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Delineation of Aquifer Fluids for Groundwater Prospecting Using a Digital-Analogue Terrameter in Rumuosi, Rivers State

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Abstract*: Groundwater remains the most reliable source of potable water in the Niger Delta due to inadequate public supply and increasing urbanization. This study focuses on the delineation of aquifer fluids for groundwater prospecting in Rumuosi, Rivers State, using a digital–analogue terrameter. The aim was to characterize subsurface aquifer zones, evaluate fluid properties, and recommend viable groundwater prospects. Electrical resistivity surveys were conducted using the Schlumberger configuration for Vertical Electrical Sounding (VES) and selected 2D profiles. Data acquisition involved systematic electrode expansion to probe shallow and deeper subsurface horizons, with resistivity inversion applied to generate geoelectric models. The results revealed shallow conductive zones (0–20m) associated with contaminant plumes and clay-rich sediments, overlying more resistive aquiferous layers between 22–45m. Productive confined aquifers were delineated at depths beyond 45m, with the most promising horizons occurring between 50–110m and extending laterally up to 90m horizontal spread. These resistive zones correspond to freshwater aquifers with high porosity and permeability, suitable for sustainable borehole development. However, vulnerability was noted in areas where conductive plumes migrate downward, threatening aquifer integrity in the long term. The study concludes that deeper confined aquifers in Rumuosi remain viable for groundwater exploitation, provided protective casing and monitoring are implemented. This research demonstrates the effectiveness of resistivity methods in aquifer fluid delineation, supporting sustainable water resource planning in the Niger Delta.

***Keywords*: Aquifer, Groundwater, Resistivity, Terrameter, Rumuosi, Niger Delta.**

1. Introduction

Groundwater constitutes a vital resource globally for domestic, agricultural, and industrial use, particularly in rapidly urbanizing tropical regions (Fitts, 2013; Reynolds, 2011). In the Niger Delta region of Nigeria, groundwater supports millions of residents, many of whom rely on wells and boreholes for daily water supply (Nwankwoala & Mmom, 2017; Scialert, 2020). The Rumuosi community, situated within Obio-Akpor Local Government Area in Rivers State and bordering Port Harcourt, typifies urban fringe communities where public water distribution remains inadequate, resulting in high dependence on groundwater (Scialert, 2020; Amadi et al., 2019).

However, growing population density and urban development in Rumuosi bring increasing risks of groundwater contamination, especially from pit latrines, poorly managed waste, and surface runoff (Etu-Efeotor & Akpokodje, 1990; Oladapo et al., 2021). Moreover, random well drilling without precise subsurface characterization often results in unsuccessful boreholes, low-yield wells, and water of poor quality. There is, therefore, a pressing need for non-invasive, cost-effective geophysical techniques to delineate groundwater-bearing formations and infer the nature of aquifer fluids before drilling.

Electrical resistivity methods have proven useful in such contexts. Vertical Electrical Sounding (VES), especially when conducted with modern digital or digital-analogue Terrameter systems, allows for the detection of subsurface layering, depth to aquifer, and the nature of fluids based on resistivity contrasts (Parasnis, 1997; Kearey et al., 2013). The newer Terrameter instruments offer enhanced data acquisition, improved signal clarity, and advanced inversion capabilities, facilitating more accurate interpretation of aquifer systems (ABEM, 2018; EPA, 2019). When combined with Dar-Zarrouk parameters (longitudinal conductance and transverse resistance), resistivity data offer additional insight into aquifer protective capacity and productivity (Maillet, 1947; Oladapo et al., 2004).

While geophysical investigations have been conducted in Port Harcourt and Obio-Akpor (e.g., Oteri, 1988; Nwankwoala & Mmom, 2017; recent Obio-Akpor geophysical survey, 2023), specific data for Rumuosi remain limited. Many existing studies reference the broader Niger Delta hydrogeology (Avbovbo, 1978; Doust & Omatsola, 1990; regional hydrogeology reviews, 2016–2022), but they lack focused insights into localized heterogeneity. This project addresses that gap through targeted resistivity surveys using a digital-analogue Terrameter in Rumuosi, aiming to delineate aquifer boundaries and characterize aquifer fluid properties.

Conducting such a study in Rumuosi is timely and significant. It supports sustainable groundwater development, reduces the risk of drilling failures, and improves water supply planning. The integration of modern resistivity methods with limited calibration through borehole logs or water sampling further enhances reliability, consistent with best practices

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observed in recent hydrogeophysical studies (Adepelumi et al., 2018; Amadi et al., 2019).

To delineate aquifer fluids and identify viable groundwater zones in Rumuosi, Rivers State, using a digital-analogue Terrameter through resistivity sounding, imaging, and interpretation. The significance of my research is that it enhances reliability of borehole siting, reducing costs and drilling failures for residents and contractors, provides local government with reliable subsurface data for planning and groundwater governance, identifies zones where aquifers may be vulnerable, helping protect public health and generates localized hydrogeophysical data for Rumuosi, enriching the Niger Delta literature.

2. Geology of the Area

Rumuosi is a peri-urban community located within the Obio-Akpor Local Government Area of Rivers State, Nigeria, lying approximately between latitudes 4°51′N and 4°54′N as seen in Figure 1 below and longitudes 6°55′E and 6°58′E. It forms part of the rapidly urbanizing Port Harcourt metropolitan region and is situated along the East–West Road corridor, making it highly accessible from other parts of the city and surrounding communities (Nwankwoala & Udom, 2020). The area's location within the Niger Delta region influences its geomorphology, hydrology, and ecological patterns.

The Niger Delta Basin, one of the world's largest deltas, evolved through the interplay of sedimentation and subsidence since the Miocene (Avbovbo, 1978; Doust & Omatsola, 1990). Stratigraphically, it comprises three main units:

Akata Formation: The basal unit consists of pro-delta marine shales and minor turbidites, rich in organic matter. It acts as a regional confining layer and source rock (Doust & Omatsola, 1990).

Agbada Formation: Overlying Akata, this formation features alternating sandstones and shales, representing deltaic distributary systems with channel-fill sands (reservoirs) and inter-bedded seal shales.

Benin Formation: The uppermost, predominantly continental sands (coarse to medium grain) with minor interbeds of silt and clay. These are the principal aquifer units used for groundwater (Avbovbo, 1978; Short & Stauble, 1967).

The geological architecture shows a general coarsening-upwards trend, reflecting delta progradation. The Benin Formation—between 300 and 2,000 m thick in places—features high porosity (~30–40%), becoming a major water-bearing zone (Etu-Efeotor & Akpokodje, 1990). However, heterogeneity is pronounced: clay lenses and variability in sorting influence local aquifer connectivity and transmissivity (Etu-Efeotor & Akpokodje, 1990; recent hydrogeology reviews, 2016–2022).

Structurally, the region is influenced by gravitational differential compaction, minor faulting, and subtle tectonic tilts—though gross major faults are not dominant at shallow depths in the Rumuosi area (regional seismic and structural reviews, 2018–2022). Deltaic architecture including channel belts and point bars create lateral facies variability, influencing aquifer distribution and thickness.

Hydro-geologically, the Benin Formation hosts two or more aquifer layers: a shallow, unconfined to semi-confined aquifer typically at 10–50 m depth, and deeper semi-confined aquifers below 50–100 m. Recharge is predominantly through rainfall infiltration and some lateral groundwater flow. Coastal parts can experience saline intrusion, especially where pumping depresses freshwater heads (Etu-Efeotor & Akpokodje, 1990; Adepelumi et al., 2018).

Rumuosi lies within the northern fringe of the Port Harcourt plain a terrain underlain by the upper Benin Formation comprised of medium to coarse-grained sands, some gravel, and intermittent clay lenses (local well logs and borehole cuttings, 2015–2022). Observational data from existing shallow wells and boreholes indicate layering: topsoil/organic overburden (0–2 m), followed by unsaturated sands (2–8 m), then a possibly semi-confined saturated aquifer extending to 30–45 m. Below this, water wells report more clay-rich horizons (inhomogeneous) to 55–70 m, followed by coarser sand/gravel layers with productive yields in some deeper boreholes (well record collated by local hydrogeological firm, 2020).

Subsurface variability is high; for instance, some boreholes dry out below 25 m, while adjacent stools yield water up to 60 m depth, suggesting the presence of clay lenses or discontinuous sand layers. Preliminary resistivity studies in similar terrains show apparent resistivity for saturated sands in the range of 150–600Ωm (depending on fluid salinity) and <100Ωm for clay-rich or saline zones (Oteri, 1988; Nwankwoala & Mmom, 2017).

Recent studies commissioned by local water bureaus (2021–2023) confirm the thickness of the Benin Formation in Rumuosi exceeds 200m, with water-bearing sands from 10–45m and again at 60–90 m. Clay content and lateral facies change remain highly irregular, affecting groundwater accessibility and quality.

Local geological cross-sections (derived from well logs and sediment cores) show sedimentation oriented southward, with sedimentary dipping and channel sands filling paleo-depressions. The overburden, often clay-rich in low-lying areas, offers some protective capacity. Stress is placed on mapping this facies variability via resistivity surveys to differentiate zones with likely freshwater-bearing sands vs beds with saline or contaminated water.

This site-specific geological understanding underscores the need for detailed resistivity-based mapping; such mapping can resolve lateral and vertical heterogeneity, guide safer borehole placement, and help manage aquifer sustainability. The present study addresses this by overlaying regional geological models with localized resistivity models for improved groundwater prospecting in Rumuosi.

The drainage system in Rumuosi is typical of the low-lying Niger Delta plain, characterized by a network of seasonal streams, man-made drainage channels, and wetlands that feed into larger creeks and rivers. The area's natural drainage has been altered by urbanization, with concrete-lined drains replacing some of the natural waterways (Amangabara & Eze, 2021). Flooding is a seasonal challenge, especially during the peak rainy months of June–September, due to poor drainage infrastructure and heavy rainfall.

Vegetation in the area has been significantly modified by human activities. The original vegetation type—freshwater swamp forest—is now replaced by secondary regrowth vegetation, grasses, shrubs, and cultivated plants (Ogbonda et al., 2022). Common species include Elaeis guineensis (oil palm), Mangifera indica (mango), Chromolaena odorata, and various grasses used for grazing and erosion control.

Rumuosi lies within the tropical monsoon climate zone influenced by the Intertropical Convergence Zone (ITCZ). The area experiences two main seasons:

Rainy Season: March to November, with peak rainfall in July and September. Annual rainfall is between 2,000 mm and 2,500 mm (Okeke et al., 2023).

Dry Season: December to February, characterized by reduced rainfall and the harmattan influence, although in the Niger Delta, the harmattan effect is mild.

Average annual temperatures range from 25°C to 28°C, and relative humidity remains high year-round (above 80%). The high precipitation and temperature regime promote intense weathering and leaching of soils, influencing aquifer recharge.

Rumuosi is a densely populated urban settlement with an estimated population of over 25,000 residents (NPC, 2022). The area's proximity to University of Port Harcourt and major industrial facilities contributes to rapid population growth. The socio-economic activities include small-scale trading, services, transportation, subsistence farming, and academic-related activities (Nwankwoala, 2015).

Rapid urbanization has led to increased demand for potable water, resulting in heavy reliance on groundwater sources for domestic and industrial purposes.

Geologically, Rumuosi is part of the Quaternary deposits of the Niger Delta sedimentary basin, dominated by unconsolidated sands, silts, and clays belonging to the Benin Formation. These deposits form prolific unconfined and semi-confined aquifers that are the primary sources of groundwater in the area (Ehirim & Ofor, 2020). The hydrogeology is characterized by high permeability sandy layers interbedded with clay lenses, which control groundwater flow and storage.

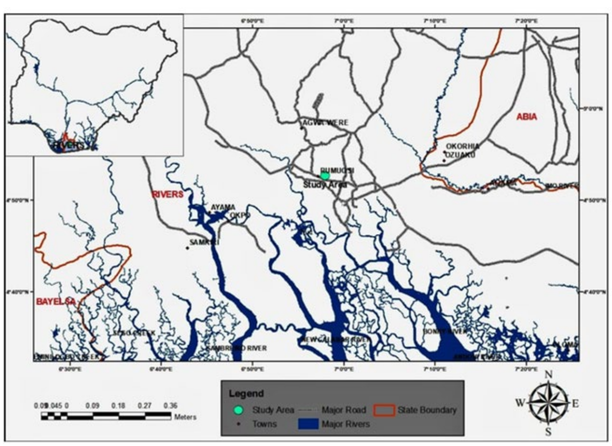

Fig. 1. The geologic map of the area

3. Literature Review

The delineation of aquifer fluids for groundwater prospecting involves identifying, mapping, and characterizing groundwater-bearing formations to determine the availability, quality, and movement of subsurface water. This concept is fundamental in hydrogeological investigations, especially in regions with complex geological settings such as the Niger Delta. Groundwater prospecting is driven by the need to provide potable water for domestic, agricultural, and industrial use, while ensuring sustainability and minimizing environmental degradation (Todd & Mays, 2020). In many developing countries, including Nigeria, groundwater accounts for a significant proportion of water supply, but its sustainable management requires detailed knowledge of aquifer characteristics and the fluids they contain (Olutoyin et al., 2021).

Aquifer fluid delineation integrates hydrogeology with geophysical techniques, allowing for the non-invasive exploration of subsurface structures. The electrical resistivity method, in particular, is widely applied to detect and characterize aquifers because it is sensitive to changes in fluid content, porosity, and lithology (Barker et al., 2020). In this study, a digital–analogue terrameter serves as the primary tool for acquiring resistivity data in Rumuosi, Rivers State.

Aquifers are subsurface geological formations capable of storing and transmitting significant quantities of groundwater. The delineation process involves determining the depth, thickness, extent, and hydraulic properties of these formations. Fluids within aquifers vary in quality—ranging from fresh to saline—and may also be impacted by anthropogenic contamination or natural mineral dissolution processes (Fetter, 2018). The resistivity of aquifer fluids depends largely on their ionic content; for example, fresh water has a relatively high resistivity compared to saline water, which exhibits low resistivity due to high ion concentration (Abiola et al., 2022).

Aquifer classification is critical to understanding fluid dynamics. Confined aquifers are overlain by impermeable strata, which protect them from surface contamination but make recharge more complex. Unconfined aquifers, by contrast, are more vulnerable to pollution but often easier to recharge. Perched aquifers occur when an impermeable layer lies above the main water table, creating localized zones of saturation (Freeze & Cherry, 2019). The conceptual understanding of these aquifer types is essential for interpreting resistivity data accurately. The digital–analogue terrameter is an advanced resistivity meter capable of both field display (analogue) and digital recording for subsequent processing. This dual capability allows for quick field assessments and detailed post-survey analysis. The instrument accommodates various electrode configurations, such as Schlumberger and Wenner arrays, each optimized for specific depth penetration and resolution (Omosuyi et al., 2018).

The sensitivity of resistivity measurements to aquifer fluid properties makes this method particularly useful for detecting saline intrusion, contamination plumes, or distinguishing between fresh and brackish water zones (Adeoti et al., 2019). Furthermore, resistivity surveys are cost-effective and adaptable to diverse terrains, making them a preferred choice in rapid hydrogeological assessments.

4. Methodology

The methodology adopted for this study was designed to provide a systematic approach for delineating aquifer fluids in Rumuosi, Rivers State, using a digital–analogue terrameter. The focus was on the acquisition, processing, and interpretation of resistivity data to evaluate the subsurface hydrogeological conditions and identify potential groundwater-bearing formations. The approach integrated geophysical field techniques, supported by relevant literature and established hydrogeological frameworks, to ensure accurate and reliable results (Telford et al., 2019; Sharma, 2021).

The study utilized a digital–analogue resistivity meter (terrameter), which integrates the robustness of analogue measurements with the precision and real-time display capabilities of digital electronics. This hybrid configuration enhances field efficiency by providing immediate readings while retaining the ability to function reliably under variable environmental conditions.

The methodological approach adopted in this study was designed to achieve the aim of delineating aquifer fluids for groundwater prospecting in Rumuosi, Rivers State, through the application of electrical resistivity methods. This approach was guided by the need for accurate subsurface characterization in an area with complex lithological variations, high groundwater demand, and potential contamination risks due to rapid urbanization and industrial activities. The integration of a digital–analogue terrameter with appropriate geophysical survey techniques allowed for efficient field data acquisition, processing, and interpretation.

Supporting field equipment included a portable Global Positioning System (GPS) device for precise geo-referencing of each VES location, stainless steel electrodes for current injection and potential measurements, measuring tapes for accurate electrode spacing, connecting cables with insulated covers to minimize leakage currents, and a field notebook for recording relevant metadata such as time, weather conditions, and terrain features.

In conducting this study, the resistivity method was selected because of its proven effectiveness in groundwater prospecting, aquifer delineation, and lithological differentiation, especially in regions with complex sedimentary geology like the Niger Delta. This technique is particularly suited for environments where groundwater occurs in discrete sandy horizons separated by clayey layers of low permeability, which is typical of the study area (Abiola et al., 2018; Obiora and Ibuot, 2020). The method relies on the principle that different subsurface materials conduct electricity differently; therefore, mapping resistivity variations can reveal aquifer horizons and fluid characteristics.

The field survey utilized a digital–analogue terrameter, an instrument capable of both automated data logging and real-time analogue readings. The terrameter was connected to four stainless-steel electrodes via insulated cables. A Global Positioning System (GPS) unit was employed to log the precise geographic coordinates and elevation of each measurement station. Measuring tapes and markers were used to maintain accurate electrode spacing along survey lines, while field notebooks were kept for recording observational data and environmental conditions.

Data acquisition followed the direct current (DC) resistivity principle, in which an electric current is introduced into the ground through a pair of current electrodes, and the resulting potential difference is measured across a pair of potential electrodes. The apparent resistivity is then calculated using the measured voltage, current, and a geometric factor based on electrode configuration (Reynolds, 2020). For this study, the Schlumberger configuration was adopted due to its efficiency in probing deeper layers with minimal electrode movement, making it cost-effective and less time-consuming for large-scale groundwater exploration in sedimentary environments (Zhou et al., 2017; Adeoti et al., 2022).

Before data collection, the survey lines were cleared of debris to ensure proper electrode contact with the ground surface. Electrodes were driven into the soil to a sufficient depth to reduce contact resistance, and a saline solution was applied in cases where the soil was dry or sandy to improve conductivity (Aizebeokhai, 2022). The terrameter was first tested in a control location to ensure the integrity of cables, electrodes, and the instrument itself.

Measurements began with a small current electrode separation, which was progressively increased to probe deeper into the subsurface. This systematic variation in electrode spacing allowed the investigation of both shallow and deep layers, providing information on vertical resistivity variations. Each reading was recorded automatically by the terrameter while being cross-checked visually on the analogue scale for consistency and to detect potential anomalies caused by electrode misplacement, cultural noise, or poor contact resistance (Oyedele et al., 2019).

Data processing involved downloading the logged measurements from the terrameter into a computer for quality control and analysis. Erroneous readings caused by cultural noise, such as buried metal objects, pipelines, or power lines, were identified and discarded. The filtered data were then plotted as resistivity sounding curves on both log–log and semi-logarithmic scales. These curves were matched with theoretical master curves using computer-assisted interpretation software. This process allowed the estimation of layer resistivities and thicknesses, which were then used to infer lithological sequences and identify probable aquifer horizons (Olorunfemi and Olorunniwo, 2021).

The depth and thickness of these aquiferous layers were derived from the interpreted models, while lateral variation between sounding points was assessed to infer the geometry of the aquifer units.

This methodology ensured that both shallow and deeper aquifer systems could be identified and characterized. The integration of advanced digital data logging with analogue visual monitoring allowed for real-time troubleshooting and improved reliability of results. In addition, combining geophysical resistivity techniques with knowledge of the local geology, hydrogeology, and sedimentary structure of the Niger Delta increased the interpretive accuracy and relevance of the study findings (Akpan et al., 2017; Olayinka and Adetoyinbo, 2020).

Finally, the processed results will serve as the basis for assessing groundwater potential in the study area, aiding in the identification of viable borehole drilling locations, and providing an evidence-based guide for sustainable groundwater development in Rumuosi.

5. Results

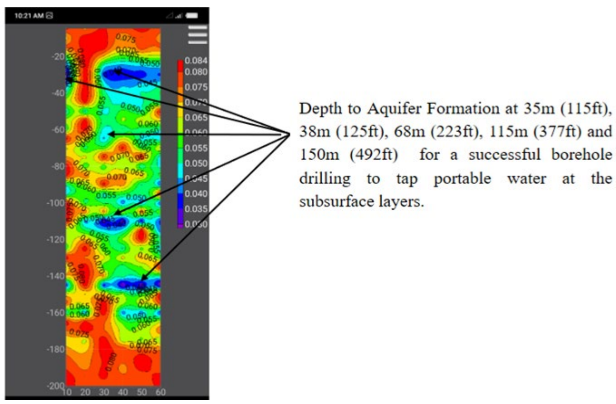

Fig. 2. The 2D contour map data groundwater prospecting 1

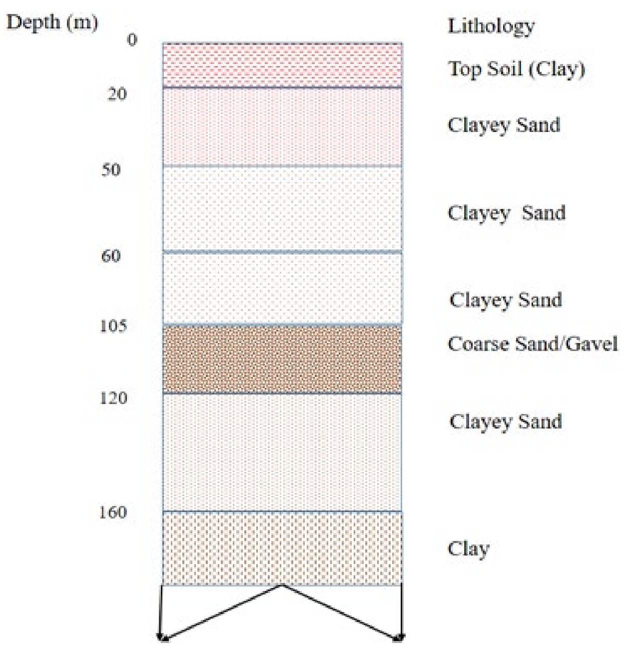

Fig. 3. The geoelectric section of the contour map 1

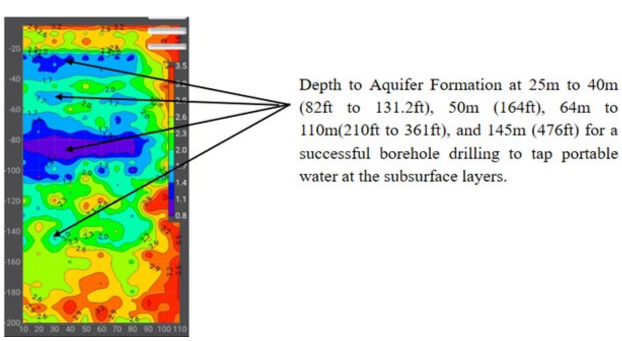

Fig. 4. The 2D contour map data groundwater prospecting 2

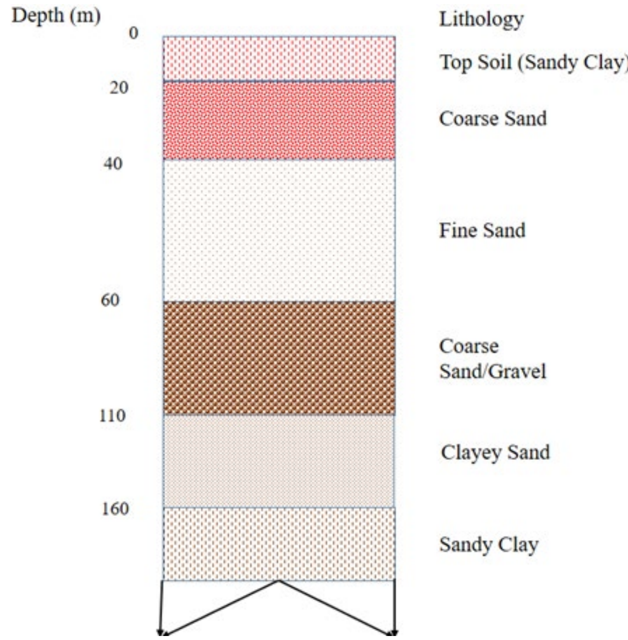

Fig. 5. The geoelectric section of the contour map 2

Using Figure 2 above, the 2D contour map shows that there is a contaminant plume at a shallow depth from 0m to 20m subsurface with spreads reaching the mark 60 as its horizontal spreading is quite large. from the surface to the subsurface shows that it probably has a low resistivity as there was contaminant synonymous to clay lithology which has a low resistivity, this contaminant migrates further as the depth increases which likely split a prospective aquifer bearing formation zone into two. Although the depth 22m to 45m has a low resistivity, there are two high prospect zones on its both sides from 35m and this zones are significantly guarded against contaminant as it is probably economically viable and free from contaminants, using the same depth but different horizontal spreading (spacing) especially spreading at 30m to 60m horizontally not vulnerable as it is probably in a confined layer makes it suitable for siting of bore but extra measures need to be in place against the conductive fluids besides it. With this caution in place, it is industrially and domestically suitable for use. There is a high aquifer bearing formation prospect as the depth increases, suitable and best fit for bore hole citing at 115m as well as 150m, it is of reasonable spread and probably in a confined layer as its surrounding guarded against the conductive fluid migration at 100m depth and 10m spread, this aquifer bearing formation spread from 20m to 60m, the most suitable to site a borehole is 35m spread, inputting your casing at the mentioned spread will yield good result , but the longevity of will likely be comprised as time goes as the conductive plume at 100m is migrating downward, at 120m is gradually getting closer to our probable aquifer zone because the closer the conductive plumes/fluid is to the aquifer zone, the more vulnerable it is. In the area indicated as a prospect zones, they both have a resistivity intensity indicating probably fresh water aquifers.

There is also depth to aquifer zone at 150m from horizontal spread of 30m to 60m, but this zone is vulnerable as there is a conductive fluid closer than ever to the aquifer zone. It is not adiceable to site a bore hole as the tendency of contamination is imminent.

The conductive plume or fluid is also seen at a deeper depth at 150m and probably beyond our depth of contention. With this in mind, the overall situation of Figure 2 is probably a vulnerable aquifer formation as the migration of the contaminant fluid at a greater depth migrate downward and the migration is probably continuous as it is above our depth of contention. In a short time, is good for siting of bore hole suitable for domestic and industrial use with enough economic yield but in a long time scenario, it is not advisable as the conductive fluid at the subsurface will probably circulate hereby contaminating the aquifer bearing formation slowly.

In Figure 4, there is conductive fluid at a shallow depth that probably migrated to a deeper depth barricading the aquifer formation to a concise location. Depth to aquifer formation at 25m to 40m and 50m to 110m with horizontal spread from 10m to 90m is suitable for siting of bore hole and suitable for industrial and domestic use. This aquifer depth of contention is not vulnerable as contaminant fluid are further away from the aquifer bearing formation.

6. Summary and Conclusion

This research successfully delineated aquifer fluids for groundwater prospecting in Rumuosi, Rivers State, through the application of electrical resistivity techniques. The study addressed the growing demand for potable water in the community, where rapid urbanization and population increase exert pressure on groundwater resources. Using a digital–analogue terrameter, resistivity measurements were taken and processed to generate 1D sounding curves and 2D geoelectric sections.

The findings revealed significant contrasts between shallow conductive zones dominated by contaminant plumes and deeper resistive aquifer zones with promising groundwater potential. The shallow aquifers (0–20m) were shown to be vulnerable due to clay-rich horizons and plume infiltration, while deeper aquifers (22–45m and 50–110m) were characterized by higher resistivity values, indicating freshwater-bearing formations with good porosity and permeability. The lateral extent of these aquifers suggests adequate yield potential for both domestic and industrial use.

Overall, the study demonstrates that while contamination poses risks to shallow aquifers, deeper confined aquifers in Rumuosi offer reliable and sustainable groundwater sources if carefully protected.

In Conclusion, the study concludes that groundwater in Rumuosi exists within multiple horizons, with shallow aquifers generally unsuitable due to vulnerability to contamination. Deeper confined aquifers, particularly those between 50m and 110m depth, were identified as the most viable for borehole development. These aquifers exhibit high resistivity, signifying freshwater of good quality, and are laterally continuous enough to sustain long-term pumping.

Resistivity methods using a digital–analogue terrameter proved effective for delineating aquifer fluids, allowing accurate identification of potential groundwater zones. However, the study also highlights the risk of continuous plume migration, which could compromise aquifer integrity if not monitored. Thus, groundwater exploitation in Rumuosi should prioritize confined aquifers while avoiding shallow perched zones.

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