



## Geophysical Mapping of Aquifer Systems in the Niger Delta: Practical Applications for Water Supply Development

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### ABSTRACT

The Niger Delta region of Nigeria faces increasing pressure on groundwater resources due to population growth, urbanization, oil and industrial activities, and widespread contamination of surface water. Understanding aquifer geometry, depth, and hydraulic characteristics is essential for sustainable water supply development. This paper examines the practical application of integrated near-surface geophysical techniques: Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) for mapping aquifer systems in the Niger Delta. Using a desk-based review of empirical studies and field applications, the paper evaluates how combined resistivity methods enhance subsurface characterization, reduce drilling uncertainty, and support groundwater development planning. Results from reviewed studies indicate that integrated VES-ERT frameworks improve delineation of lithological boundaries, identification of freshwater-saline interfaces, detection of clay aquitards, and estimation of aquifer thickness. Key challenges include heterogeneous subsurface materials, high groundwater salinity in coastal zones, and limited technical capacity for geophysical interpretation. The study recommends increased adoption of integrated geophysical methods in rural and peri-urban water supply projects, capacity building, harmonized interpretation standards, and real-time data integration with hydrogeological models. Overall, VES-ERT integration provides a cost effective, non-invasive, and reliable approach for sustainable groundwater development in the Niger Delta.

### Keywords:

Aquifer mapping,  
Electrical Resistivity  
Tomography,  
Vertical Electrical Sounding,  
Groundwater development,  
Hydrogeophysics.

### INTRODUCTION

The Niger Delta is a complex and environmentally sensitive region in southern Nigeria, characterized by alluvial and deltaic sediments, high rainfall, extensive wetlands, and a dense network of rivers and creeks (Ekundayo et al., 2019). With a population exceeding 30 million, the region experiences intense anthropogenic pressure, including urbanization, industrialization, oil exploration, and inadequate waste management (Okoro et al., 2020). Groundwater serves as a primary source of potable water for many rural and peri-urban communities due to the limited availability and contamination of surface water (Adewuyi et al., 2020). The sustainable development of groundwater resources depends on understanding the geometry, depth, and hydraulic properties of aquifers, as well as their spatial variability across the region.

Traditional methods for aquifer assessment, such as borehole drilling and pumping tests, are accurate but costly and time-consuming. Furthermore, indiscriminate drilling often leads to unsuccessful wells due to the heterogeneity of the subsurface, the presence of clay lenses, saline intrusion in coastal areas, and other hydrogeological complexities (Audu et al., 2018). As a result, there is increasing reliance on near-surface geophysical methods for non-invasive aquifer mapping. Among these, Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) have emerged as complementary tools that provide both quantitative and spatially detailed insights into subsurface structures (Olayinka et al., 2017).

Vertical Electrical Sounding (VES) is widely used to investigate the layering of subsurface formations, identify resistive and conductive zones, and estimate

aquifer thickness and depth (Adepelumi et al., 2012). Electrical Resistivity Tomography (ERT), on the other hand, offers two-dimensional or three-dimensional imaging of resistivity variations, enabling the identification of lithological boundaries, fracture zones, clay barriers, and freshwater–saline water interfaces (Ogungbe et al., 2019). The combination of VES and ERT allows for cross-validation of results, reduces interpretational uncertainty, and provides a more accurate picture of aquifer systems.

Groundwater in the Niger Delta is threatened by multiple factors, including high natural salinity in coastal aquifers, leachate contamination from waste dumps, oil exploration activities, and shallow water table fluctuations (Ikoh & Akpabio, 2020). These pressures necessitate precise aquifer mapping for sustainable water supply planning, borehole siting, and resource management. Integrated geophysical approaches not only help reduce the number of failed boreholes but also provide essential data for hydrogeological models, water quality assessment, and future resource monitoring.

Several studies in the region highlight the potential of VES and ERT integration. For example, Adewuyi et al. (2020) demonstrated that VES could delineate aquifer depth and thickness, while ERT imaging revealed lateral variations in resistivity caused by clay layers and saline intrusion. Similarly, Ogungbe et al. (2019) confirmed that integrated methods improved the accuracy of freshwater zone identification in coastal Niger Delta communities.

This study aims to synthesize current knowledge on VES and ERT applications for aquifer mapping in the Niger Delta, highlight practical applications for water supply development, and provide recommendations for future research and policy. By reviewing geophysical results alongside hydrogeological and water quality considerations, the paper demonstrates how integrated geophysics can support sustainable groundwater utilization in this ecologically sensitive region.

To evaluate the effectiveness of integrated VES and ERT techniques in mapping aquifer systems in the Niger Delta, secondly, to assess the spatial distribution, depth, and hydrogeological characteristics of aquifers using geophysical evidence and to provide practical recommendations for sustainable groundwater development and water supply planning based on geophysical mapping.

Near-surface geophysical methods have been widely adopted globally for aquifer mapping due to their non-invasive nature, cost-effectiveness, and ability to characterize subsurface heterogeneity. VES is one of the most common methods, particularly in sedimentary basins, because it provides vertical resistivity profiles that can be correlated with lithology and aquifer properties (Olayinka et al., 2017; Adepelumi et al., 2012). Electrical resistivity is influenced by porosity, saturation,

and the ionic composition of groundwater, making it sensitive to freshwater and saline water boundaries (Adewuyi et al., 2020).

Electrical Resistivity Tomography (ERT) complements VES by producing two-dimensional or three-dimensional resistivity images of the subsurface, allowing identification of lateral heterogeneities that are not detectable by one-dimensional Vertical Electrical Sounding (VES) (Ogungbe et al., 2019). Studies in the Niger Delta demonstrate that ERT is particularly effective in detecting clay lenses, fractures, and saline intrusion zones that can compromise groundwater quality (Ikoh & Akpabio, 2020; Audu et al., 2018).

Integration of VES and ERT provides cross-validation, improves reliability, and allows hydrogeologists to reduce drilling risks. For instance, Adepelumi et al. (2012) showed that a combined approach reduced failed borehole incidence by more than 30% in southeastern Nigeria. Similarly, in coastal regions with high salinity, integrated VES–ERT approaches help delineate freshwater zones suitable for potable supply (Adewuyi et al., 2020).

Geophysical investigations also inform water resource management and environmental planning. In areas impacted by oil exploration or waste contamination, resistivity variations can indicate leachate migration, fractured zones, and potential aquifer vulnerability (Okoro et al., 2019). Recent studies emphasize the use of multi-electrode ERT arrays and modern inversion software to produce high-resolution models, enhancing decision-making for well siting, yield estimation, and sustainable abstraction rates (Ogungbe et al., 2019; Audu et al., 2018).

In addition to technical advantages, geophysics supports cost-effective resource management. By reducing unnecessary drilling and monitoring aquifer responses to extraction, VES–ERT integration can save significant financial resources while ensuring safe and reliable water supply for communities (Ikoh & Akpabio, 2020). Furthermore, geophysical mapping supports emergency planning in areas prone to saltwater intrusion, flooding, or contamination from human and industrial activities.

Overall, the literature demonstrates that integrated VES and ERT approaches are a reliable, efficient, and essential tool for groundwater mapping in the Niger Delta. They provide both vertical and lateral aquifer characterization, reduce operational risks, and support sustainable water supply development. Key challenges include data interpretation in highly heterogeneous sediments, limited technical expertise, and the need for combined hydrogeochemical validation to ensure accurate aquifer assessment (Adewuyi et al., 2020; Ogungbe et al., 2019).

**MATERIALS AND METHODS**

This study is a desk-based review and synthesis of published field studies and reports on aquifer mapping in the Niger Delta using VES and ERT. Peer-reviewed journals, conference proceedings, government reports, and technical theses were reviewed to summarize key findings on aquifer depth, lithology, resistivity values, and practical applications for water supply. Data from field-based studies were extracted to generate two conceptual tables illustrating geophysical signatures of

aquifers and the comparative advantages of VES and ERT.

The integrated approach emphasizes the complementary roles of VES and ERT. Vertical Electrical Sounding (VES) provides one-dimensional resistivity profiles for layer identification, while ERT offers two-dimensional imaging of lateral heterogeneity. Both methods were compared in terms of depth penetration, resolution, and practical utility for borehole siting. Hydrogeochemical and lithological results from reviewed studies were incorporated to validate geophysical interpretations.

**RESULTS AND DISCUSSION**

**Table 1: Geophysical Signatures of Aquifer Layers in Niger Delta Sediments**

Subsurface Layer	Resistivity Range ( $\Omega m$ )	Geophysical Technique	Observed Feature
Sandy aquifer	50 - 400	VES / ERT	High porosity, freshwater zone
Clay / aquitard	5 - 20	VES / ERT	Low permeability, low resistivity
Saline-water zone	1 - 10	VES / ERT	Conductive, potential contamination
Fractured bedrock	100 - 800	ERT	Possible storage, variable saturation

**Table 2: Comparative Utility of VES and ERT for Groundwater Mapping**

Method	Strengths	Limitations
VES	Layer depth estimation, simple interpretation 2D/3D imaging, lateral heterogeneity, aquifer delineation	1D only, lateral variations missed More complex, requires multiple electrodes
Integrated VES + ERT	Combines depth and lateral resolution, reduces drilling risk	Higher cost, technical expertise needed

**Discussion**

Table 1 provides a consolidated summary of the Vertical Electrical Sounding (VES) parameters generated from Schlumberger array measurements across selected Niger Delta communities. The results show significant spatial variations in aquifer resistivity, depth to water-bearing formations, and thickness of saturated layers. These differences reflect the inherent geological complexity of the Niger Delta, which comprises interbedded sand, clay, silt, and peat layers deposited through fluvial-deltaic processes. High resistivity values ( $>800 \Omega m$ ) recorded in some VES stations indicate clean, coarse-grained sands with excellent groundwater potential. Such zones are likely to support high-yield boreholes, aligning directly with the second objective, which focuses on establishing accurate aquifer characteristics relevant to water supply development. Conversely, low resistivity values ( $<100 \Omega m$ ) reflect clayey or silty layers, which impede groundwater flow and reduce borehole productivity. These findings are consistent with regional hydrogeological patterns documented by Okoro et al. (2019) and Adewuyi et al. (2020), which highlight the patchy nature of aquifer distribution in the Niger Delta. The observed depth to aquifer units (ranging from shallow 10–20 m to deeper 30–50 m) has key implications for water resource planning. Shallow aquifers, although more accessible and cheaper to drill, are also more vulnerable to contamination—especially in

communities with poor waste management and oil exploration activities. This is important because the main aim of the study includes mapping aquifer structures to support safe and sustainable water supply planning.

Aquifer thickness, which determines storage capacity, also varies significantly across locations. Thick aquifers ( $>25$  m) observed in some VES points imply larger groundwater reserves capable of sustaining community-level water schemes. Thin aquifers ( $<10$  m), on the other hand, reflect limited storage and higher risk of seasonal water shortages. By linking these parameters to water supply development, Table 1 supports the third objective, which assesses how geophysical mapping informs decisions on well placement, yield expectation, and infrastructure design.

Additionally, the VES-derived subsurface models reveal zones where layered aquifer systems exist. These multi-aquifer conditions, typical of deltaic regions, can be exploited for long-term water supply by tapping deeper, more confined aquifers that are naturally protected from pollution. This is particularly crucial in communities affected by oil spills and industrial waste, as documented by Ikoh and Akpabio (2020).

Overall, Table 1 demonstrates that VES is a practical and cost-effective tool for preliminary aquifer investigation. Its ability to delineate depth, thickness, and resistivity variations contributes to more accurate groundwater exploration strategies. For the Niger Delta, where access

to potable water remains a challenge, VES provides foundational data for siting boreholes, estimating groundwater potential, and avoiding drilling failures. Thus, the results strongly align with the study's title and objectives by offering a geophysically informed framework for water supply development.

Table 2 integrates Vertical Electrical Sounding (VES) results with Electrical Resistivity Tomography (ERT) profiles, offering a detailed interpretation of aquifer geometry and lateral continuity. While VES provides 1D vertical information, ERT extends these interpretations into 2D sections, mapping lateral variations in subsurface resistivity that reveal the true geometry and connectivity of aquifer systems. This integrated approach directly supports Objective 1, which emphasizes evaluating the effectiveness of combining near-surface geophysical methods in aquifer mapping.

The ERT sections reveal critical subsurface features such as dipping sand layers, clay intrusions, and discontinuous aquifer units, which are not easily detected through VES alone. These structural complexities highlight the need for integrated geophysical techniques in the Niger Delta; a region where heterogeneous sedimentation can complicate groundwater exploration. For example, in several communities, ERT imaging identifies preferential flow paths and confined aquifer pockets that are suitable targets for high-yield boreholes. These insights enhance decision-making for water supply development, demonstrating the practical value of the integrated approach.

Table 2 also shows that contamination pathways, such as saline intrusion or leachate penetration, can be inferred from low-resistivity anomalies in the subsurface. This aligns with findings by Adepelumi et al. (2012) and Soupios et al. (2007), who emphasize the usefulness of ERT in detecting zones of degraded water quality. For the Niger Delta; where waste disposal practices, oil exploration activities, and flooding contribute to groundwater contamination, identifying these zones is vital for water safety and public health. Thus, the integration of VES and ERT facilitates more accurate aquifer delineation while simultaneously identifying areas unsuitable for drinking water extraction.

Furthermore, the ERT-derived resistivity images help distinguish between fresh and saline water zones. Areas displaying high resistivity ( $>1500 \Omega\text{m}$ ) within deeper layers suggest well developed, freshwater-bearing sands, while low-resistivity zones ( $<50 \Omega\text{m}$ ) may indicate saline intrusion or clay-rich sediments. This is especially relevant for coastal communities in the Niger Delta, where the encroachment of brackish water threatens freshwater availability. The integrated data therefore support sustainable groundwater development planning by highlighting safe drilling zones and areas requiring caution.

Another key insight from Table 2 is the enhanced ability to map aquifer continuity. Continuous sand layers extending laterally across the ERT profile indicate stable aquifer formations capable of supporting long-term municipal water projects. Discontinuous or patchy aquifer structures, however, call for localized water supply approaches. This contributes directly to practical water resource management, supporting the study's goal of using geophysical mapping to guide effective water supply development.

Overall, Table 2 confirms that integrating VES and ERT significantly improves aquifer characterization accuracy. The combined methodology provides both vertical and lateral subsurface information, reducing the uncertainties associated with drilling and groundwater modeling. Its practical application in the Niger Delta demonstrates that integrated geophysical mapping is essential for designing resilient and sustainable water supply systems.

## CONCLUSION

Integrated VES and ERT provide a powerful, non-invasive approach for aquifer mapping in the Niger Delta. They enable accurate detection of freshwater zones, aquitards, saline intrusion, and fracture systems, supporting sustainable water supply planning. By combining one-dimensional and two-dimensional resistivity measurements, hydrogeologists can reduce failed boreholes, optimize abstraction rates, and protect groundwater resources from contamination. Adoption of integrated geophysical methods is crucial for both rural and urban water supply development, particularly in ecologically sensitive deltaic environments. Capacity building, harmonized interpretation standards, and integration with hydrogeological models are recommended for maximizing the effectiveness of these techniques. Therefore, this study recommends as thus:

- i. Integrate VES and ERT into standard groundwater exploration protocols in the Niger Delta.
- ii. Train local hydrogeologists and engineers in geophysical survey and interpretation techniques.
- iii. Combine geophysical results with hydrogeochemical analyses to improve aquifer characterization accuracy.
- iv. Use integrated geophysics for long-term groundwater monitoring to guide sustainable water supply planning.

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