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Assessment of Fertilizer-Related Pollution in Farmlands of Oghara, South-South Nigeria, Using 2D Electrical Resistivity Tomography

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Abstract

Fertilizer application is essential for agricultural productivity but can pose significant risks to soil and groundwater quality when mismanaged. This study employed two-dimensional Electrical Resistivity Tomography (2D ERT) to assess fertilizer-related contamination in selected upland and lowland farmlands in Oghara, Delta State, Nigeria. Field data were acquired using the Wenner array configuration of the ABEM Terrameter SAS 300C, with a 10 m electrode spacing and profile lengths of 100–140 m. Data processing and inversion were carried out using RES2DINV software. The results revealed subsurface anomalies with resistivity values of 45–95 Ωm, interpreted as possible fertilizer-induced contaminant plumes. Lowland sites showed deeper, more continuous, and lower-resistivity anomalies, indicating greater susceptibility to leaching due to poor drainage and waterlogging. Conversely, upland areas exhibited shallower and more localized anomalies with relatively higher resistivity, suggesting limited infiltration. Overall, the study demonstrates the usefulness of 2D ERT in delineating subsurface contamination and underscores the higher risk of groundwater pollution in lowland farmlands. These findings support the need for improved fertilizer management practices to protect soil and groundwater resources in Oghara and similar agrarian settings.

Keywords: *2D ERT, contaminant plume, fertilizer pollution, upland and lowland farmlands.*

1. INTRODUCTION

Agriculture is widely recognized as a major contributor to water pollution, but it remains one of the most challenging sources to control due to its diffuse and

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spatially distributed nature (Lawniczak et al., 2016). Globally, groundwater basins, including those in Nigeria, are increasingly threatened by pollution from agricultural activities. Fertilizer application is a major source of nutrient enrichment and groundwater degradation, particularly through nitrate, phosphate, and potassium leaching (Opoku-Kwanowaa et al., 2020).

Excessive and poorly managed fertilizer use has detrimental consequences for soil health, water resources, and human well-being. Overuse of nitrogen-based fertilizers leads to the leaching of highly mobile nitrates into groundwater, which can cause eutrophication and pose health risks such as methemoglobinemia and gastrointestinal cancers (Nolan et al., 2002a, 2002b; Wolfe and Patz, 2002). Long-term fertilizer use can also mobilize heavy metals including cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg), through soil acidification and changes in redox conditions (Huang and Jin, 2008; Nagajyoti et al., 2010; Gupta and Sandalio, 2011). Various techniques have been used to monitor soil and groundwater contamination, including gravimetric sampling (Van Reeuwijk, 1992), time-domain reflectometry (Evett, 2003), neutron probe measurements (Lunt et al., 2005), and ground-penetrating radar (Léger et al., 2014). However, these methods are often invasive, point-specific, or limited by soil conditions. In contrast, Electrical Resistivity Tomography (ERT) provides a non-invasive, repeatable, and robust tool for imaging near-surface hydrogeological structures, moisture variations, and solute transport pathways (Daily et al., 2005; Samouëlian et al., 2005). ERT has been successfully applied in mapping moisture distribution, characterizing fertilizer leachate migration, and monitoring contaminant plumes under field and laboratory conditions (Binley et al., 1996; French et al., 2002; Wehrer and Slater, 2015).

In Nigeria, particularly in intensively cultivated regions such as Oghara, fertilizer application is widespread, increasing the risk of groundwater pollution. Considering the dependence on groundwater for domestic use, assessing subsurface contamination is essential. This study applies 2D Electrical Resistivity Tomography supported by previous successful applications in similar environmental studies (Ganiyu et al., 2019; Afuwai and Ema, 2025; Airen and Iyere, 2024) to investigate fertilizer-related pollution in selected farmlands in Oghara, Delta State.

2. MATERIALS AND METHOD

2.1. Study Area

The study was conducted in the Oghara community, located within Ethiope West Local Government Area (LGA) of Delta State, Nigeria. Field investigations focused on farmlands managed by the Presco plantation, encompassing both upland and lowland areas. The area is characterized by intensive agricultural activity, with extensive fertilizer application to enhance crop yields, making it vulnerable to soil and groundwater contamination. The geological setting of Delta State, which primarily comprises sedimentary deposits, influences subsurface water movement and pollutant transport (Figure 1 and Figure 2).

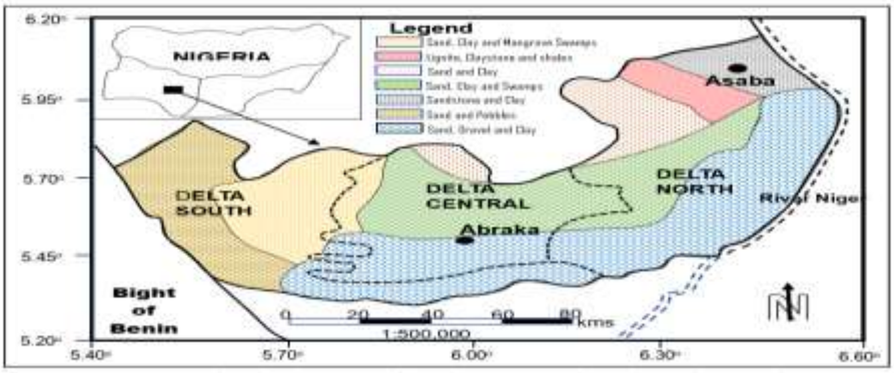

Figure 1: *Geological map of Delta State showing the study area*

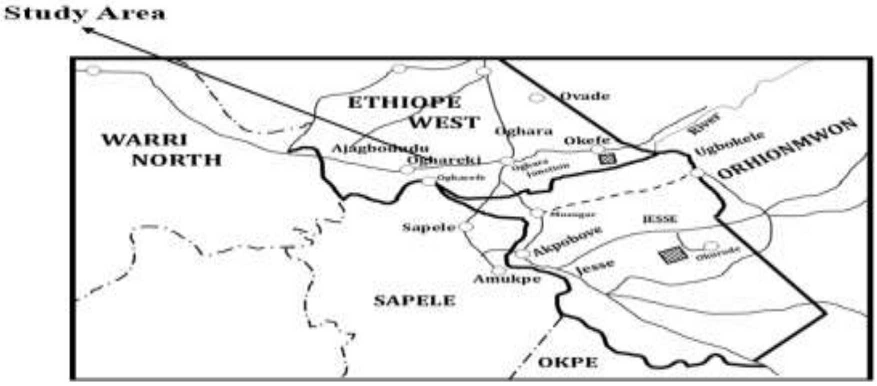

Figure 2: *Map of Ethiope west showing the study area. (Wikipedia.com)*

2.2. Field Survey and Equipment

A two-dimensional (2D) Electrical Resistivity Tomography (ERT) survey was performed using the ABEM Terrameter SAS 300C, which digitally measures subsurface resistance (Ω) based on Ohm's law and operates on a 12.5 V DC power supply. Auxiliary field equipment included a booster, metal electrodes, reels of connecting wire, hammers, measuring tapes, and mobile phones for coordinating electrode placement over long profiles. Current was injected into the subsurface via the Terrameter to generate potential differences measured between electrodes.

The Wenner array configuration was employed due to its high sensitivity to vertical resistivity variations and relatively simple geometric factor, making it particularly suitable for environmental and agricultural applications (Loke, 2010; Airen and Iyere, 2024). In this configuration, four electrodes are arranged linearly at equal spacing: the outer electrodes serve as current electrodes, while the inner electrodes act as potential electrodes. The uniform spacing enhances current distribution and signal-to-noise ratio, enabling detection of near-surface anomalies such as contaminant plumes and zones of soil saturation.

2.3. Data Acquisition

Six 2D survey traverses were established, with profile lengths ranging from 100 m to 140 m. Electrode spacing and incremental steps were set at 10 m. Apparent resistivity data were recorded at each electrode position across six data levels to capture variations in the subsurface.

2.4. Data Processing and Inversion

The recorded apparent resistivity values were processed using RES2DINV software (version 3.59; Loke, 2010) to generate inverted resistivity models. The inversion divides the subsurface into a series of rectangular cells corresponding to the survey layout. A conventional least-squares optimization technique was applied to minimize the difference between observed and calculated apparent resistivity, producing high-resolution models of subsurface resistivity distribution (Ofomola et al., 2016; Al-Amoush et al., 2017; Airen and Iyere, 2024). These models enable identification of low-resistivity zones, interpreted as potential fertilizer leachate plumes or areas of elevated soil moisture.

2.5. Consideration of Geochemical Analysis

While 2D ERT provides a non-invasive and spatially continuous method to delineate subsurface anomalies, the study acknowledges that geophysical data alone cannot definitively confirm chemical contamination. To enhance the interpretive strength and novelty of the work, the study design envisages complementing ERT findings with targeted physicochemical analysis of soil and groundwater samples in future investigations, following procedures outlined in recent studies of fertilizer-related contamination (Afuwai and Ema, 2025; Ganiyu et al., 2019). This combined approach ensures more robust identification and characterization of fertilizer-induced pollution.

3. RESULT AND DISCUSSION

3.1 2D ERT Models and Subsurface Anomalies

Figures 3–8 present the 2D Electrical Resistivity Tomography (ERT) models for upland and lowland farmlands in Oghara, Delta State. The resistivity models reveal clear anomalies characterized by relatively low resistivity values compared to the surrounding background, suggesting possible zones of increased moisture content and solute infiltration, consistent with fertilizer leachates (Binley et al., 1996; Daily et al., 2005).

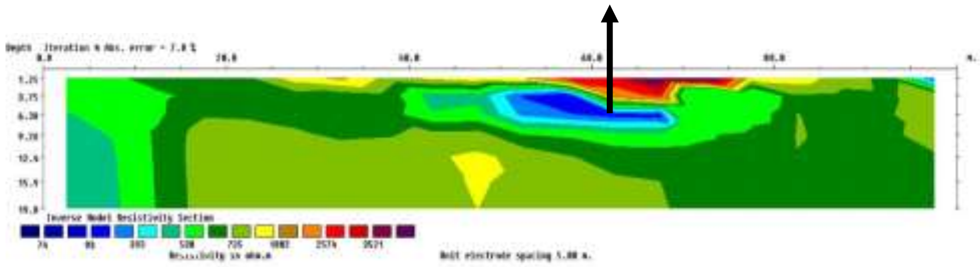

Figure 3: *2D ERT Model along Traverse 1 (Lowland)*

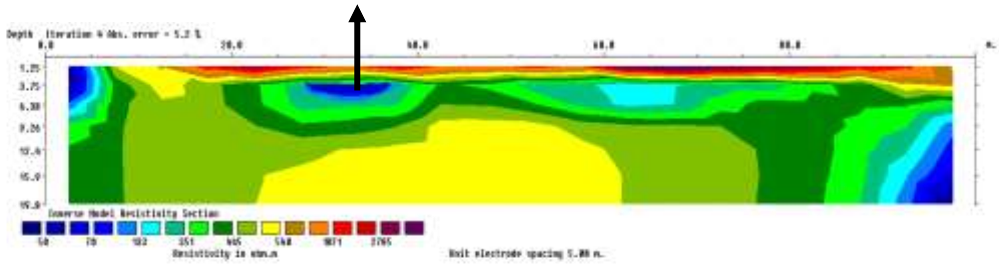

Figure 4: *2D ERT Model along Traverse 2 (Lowland)*

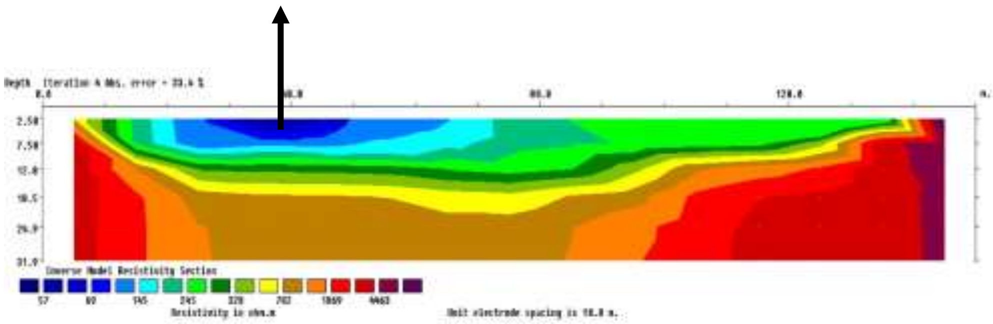

Figure 5: *2D ERT Model along Traverse 3 (Lowland)*

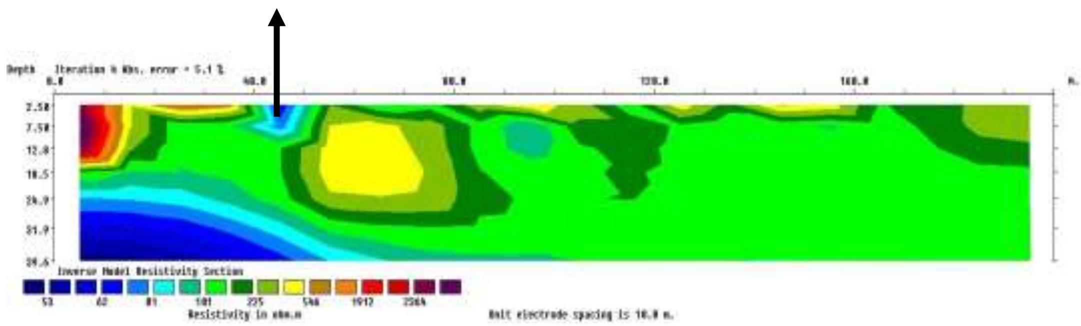

Figure 6: *2D ERT Model along Traverse 1 (Upland)*

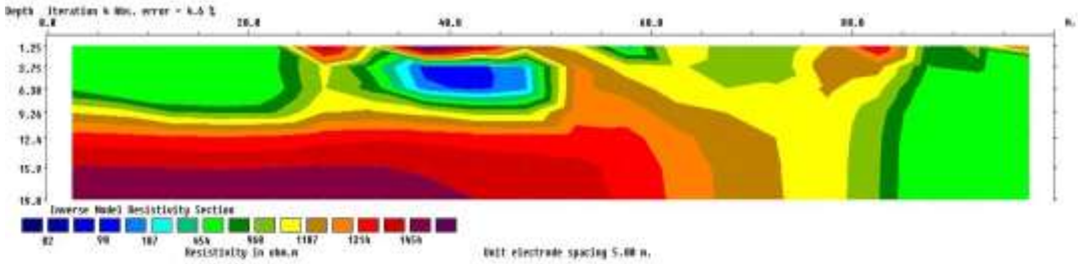

Figure 7: *2D ERT Model along Traverse 2 (Upland)*

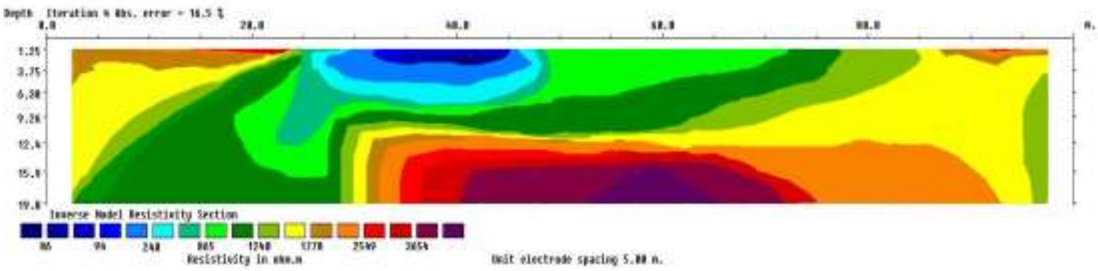

Figure 8: *2D ERT Model along Traverse 3 (Upland)*

3.1.1 Lowland Farmlands

- Traverse 1 (Figure 3): A plume is observed between 54 m and 67 m laterally, extending vertically to ~6.4 m. Resistivity values range from 70–95 Ωm, which are lower than typical uncontaminated sandy or loamy soils (Samouëlian et al., 2005), indicating probable fertilizer infiltration in the shallow subsurface.
- Traverse 2 (Figure 4): A distinct plume occurs between 25.4 m and 39.5 m laterally, spanning depths of 3–6.5 m. The lower resistivity range (50–75 Ωm) suggests higher solute concentration and moisture retention, consistent with local waterlogging conditions.
- Traverse 3 (Figure 5): The plume extends from 23 m to 50.7 m laterally and reaches a depth of ~6.3 m. Resistivity values (45–69 Ωm) are the lowest among the lowland traverses, highlighting stronger influence of fertilizer leachates, exacerbated by poor drainage typical of low-lying farmlands (Afuwai and Ema, 2025).

3.1.2 Upland Farmlands

- Traverse 1 (Figure 6): Anomaly appears between 41.7 m and 43 m laterally, extending vertically to 2.8 m. Resistivity values (62–95 Ωm) suggest limited infiltration, likely due to better drainage and lower water retention in upland soils.
- Traverse 2 (Figure 7): A confined plume is observed between 38.2 m and 43.1 m laterally, extending to 3.3–7 m depth. Resistivity values of 75–90 Ωm

indicate moderate infiltration, consistent with soil porosity and slope-controlled drainage.

- Traverse 3 (Figure 8): The plume spans 33.5 m to 46 m laterally and reaches 2.8 m depth, with resistivity values of 72–95 Ωm. This shallow, narrow anomaly reflects minimal downward migration of contaminants in upland terrain (Ganiyu et al., 2019).

3.2 Comparative Interpretation

Overall, lowland farmlands exhibit deeper and more extensive contaminant plumes with lower resistivity, indicating higher vulnerability to fertilizer leaching due to water accumulation, poor drainage, and longer residence time of infiltrating solutes (Binley et al., 1996; Afuwai and Ema, 2025). In contrast, upland farmlands display shallower and more localized anomalies with higher resistivity, reflecting better natural drainage, lower moisture retention, and reduced mobility of contaminants.

The variation in resistivity across profiles emphasizes the combined influence of topography, soil texture, permeability, and hydrological conditions on the transport and concentration of fertilizer-related pollutants. These findings suggest that low-lying farmlands in Oghara are at greater risk of subsurface contamination, which may eventually impact groundwater quality if unchecked.

3.3 Limitations and Need for Geochemical Validation

While 2D ERT effectively delineates zones of altered resistivity that likely correspond to contaminant plumes, resistivity anomalies alone cannot definitively confirm chemical contamination. Variations may also result from natural soil heterogeneities, moisture fluctuations, or organic matter content. Hence, geochemical analysis of soil and groundwater samples is necessary to validate the ERT interpretations and quantify fertilizer-derived pollutants (Afuwai and Ema, 2025; Ganiyu et al., 2019). Future work integrating both geophysical and physicochemical data would provide robust evidence for fertilizer-related contamination in the study area.

4. CONCLUSION

This study has demonstrated the effectiveness of 2D Electrical Resistivity Tomography (ERT) in mapping potential fertilizer-related pollution in farmlands of Oghara, South-South Nigeria. The results revealed marked differences between lowland and upland sites, with lowland areas exhibiting deeper and more extensive low-resistivity anomalies, indicative of solute-rich plumes and higher susceptibility to fertilizer leachate accumulation. In contrast, upland sites showed shallow, localized anomalies, reflecting limited contaminant infiltration due to better drainage and lower moisture retention.

The findings highlight the critical influence of topography, soil properties, and hydrological conditions on subsurface contaminant mobility, offering valuable insights for assessing groundwater vulnerability. While ERT effectively delineates plume geometry and migration pathways, it does not directly identify chemical constituents. Therefore, integrating physicochemical analysis of soil and groundwater is recommended to confirm the presence and concentration of fertilizer-derived pollutants. To mitigate contamination risks, the study underscores the importance of adopting best management practices, such as controlled fertilizer application, soil conservation strategies, and monitoring of vulnerable lowland farmlands. These measures can help safeguard groundwater resources and promote sustainable agriculture in Oghara and similar agrarian regions.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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