from Vertical Electrical Sounding (VES). Recognizing the rising demand for groundwater driven by rapid urbanization, the study employed the Schlumberger array configuration at two VES locations to probe subsurface lithology and delineate aquiferous zones. Field measurements of apparent resistivity were processed using partial curve matching and computer-assisted inversion to construct resistivity sounding curves and geoelectric sections. Results revealed a complex multi-layered subsurface typical of the Niger Delta's Benin Formation. VES-1 exhibited an H-type curve, indicating a low-resistivity clayey sand layer sandwiched between higher resistivity sands and gravels, suggesting a confined aquifer protected by an overlying clay layer. VES-2 showed a Q-type curve, reflecting alternating conductive and resistive layers, culminating in a thick, deep sand/gravel unit interpreted as a productive aquifer. Aquifer depths were identified from approximately 20 m to over 80 m, consistent with regional hydrogeology. The study underscores the effectiveness of resistivity methods in groundwater exploration, providing critical data for borehole siting, contamination risk reduction, and sustainable resource management. Limitations include a limited number of VES points and absence of direct borehole correlation, which are recommended for future studies. Overall, the research contributes updated hydrogeological insights into Alakahia, supporting efforts to meet growing water needs through informed groundwater development.

Keywords: *resistivity, evaluation, aquifer, interpretation, depth, groundwater*

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I. Introduction

Groundwater remains an indispensable natural resource, serving as the primary source of potable water for billions globally (Fetter, 2001; Todd & Mays, 2005). In many urban and peri-urban areas of Nigeria, rapid population growth and infrastructural development have heightened dependence on groundwater as municipal supply systems struggle to meet demand (Oteri, 1988; Nwankwoala & Mmom, 2017). Alakahia, located within Obio-Akpor Local Government Area of Rivers State, exemplifies this challenge, with rising population density increasing pressure on limited and poorly characterized aquifer systems.

Proper evaluation of aquifer depths, geometry and protective capacities is fundamental for sustainable groundwater development, resource management and contamination prevention (Fitts, 2013). Traditionally, borehole drilling provides direct lithological and stratigraphic data; however, this method is invasive, costly and spatially restricted (Reynolds, 2011). In contrast, geophysical methods—particularly the electrical resistivity method (ERM)—offer a non-invasive, cost-effective approach for subsurface characterization over larger areas (Kearey et al., 2013).

The electrical resistivity method is built on the principle that different earth materials conduct electricity differently, largely due to their lithology, porosity, saturation and pore water chemistry (Parasnis, 1997). Vertical Electrical Sounding (VES), often using the Schlumberger array, measures apparent resistivity as electrode spacing increases, allowing inference of layered earth structure and aquifer depths (Telford et al., 1990). The interpretation of resistivity sounding curves (plots of apparent resistivity versus electrode spacing) thus becomes critical in identifying aquiferous layers and estimating their depths (Koefoed, 1979).

In the Niger Delta region, the complex depositional environment and the dominance of the Benin Formation make ERM particularly effective (Avbovbo, 1978; Etu-Efeotor & Akpokodje, 1990). Previous studies (Oteri, 1988; Nwankwoala & Mmom, 2017) have demonstrated the utility of ERM for groundwater exploration, yet spatial gaps remain, especially in rapidly developing communities like Alakahia, where up-to-date subsurface data are scarce. This research, therefore, seeks to interpret resistivity curves obtained from VES surveys in parts of Alakahia to evaluate aquifer depths, offering critical information for sustainable water resource planning.

The aim of this study is to evaluate aquifer depths in parts of Alakahia through the interpretation of resistivity curves.

Alakahia is characterised by rapid urban growth, which places enormous demand on groundwater resources. Unfortunately, there is limited up-to-date subsurface hydrogeological data to support efficient water resource planning. Traditional drilling is expensive and often arbitrary without prior geophysical evaluation. Hence, there is a pressing need to use non-invasive, cost-effective geophysical techniques to evaluate aquifer depths and guide future groundwater development (Olorunfemi & Olorunniwo, 1985).

The study covers selected locations within Alakahia, Rivers State. It focuses primarily on Data acquisition using Schlumberger array configuration, interpretation of apparent resistivity curves and estimation of aquifer depths and thicknesses.

The findings from this study will provide updated subsurface information for water resource planners, serve as a guide for borehole drilling to reduce the risk of dry wells, contribute to academic research on the hydrogeology of Rivers State and support sustainable groundwater management.

The limitation of this study is that:

1. Only two VES points were used, limiting lateral correlation.
2. Depth of investigation depends on electrode spread; deeper layers beyond ~80–100m may remain unresolved.
3. Non-uniqueness in resistivity interpretation: different lithologies can show similar resistivity values.
4. Field conditions (e.g., cultural noise, infrastructure) may affect data quality.
5. Absence of borehole data limited lithological confirmation.

Groundwater resource evaluation is a multidisciplinary process that combines geological, hydrogeological, and geophysical knowledge to identify, quantify, and protect aquifers (Fetter, 2001). In rapidly urbanizing areas like Alakahia, non-invasive geophysical methods, notably the electrical resistivity method (ERM), are critical for estimating aquifer depths and delineating subsurface stratigraphy (Reynolds, 2011). This chapter reviews existing literature, presents the study's conceptual and theoretical foundations, and summarizes empirical studies relevant to aquifer evaluation using resistivity methods, particularly in the Niger Delta region.

A conceptual framework acts as a blueprint, clarifying the relationship between the study's core concepts and guiding the interpretation of data (Maxwell, 2013). For this study, the key concepts are:

Aquifer: a permeable geological formation capable of storing and transmitting significant quantities of groundwater (Fitts, 2013).

Electrical resistivity: the capacity of subsurface materials to resist the flow of electric current, expressed in ohm-meters (Parasnis, 1997).

Resistivity sounding curves: plots of apparent resistivity values against electrode spacing (AB/2), used to interpret subsurface layering and identify aquiferous zones (Koefoed, 1979).

The framework assumes that variations in subsurface resistivity are directly related to differences in lithology, porosity, and water content (Telford et al., 1990). By acquiring resistivity data, generating sounding curves, and interpreting these curves, it is possible to delineate aquifer horizons and estimate their depths.

In Alakahia, the underlying geology is dominated by the Benin Formation, composed mainly of sands, gravels, and thin clay intercalations (Avbovbo, 1978). This unconsolidated, highly porous formation makes electrical resistivity methods particularly effective for aquifer detection (Nwankwoala & Mmom, 2017). The conceptual link, therefore, is clear: subsurface lithological variations lead to resistivity contrasts, which can be interpreted to locate and characterise aquifers.

The Schlumberger array, involving two current electrodes (A, B) and two potential electrodes (M, N), is sensitive to vertical changes in resistivity (Telford et al., 1990). As the electrode spacing (AB/2) increases, the depth of investigation increases.

Apparent resistivity values are calculated and plotted against AB/2 on bi-log graphs, forming resistivity sounding curves. Interpretation methods include:

Partial curve matching: manual matching of field curves with standard master curves (Koefoed, 1979). Iterative modelling to fit field data and derive true resistivity and layer thicknesses (Loke, 1999), Software tools like IPI2Win have streamlined this process, improving accuracy (Loke, 1999).

While extensive studies exist for parts of Port Harcourt and Obio-Akpor, recent rapid urbanisation in Alakahia has created new hydrogeological complexities. Current data on aquifer depths and protective clay cover are limited. This study aims to fill that gap using updated resistivity

The integration of theoretical principles, empirical studies, and the study's conceptual framework provides a strong basis for using ERM to evaluate aquifer depths. This review highlights the method's strengths and limitations, previous findings in similar geological settings, and the specific need for updated studies in Alakahia.

1. **Geology of The Area**

Alakahia is situated within the Niger Delta Basin as shown in Figure 1. below, one of the world's largest deltaic environments, underlain predominantly by the Benin Formation (also known as Coastal Plain Sands). The Benin

Formation is of Miocene to Recent age and comprises mainly unconsolidated, coarse- to medium-grained sands, gravels, minor clay intercalations, and occasional silt lenses (Avbovbo, 1978; Short & Stauble, 1967).
The formation is highly porous and permeable, making it a prolific aquifer system (Nwankwoala & Mmom, 2017). Beneath the Benin Formation lie the Agbada Formation (alternating sandstones and shales, which serve as reservoirs and seals in petroleum systems) and the basal Akata Formation, which consists mainly of shales (Doust & Omatsola, 1990).
Alakahia is situated in Obio-Akpor Local Government Area of Rivers State, Nigeria. Geographically, it lies between latitude 4°51'N–4°55'N and longitude 6°54'E–6°57'E. The area experiences a humid tropical climate with high annual rainfall (~2,400 mm) (NIMET, 2018). The topography is generally low-lying and gently undulating. Geologically, Alakahia falls within the Niger Delta Basin, mainly underlain by the Benin Formation, characterised by unconsolidated sands, gravels, and occasional clay intercalations (Avbovbo, 1978).
Alakahia's drainage is typical of the Niger Delta's lowland coastal plain, characterized by a dense network of meandering streams and creeks. These streams generally flow in a southeastward direction towards the Bonny River and the Atlantic Ocean (Nwankwoala, 2011). The drainage pattern is dendritic, shaped by the underlying unconsolidated sands and flat topography, which promote diffuse surface runoff and shallow infiltration (Iloeje, 2001).
The natural vegetation of Alakahia falls within the freshwater swamp forest zone, transitioning into lowland rainforest. Typical flora includes raffia palms (Raphia hookeri), oil palms (Elaeis guineensis), bamboo stands, and numerous broadleaf species (Keay, 1959). Human activities, especially urban development, have led to the replacement of large areas with secondary vegetation, gardens, and scattered trees (Areola, 1982). Pockets of marshy areas still support grasses, sedges, and aquatic plants.
Alakahia experiences a humid tropical climate dominated by two seasons:
Wet season: April to October, with peak rainfall in July and September.
Dry season: November to March.
Annual rainfall averages 2,200–2,500 mm (NIMET, 2018). Temperatures remain fairly uniform year-round, ranging from about 25°C to 32°C. Relative humidity is high, often above 80%, especially during the wet season (Ojo, 1977). The area benefits from the moderating influence of the Atlantic Ocean, leading to reduced temperature extremes and high moisture content in the atmosphere.
Alakahia is part of Obio-Akpor Local Government Area, one of the most urbanised and densely populated LGAs in Rivers State. According to Nigeria's National Population Commission (NPC, 2006) and recent projections, Obio-Akpor has experienced rapid population growth, driven by migration and urban expansion. Estimates suggest a local population density exceeding 2,000 persons/km², reflecting the influence of nearby Port Harcourt metropolis as a major commercial and administrative hub (Oyegun, 1994).

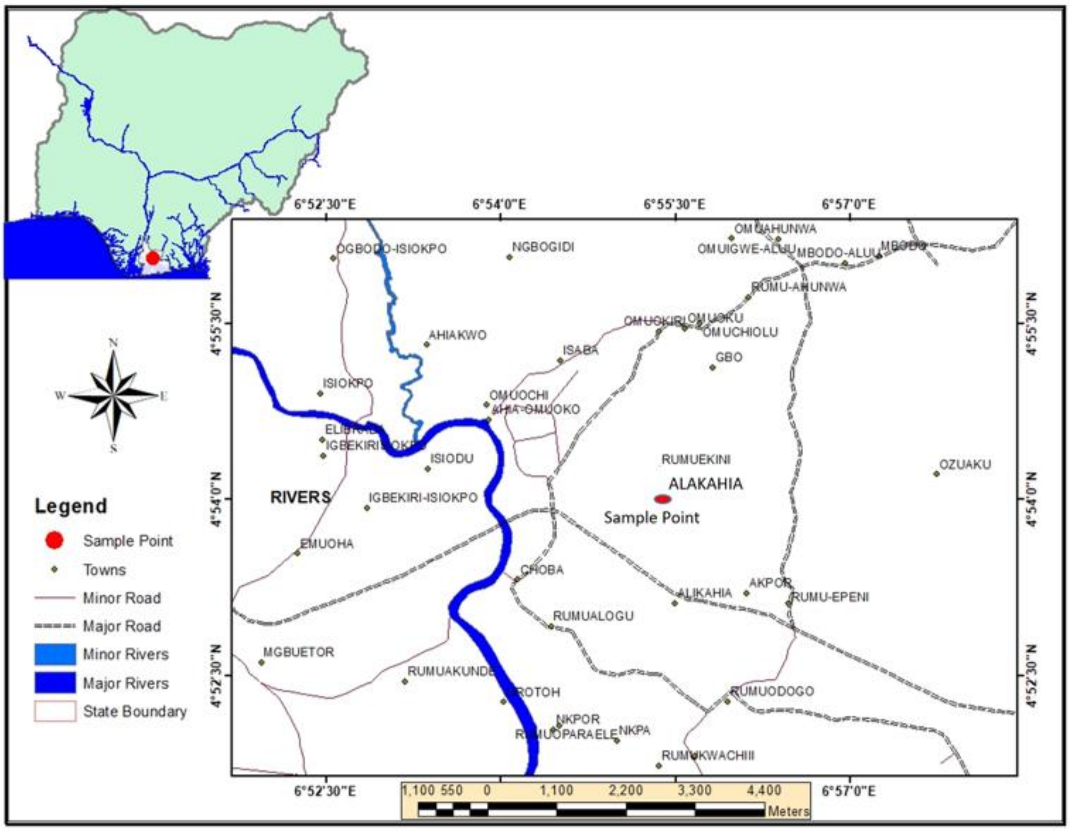

Figure 1: The Geologic Map of the Area

II. Methodology

The study employed the Vertical Electrical Sounding (VES) technique of the Electrical Resistivity Method (ERM), specifically using the Schlumberger array configuration, to investigate aquifer depths and subsurface lithological variation in parts of Alakahia, Rivers State, Nigeria. This approach was chosen because of its proven effectiveness in evaluating layered earth structures and its adaptability to the geological complexity of the Niger Delta's Benin Formation.

Two VES stations (VES-1 and VES-2) were strategically located within Alakahia based on accessibility, spatial distribution, and anticipated geological variability. Site selection also accounted for minimal interference from nearby infrastructure, power lines, and metallic objects, which could affect data quality.

At each station, fieldwork involved the following key steps:

3.2.1. Electrode Arrangement:

The Schlumberger array uses four electrodes placed collinearly along the ground surface:

Two outer electrodes (A and B) inject electric current into the ground.

Two inner electrodes (M and N) measure the resulting potential difference. Starting with small electrode spacing to probe shallow depths, the spacing between the current electrodes (AB/2) was gradually increased. As AB/2 increases, the depth of investigation also increases, allowing exploration of deeper geological horizons.

At each spacing, the potential difference (ΔV) and injected current (I) were recorded, from which apparent resistivity (ρa) was computed using the formula:

$$\rho_a = K \cdot \frac{\Delta V}{I}$$

where K is the geometric factor dependent on electrode spacing.

Field measurements were systematically logged, noting each AB/2 spacing, current strength, potential difference, and computed apparent resistivity and the acquired field data underwent detailed processing and interpretation in several stages, plotting Resistivity Sounding Curves, where apparent resistivity (ρa) values were plotted against half current electrode spacing (AB/2) on bi-logarithmic scales, resulting in resistivity curves characteristic of subsurface layering.

Curve Matching and Modelling: Partial Curve Matching where Initial qualitative interpretation by comparing field curves to standard master curves (e.g., H-, K-, Q-, A-type) from literature (Koefoed, 1979 and computer-Assisted Inversion Using software (1P2W1N) to iteratively adjust model parameters (layer resistivities and thicknesses) until computed curves closely matched field curves.

III.Results

The present study investigated aquifer depth evaluation in parts of Alakahia, Rivers State, through the interpretation of resistivity sounding curves obtained from Vertical Electrical Sounding (VES) surveys. Two VES points (VES-1 and VES-2) were explored, producing characteristic resistivity curves and geoelectric sections that together revealed significant insights into the lithological and hydrogeological framework of the study area.

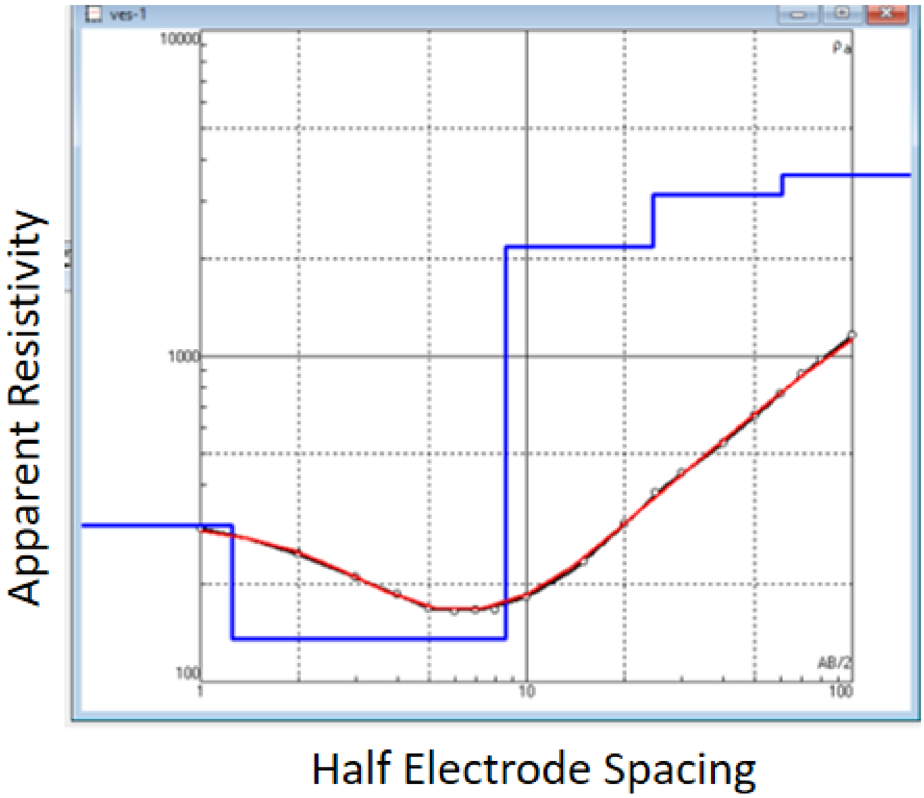

Figure 2: The Resistivity Curve of VES-1 for Alakahia

S/n	Resistivity (Ωm)	Depth (m)	Thickness (m)
1	301.3	1.247	1.247
2	135.4	8.593	7.346
3	2164	24.5	15.91
4	3141	60.88	36.37
5	3605		

Table 1: Table showing the apparent resistivity, depth and thickness of the curve

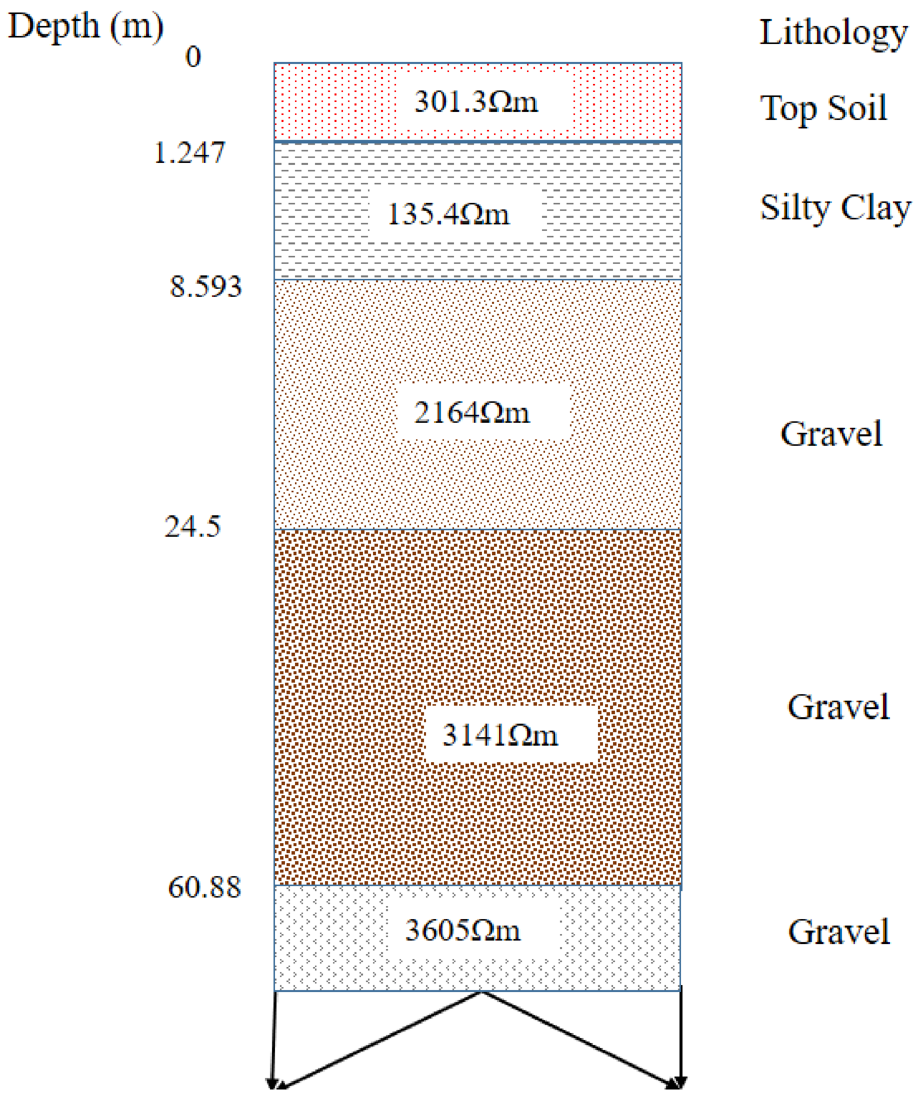

Figure 3: The geoelectric section for VES-1

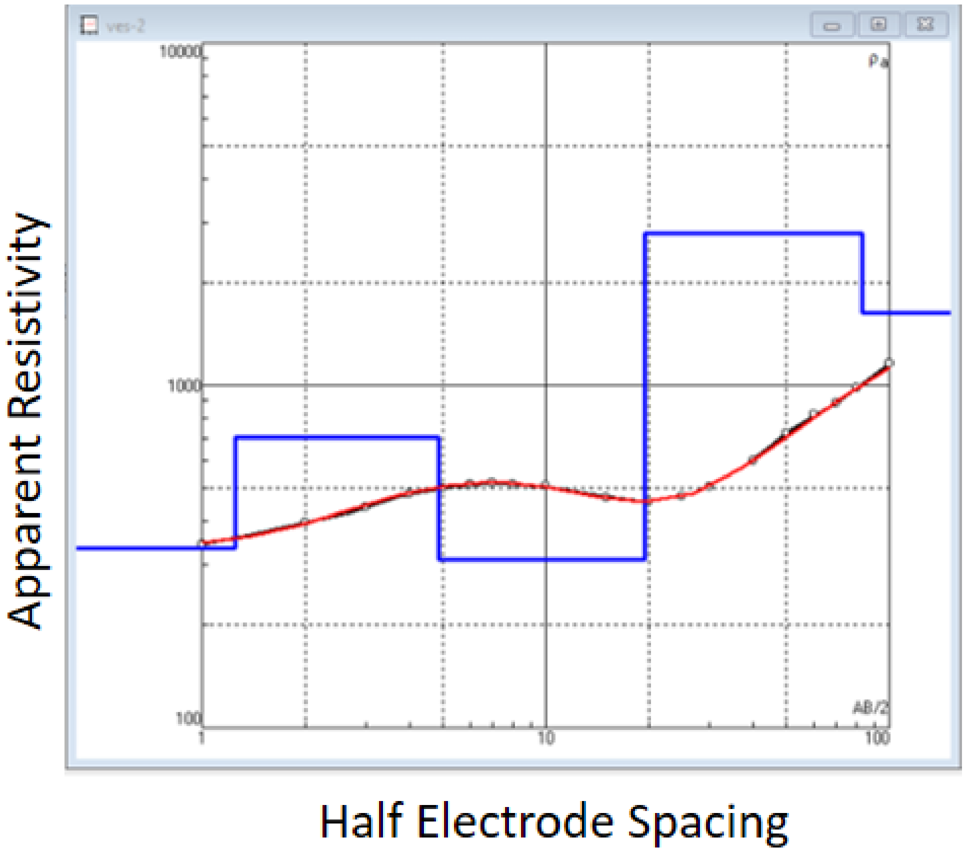

Figure 4: The Resistivity Curve of VES-2 for Alakahia

S/n	Resistivity (Ωm)	Depth (m)	Thickness (m)
1	334	1.25	1.25
2	705	4.88	3.63
3	310	19.38	14.5
4	2780	83.18	63.8
5	1629		

Table 2: Table showing the apparent resistivity, depth and thickness of the curve

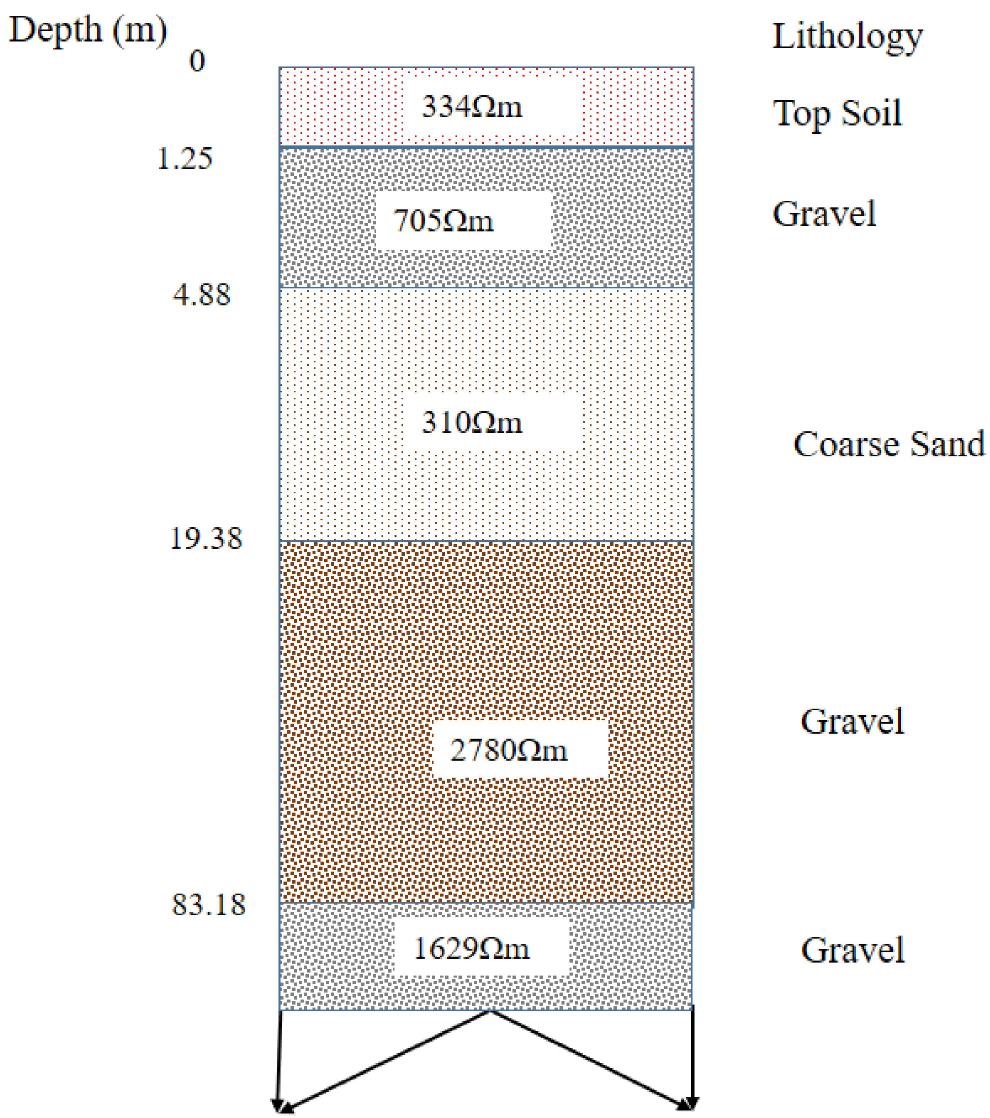

Figure 5: The geoelectric section for VES-2

IV.Discussion

The data was processed to obtain the apparent resistivity components of the layers, so that, a plot of apparent resistivity values and half-current electrode spacing values can be done using a software. The software produced a 2D resistivity curve and table of values called geophysical parameters. These parameters are used to produce a geoelectric section for lithological characterization and evaluation.

The resistivity curve in Figure 2 revealed a five (5) sub-surface stratigraphic earth model, four thickness of medium, depth to potential aquifer Formation, suggesting a complex lithological structure beneath the Cricket field. This vertical electrical sounding (VES) technique provides insight into varying resistivity properties of different geological formations at increasing depth, characterized by an initial high resistivity layer, followed by a lower resistivity middle layer, and then an increase in resistivity in deeper layers. The resistivity trend is in the form of $\ell_1>\ell_2<\ell_3<\ell_4<\ell_5$, 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. This is a very good aquifer system as it obeys the law of increase in in resistivity as depth increases. From Table 1, the topmost layer has a resistivity of 301.3Ωm and thickness of about 1.25m, suggesting a lateritic or sandy topsoil with moderate compaction and moisture content. The second layer, with a resistivity of 135.4Ωm and thickness of ~7.35m, likely represents a clayey sand or sandy clay, which typically exhibits lower resistivity due to higher clay content and water saturation.

The third layer shows a dramatic increase to 2164Ωm over a thickness of ~15.9m, indicating a coarse sand or gravel-rich layer with lower moisture content or higher resistivity due to fewer conductive minerals. The fourth layer, at 3141Ωm and extending over ~36.4m, suggests even coarser, less clay-rich sands or gravels, likely serving as the main aquiferous unit. The bottom layer, at 3605Ωm, points to a massive sand/gravel unit, possibly partially saturated or highly compacted.

The H-type curve signifies the presence of a confined aquifer beneath a conductive (clay-rich) layer. This arrangement often offers good water quality since the clay layer above can act as a protective cap, preventing contamination from surface pollutants.

The resistivity curve in Figure 4 also revealed a five (5) sub-surface stratigraphic earth model and four (4) thickness layer, depth to potential aquifer Formation, suggesting a complex lithological structure beneath the Cricket field. This vertical electrical sounding (VES) technique provides insight into varying resistivity properties of different geological formations at increasing depth. The resistivity trend is in the form of $\boldsymbol{\ell_1<\ell_2>\ell_3<\ell_4>\ell_5}$, which is characteristic of **an Q-type resistivity curve type**, this pattern reveals alternating resistive and conductive layers, a feature often seen in sedimentary basins where depositional environments vary laterally and vertically. This suggests a more heterogeneous subsurface, common in sedimentary environments with variable deposition. From Table 2, the surface layer (334Ωm) with a thickness of 1.25m may represent sandy topsoil with moderate moisture. The second layer, with higher resistivity (705Ωm) and 3.63m thickness, likely consists of dry lateritic sands. The third layer has lower resistivity (310Ωm) and 14.5m thickness, suggesting a clayey or saturated sand layer, which may serve as the first aquifer horizon.

Below this, the fourth layer's resistivity jumps to 2780Ωm over 63.8m thickness, indicating a significant coarse sand or gravel unit, highly likely to function as a productive aquifer. The deepest layer shows a resistivity of 1629Ωm, suggesting compact sands or gravels with moderate saturation or perhaps a change in lithology.

The Q-type curve signifies alternating resistive and conductive layers, characteristic of layered sands and clays. The presence of these alternations highlights the complexity of the Niger Delta's depositional environment, shaped by fluvial and deltaic processes.

Figures 3 and 5 display the geoelectric sections constructed from interpreted resistivity data. These sections visually represent subsurface layers, showing their resistivities, thicknesses, and depths.

For VES-1, the geoelectric section confirms:

Thin topsoil/lateritic cover

Clayey sand as the first significant conductive layer

Deeper massive coarse sands or gravels with high resistivity, forming the main aquifer zone

For VES-2, the section reveals:

A complex arrangement with alternating clayey sands and coarse sands

Thick coarse sand/gravel unit between ~20 m to over 80 m depth, highly promising as an aquifer.

These observations align with the known geology of the Niger Delta, particularly the Benin Formation, dominated by unconsolidated sands and occasional clay intercalations.

The results underscore the presence of at least two aquifer systems: a shallow aquifer (clayey sand) and a deeper, thicker, higher resistivity aquifer (coarse sands/gravel), protective clay layers above deeper aquifers reduce contamination risk, enhancing groundwater quality and thick saturated sands and gravels suggest high yield potential for boreholes.

Such data guide water resource planners, enabling targeted borehole drilling, avoiding dry wells, and protecting water quality.

This research, grounded in established hydrogeophysical principles, fills a data gap in Alakahia's subsurface characterization. It shows how non-invasive methods like resistivity sounding guide groundwater exploration, supporting sustainable resource development.

V.Summary and Conclusion

This study used VES and resistivity curve interpretation to evaluate aquifer depths in Alakahia, Rivers State. Two sites (VES-1 and VES-2) were surveyed. VES-1 showed an H-type curve, revealing a thick, deep, resistive sand/gravel aquifer beneath a conductive clayey layer while VES-2 exhibited a Q-type curve, highlighting a heterogeneous subsurface with alternating layers, culminating in a thick coarse sand/gravel aquifer.

The geoelectric sections confirmed aquifer depths (~20–83m) and the presence of protective clay layers.

The study demonstrated that resistivity methods effectively characterize aquifer systems in the Niger Delta, aiding groundwater exploration.

The Benin Formation in Alakahia comprises multiple aquiferous horizons, mainly unconsolidated sands and gravels, the Resistivity sounding successfully identified aquifers, with depths ranging from shallow (~20 m) to deeper (>80 m) and the presence of protective clay layers reduces the risk of contamination in deeper aquifers. The deeper, high-resistivity sand/gravel aquifers are likely the most productive and suitable for groundwater exploitation.

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