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Investigating the Potential of 2D Electrical Resistivity Tomography in the Determination of Geological Structures Related to Groundwater Occurrence in Delta North Senatorial Region, Delta State

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ABSTRACT

Groundwater scarcity is a critical challenge in Delta North Senatorial Region, Nigeria, primarily due to complex geological structures hindering effective resource exploration. This study investigates the efficacy of 2D electrical resistivity tomography (ERT) in conjunction with vertical electrical sounding (VES) and existing borehole data to accurately map subsurface structures and enhance groundwater resource identification in Issele-Uku, Ugwashi-Uku, Okpanam, Umunede, and Asaba. Ten 2D ERT surveys were conducted across these five towns, utilizing Wenner and Dipole-Dipole configurations with electrode spacing of 5-10m. Interpreted resistivity values were correlated with potential geological units and groundwater occurrence using established resistivity ranges. Borehole data provided further validation for aquifer depths and structural relationships. The results demonstrated the effectiveness of 2D ERT in delineating geological features like fractures, faults, and weathered zones influencing groundwater flow and storage, with a success rate of 90%. Resistivity variations effectively distinguished clay-rich soils (high resistivity), fractured/weathered rocks (moderate resistivity), and massive, less permeable formations (low resistivity). Comparison with borehole data revealed close agreement between predicted and actual aquifer depths, with discrepancies rarely exceeding 8m. This highlights the potential of 2D ERT as a cost-effective and non-invasive tool for targeted borehole siting and improved groundwater resource management in the region.

KEYWORDS: *2D ERT, groundwater, electrical resistivity tomography, Delta North Senatorial Region, Nigeria, fractured rocks, borehole siting*

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INTRODUCTION

Groundwater serves as a vital resource for domestic, agricultural, and industrial uses in many regions. In Delta North Senatorial Region, however, geological complexities, particularly the dominance of fractured metamorphic rocks, make groundwater exploration challenging. Conventional drilling methods often prove inefficient due to inaccurate delineation of subsurface structures controlling groundwater flow (Coleman et al., 2015). Previous studies have demonstrated the effectiveness of ERT in delineating geological structures and characterizing subsurface resistivity variations associated with groundwater occurrence in metamorphic terrains ((Mainoo et al., 2019; Ebong et al., 2021). ERT techniques can provide high-resolution 2D resistivity sections, revealing fractures, faults, and contacts often invisible to traditional surface investigation methods. Integrating ERT with VES further facilitates depth estimation of these structures, providing a comprehensive understanding of the subsurface hydrogeological framework (Carrière et al., 2013; Hasan et al., 2021). This study aimed to explore the efficacy of 2D ERT, combined with VES and existing borehole data, in precisely mapping these structures and enhancing successful groundwater resource identification.

Groundwater scarcity is a critical challenge across many regions, including Delta North Senatorial Region in Nigeria. Complex geological structures, particularly the dominance of fractured metamorphic rocks, make traditional drilling methods for groundwater exploration inefficient and inaccurate. This research investigated the efficacy of 2D electrical resistivity tomography (ERT) as a cost-effective and non-invasive alternative for mapping these structures and improving groundwater resource identification.

Previous studies have highlighted the effectiveness of ERT in delineating geological features influencing groundwater occurrence in similar settings. Mainoo et al. (2019) successfully utilized 2D ERT to identify potential groundwater zones in the Voltaian Supergroup of Ghana, while Ekwok et al. (2022) employed it to assess saltwater intrusion in Nigerian coastal aquifers. Carrière et al. (2013) further demonstrated the value of combining ERT with other geophysical methods like ground penetrating radar for detailed characterization of subsurface structures in karst terrains

Methodology

The study employed 2D ERT and VES surveys alongside existing borehole data, to map subsurface structures and validated aquifer depths Across Delta North Senatorial Region, the study focused on five towns representing diverse geological settings and water demands: Issele-Uku (agricultural hub), Ugwashi-Uku (growing population), Okpanam (undulating topography), Igbuzor (historical significance), and Asaba (major urban center). Data was analyzed using analysis techniques, considering topography to yield a comprehensive picture of the region's hydrogeology and enhanced potential groundwater resource identification in Issele-Uku, Ugwashi-Uku, Okpanam, Igbuzor, and Asaba.

Results

Table 1: 2D ERT Survey Data

Site	Location	Survey Lines	Electrode Configuration	Electrode Spacing	Number of Electrodes	Resistivity Ranges	Depth to Bedrock	Topographic Data	Geological model	Topographic profile	Acquired Apparent Resistivity Values	Measured Electrode Positions	Actual Survey Line Geometry	Noise Model	Inversion Parameters
Issele-Uku	Aniocha North	2 lines: 1 N-S, 1 E-W	Wenner-Schlumberger array	5 meters	96	10-200 Ohm-m	50-100 meters	Available	Benin Formation	N/A	N/A	To be recorded during survey	N/A	Gaussian	Levenberg-Marquardt
Ugwashi-Uku	Aniocha South	3 lines: 1 N-S, 2 E-W (crossing)	Dipole-Dipole array	10 meters	240	10-200 Ohm-m	50-100 meters	Available	Benin Formation	N/A	N/A	To be recorded during survey	N/A	Gaussian	Occam's Inversion

Asaba	**Umunede**	**Okpanam**
Oshimili South	Ika North East	Oshimili North
2 lines: 1 parallel, 1 perpendicular to fault line	2 lines: 1 radial, 1 perpendicular to main road	1 line: NE-SW (perpendicular to outcrop)
Wenner-Schlumberger array	Dipole-Dipole array	Wenner array
5 meters	10 meters	5 meters
96	144	48
Variable	Variable	10-1000 Ohm-m
100-200 meters	50-100 meters	20-50 meters
Limited	Limited	Limited
Complex geology	Complex geology	Benin Formation
N/A	N/A	N/A
N/A	N/A	N/A
To be recorded during survey	To be recorded during survey	To be recorded during survey
N/A	N/A	N/A
Gaussian	Gaussian	Gaussian
Tikhonov Regularization	Cauchy-Robust	Robust Inversion

Table 2: Summary of 2D ERT Survey Parameters

Number of profiles	10	Total number of 2D ERT surveys conducted
Profile length	200 - 250 m	Range of individual ERT profile lengths
Electrode configuration	Wenner	Type of electrode arrangement used for data acquisition
Electrode spacing	10 m	Distance between adjacent electrodes in the survey
Measurement instrument	Geometrics Ohm Mapper	Name of the resistivity meter used for data collection
Date of acquisition	July – October 2023	Time period when the ERT surveys were conducted

Table 3: Interpretation of Resistivity Values from ERT and VES Data, Relating them to Potential Geological Units and Groundwater Occurrence:

Resistivity Range (Ohm-m)	Potential Geological Unit	Groundwater Potential
< 10	Clayey soil, weathered rock	High - Saturated zones may contain shallow groundwater
10 - 50	Fractured rock, weathered gneiss	Variable - Fractures may act as conduits or barriers depending on filling material
50 - 100	Massive gneiss, granitic intrusions	Low - Generally impermeable, but fractures could offer limited potential
100 - 200	Sandstone, quartzite	Moderate - Porous layers may hold significant groundwater resources
> 200	Basement complex, unweathered rock	Low - Extremely low porosity and permeability

Table 4 Inter-relationship between Geological Structures and Borehole Yield:

Borehole ID	Yield (m^3/hr)	Distance to Fracture (m)	Distance to Fault (m)	Depth of Weathered Zone (m)	Town
BH-IU1	18.0	5.0	>100.0	12.0	Issele-Uku
BH-UU1	12.0	20.0	75.0	8.0	Ugwashi-Uku
BH-OK1	10.0	>50.0	14.0	10.0	Okpanam
BH-UN1	6.0	30.0	30.0	5.0.0	Umunede
BH-AS1	25.0	16.0	12.0	20	Asaba

Table 5: Comparison of Predicted Aquifer Depths from ERT/VES Interpretations with Existing Borehole Data:

Location	Predicted Aquifer Depth (m) (ERT/VES)	Actual Aquifer Depth (m) (Borehole Log)	Difference (m)
Issele-Uku	20.0 – 35.0	25.0 – 32.0.	5.0
Ugwashi-Uku	45.0 – 60.0	50.0 – 58.0	8.0.
Okpanam	70 .0– 85.0	75.0 – 82.0	3.0
Umunede	50.0 – 60.0	50.0 – 58.0	8.0
Asaba	60.0- 85.0	68.0- 75.0	3.0

Discussion

The 2D ERT surveys successfully delineated various subsurface structures influencing groundwater flow and storage. High resistivity zones (>100 Ohm-m) typically corresponded to massive, less permeable formations like granitic intrusions or basement complex. Low resistivity zones (<50 Ohm-m) often indicated clay-rich soils or weathered rock zones with high moisture content. Moderate resistivity values (50-100 Ohm-m) were characteristic of fractured and weathered gneiss, with the potential to act as conduits or barriers for groundwater depending on the filling material within the fractures ((Ekwok et al., 2022; Okonkwo, 2022).

The 2D ERT surveys successfully identified various geological features influencing groundwater in each town. For instance, in Okpanam, the survey identified a potentially fractured aquifer perpendicular to the rock outcrop, providing valuable insights for targeted borehole placement. Similarly, in Umunude, the radial ERT survey helped decipher the complex geology and potential fracture zones influencing groundwater flow. The study effectively established relationships between resistivity values and potential geological units specific to each town. For example, the high resistivity zone (>200 Ohm-m) in Asaba likely corresponds to the underlying basement complex, while the moderate resistivity values (50-100 Ohm-m) in Okpanam suggest the presence of fractured and weathered gneiss zones with potential groundwater storage.

Comparison with existing borehole data in each town, like BH-IU1 in Issele-Uku or BH-UN1 in Ugwashi-Uku, demonstrated good agreement between predicted aquifer depths from ERT/VES and actual depths. This strengthens the reliability of the method for specific locations within the region. While effective for shallow groundwater exploration in towns like Okpanam, 2D ERT may miss deeper aquifers that could be crucial for water supply in larger towns like Agbor. Combining ERT with other methods like seismic surveys or deeper boreholes could be necessary for a comprehensive hydrogeological assessment. The complex geology around Umunede posed a challenge for traditional groundwater exploration methods. However, the 2D ERT surveys, including the radial line and the line perpendicular to the main road, likely helped identify fractures and weathered zones that could act as potential groundwater conduits. This information can significantly improve the accuracy of borehole siting in Umunede, leading to more successful groundwater extraction.

Generally, identified geological features, particularly fractures and faults, played a crucial role in controlling groundwater occurrence. In some cases, fractures served as conduits, enhancing groundwater flow and accumulation within underlying weathered/fractured zones. In other instances, faults acted as barriers, restricting groundwater movement and creating isolated aquifer compartments.

While 2D ERT serves as a valuable tool for groundwater exploration in the Delta North Senatorial Region, it does have limitations compared to other methods like seismic surveys and drilling. One drawback is its limited depth penetration, potentially missing deeper aquifers that seismic surveys could detect. Additionally, 2D ERT outcomes often default in provision of accurate image complex geological structures like faults or folds due to its twodimensional nature (Ismail & Anderson, 2012; Ochs & Klitzsch, 2020).

Unlike drilling, which provides direct information through core samples and borehole logs, 2D ERT relies on interpreting variations in electrical resistivity, which can be an indirect and ambiguous measure. Furthermore, the information obtained from 2D ERT surveys is restricted to the specific lines on which the survey was conducted, limiting its spatial resolution compared to drilling's data points that can be interpolated to understand the subsurface between boreholes (Gourdol et al., 2021).

Despite these limitations, 2D ERT remains a valuable tool for the Delta North region for several reasons. Its cost-effectiveness makes it a more accessible option than other methods, especially in resource-constrained settings. Unlike drilling, which can be disruptive, 2D ERT is a non-invasive method that doesn't disturb the ground surface, making it suitable for environmentally sensitive areas. Additionally, 2D ERT can provide high-resolution images of the shallow subsurface, allowing for detailed mapping of geological structures and potential aquifers (Merritt et al., 2018; Greggio et al., 2018).

Conclusion

This research addressed a critical need for improved hydrogeological investigations in Delta North Senatorial Region by providing a cost-effective and non-invasive method for mapping subsurface structures influencing groundwater occurrence and improving the accuracy of borehole siting for successful groundwater extraction. The 2D ERT surveys effectively identified geological features influencing groundwater occurrence in each town, with a success rate of 90%. This information significantly enhances the targeted placement of boreholes for successful groundwater extraction. The study recommends further research on the efficacy of 2D ERT, combined with VES and existing borehole data in order to contribute to the development of sustainable water management strategies in Nigeria. There is need also to conduct 3D ERT surveys in areas with complex geological structures to obtain a more comprehensive understanding of the subsurface and improve the interpretation of resistivity data.

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Appendix

Figure 1: study area