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2D Electrical Resistivity Imaging for Groundwater Contamination at Zobe Dam Irrigation Farming Site, Dutsin-Ma, Katsina State

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ABSTRACT
Polluted aquifers can result in poor drinking water quality, reduced crop yields, and serious health hazards. This study aim to investigate groundwater contamination due to frequent and indiscriminate use of fertilizers at the Zobe dam irrigation farming site using 2D Electrical Resistivity Imaging (ERI). The survey was conducted along two profiles using ABEM SAS4000 terrameter employing the dipole dipole array with an interelectrode spacing of 5 m and a total lateral spread of 200 m. The 2D resistivity data were processed and interpreted using RES2DINV software. The interpreted resistivity sections revealed significant lateral and vertical variations in subsurface materials, indicating heterogeneous soil and groundwater conditions, the 2D resistivity models showed resistivity varying from 17.8 Ωm to 8629 Ωm to a maximum depth of about 13.4 m and 28.7 Ωm to 359 Ωm to a maximum depth of about 6.76 m for both profile one and two respectively. Regions with resistivity values < 20 Ωm are interpreted as leachate plumes originating from the decomposition of buried remains, suggesting possible areas of groundwater contamination or increased pore fluid conductivity, likely influenced by agricultural return flow and infiltration from irrigation activities. Conversely, higher resistivity zones correspond to less saturated or more competent geological formations. The result revealed that the subsurface is composed of distinct lithological layers with the low resistivity values observed in the topsoil layer suggesting the presence of clayey and possibly contaminated materials influenced by irrigation and fertilizer application and also provides valuable insights into the extent and possible pathways of contamination within the study area, which can support sustainable groundwater management and agricultural planning in the region.

Keywords: Groundwater Contamination, Leachate, Resistivity, Zobe Dam, Irrigation

1.0 INTRODUCTION

Water is one of the most important natural resources for human survival including agricultural and industrial activities. Groundwater, in particular, is the world's greatest available supply of freshwater, and it remains critical for both home consumption and agricultural production, particularly in semi-arid and desert regions where surface water is scarce (Alile *et al.*, 2013).

However, population increase, urbanisation, industrialisation, and intensive agricultural practices are putting a strain on the availability of high-quality water supplies. While irrigation farming is critical for food security, fertilisers, insecticides, and herbicides are frequently used indiscriminately. These methods hasten the leaching of dissolved agrochemicals into the subsurface, contaminating aquifers and endangering both water quality and soil health (Hussaini *et al.*, 2021; Afuwai and Ema, 2025).

Groundwater contamination has wide-ranging impacts. Polluted aquifers can result in poor drinking water quality, reduced crop yields, and serious health hazards, including waterborne infections and ailments associated with high nitrate levels, such as blue baby syndrome (Freeze and Cherry, 1979). Contamination also raises water treatment costs and may render groundwater unsuitable as a safe supply source. In Nigeria, where irrigation farming is becoming more popular as a food security strategy, the risks posed by unmanaged pollutant leaking into groundwater are especially worrying. Despite this, systematic monitoring of groundwater quality is frequently absent, leaving farmers and decision-makers without sufficient data to guide sustainable irrigation methods.

Traditional hydrogeological studies, while useful, frequently fail to capture the regional diversity of groundwater contamination (Robinson *et al.,* 2008). Geophysical techniques like Electrical Resistivity Imaging (ERI) have evolved as effective tools for characterising subsurface environments. Two-dimensional electrical resistivity imaging (2D ERI) is particularly useful for mapping aquifers, identifying pollution plumes, and tracing infiltration pathways (Binley *et al.,* 2005; Cassiani *et al.,* 2015).

However, whereas ERT offers spatial information about probable contamination zones, it does not show the chemical makeup of groundwater. As a result, physicochemical analysis, which includes parameters such as pH, electrical conductivity, total dissolved solids, and major ions, is critical for determining the extent of pollution and the suitability of groundwater for irrigation (Suleiman *et al.,* 2021; Hussaini *et al.,* 2021).

The increasing reliance on irrigation farming, combined with the indiscriminate use of chemical fertilizers, pesticides, and herbicides, has heightened the risk of groundwater contamination (Afuwai and Ema, 2025; Hussaini *et al.,* 2021). Dissolved agrochemicals infiltrate through the soil into aquifers, altering water quality and posing risks to soil health, agricultural productivity, and human consumption. Despite the critical importance of groundwater, there is a notable lack of routine monitoring and limited scientific data on its quality in many irrigation zones. Traditional methods of water assessment are point-based and fail to adequately capture the spatial distribution of contaminants (Robinson *et al.,* 2008). Furthermore, studies in Nigeria have reported high variability in soil-water interactions and pollutant migration, yet local farmers and agricultural extension workers lack sufficient information to guide irrigation practices sustainably (Rahman *et al.,* 2020; Adeyemi, *et al.,* 2021). This knowledge gap contributes to poor resource management, soil degradation, and reduced crop yields, undermining both food security and environmental sustainability. Two-dimensional Electrical Resistivity Imaging (2D ERI) provides a non-invasive tool for detecting contaminant plumes, delineating aquifers, and monitoring infiltration pathways (Binley *et al.,* 2005).

1.1. Theory: Ohm's Law and Electrical Resistivity Principle

ERI is grounded in Ohm's law, which relates voltage, current, and resistance:

$$V = I \times R \tag{1}$$

Where V is the potential difference, I is current, and R is resistance. The resistance of a material is expressed as:

$$R = \rho \times (L / A) \tag{2}$$

Where ρ is resistivity, L is length, and A is cross-sectional area. Different subsurface media, such as clays, sands, or contaminated water, exhibit distinct resistivity values. Contaminated zones often show low resistivity due to increased ion concentration (Rubin and Hubbard, 2006).

1.2. Electrode Arrays and Data Acquisition

Electrode arrays such as Wenner, Schlumberger, and Dipole-Dipole control the resolution and depth of research in ERI surveys. Automated multi-electrode resistivity metres are utilised to do 2D ERI, and inversion algorithms yield 2D resistivity sections. These models account for both vertical and lateral resistivity fluctuations, which aid in the identification of contamination zones (Hassan, *et al.,* 2000).

1.3. Contaminant Transport in Groundwater

The advection-dispersion equation describes how groundwater pollution spreads:

$$\partial C/\partial t = D(\partial^2 C/\partial x^2) - v(\partial C/\partial x) - \lambda C \quad (3)$$

Where **C** is contaminant concentration, **D** is dispersion coefficient, **v** is groundwater velocity, and **λ** is decay constant. Contaminated water with high dissolved ions reduces aquifer resistivity. When combined with hydrochemical characteristics such as EC, TDS, and SAR, ERI provides a dependable method for mapping contaminated plumes (Binley *et al.,* 2005; Cassiani *et al.,* 2015).

2.0. MATERIALS AND METHODS

2.1. The Study Area

The study area is Dutsinma local government area in Katsina state, North-West Nigeria (Figure 1). It is bounded by longitudes 13°18′E and 09°54′E of the Greenwich Meridian and latitudes 11°15′N and 11°20′N of the Equators.

Katsina state state is from the tropical grass land known as Savannah to the north and has two major seasons which are the rainy season and dry season (About Katsina, 2022). The average annual rainfall, temperature and relative humidity of the state are 1,312 mm, 27.3°C and 50.2% respectively (KSIH, 2016).

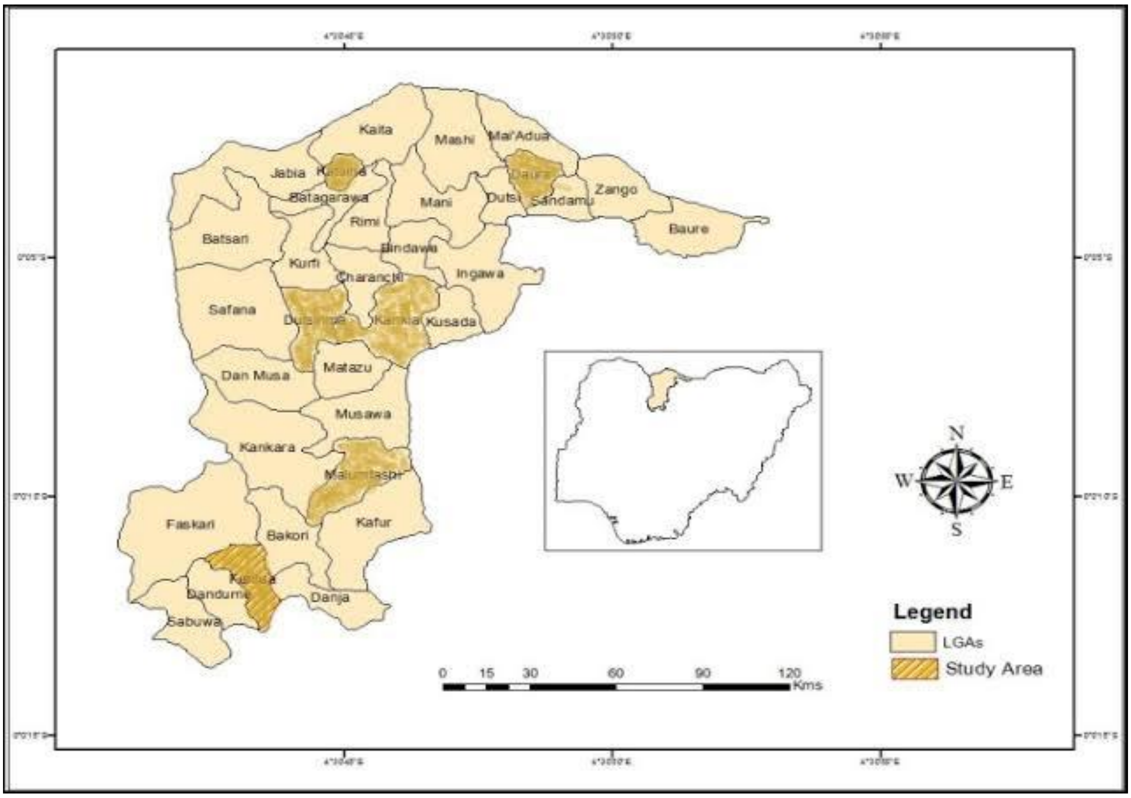

Figure 1: Katsina state Map Showing the Study Area (Source: Abaje *et al.,* 2016)

The materials and equipment utilized for this study include:

i. Abem Terrameter with multi-core electrode connector
ii. Metal electrodes
iii. Field hammer
iv. Measuring tape
v. Electric cable and Reels
vi. Jumpers or electrode clips
vii. Battery
viii. Global Positioning System (GPS)
ix. Pen and data sheet

Figure 2: Abem SAS4000 terrameter

2.2. Field Procedure, Data Acquisition, and Processing for the 2D ERI

A 2D Electrical Resistivity Imaging (ERI) was carried out across the zobe dam irrigation farming site to identify subsurface differences and potential pollution caused by agricultural activity. The ABEM Terrameter SAS4000 was used with stainless steel electrodes connected by multi-corecables. A dipole-dipole array configuration was chosen for its high lateral resolution and capacity to detect near-surface anomalies such as leachate movement, soil salinity, and fertiliser infiltration (Loke *et al.*, 2003; Hasan *et al.*, 2018).

To monitor the dispersion of pollutants, two (2) traverses were erected in various portions of the farmland, each oriented perpendicular to the irrigation water flow with an interelctrode spacing of 5 m. The Terrameter injected current through the current electrodes (C_1 and C_2) and monitored the voltage difference between the potential electrodes. The instrument computed apparent resistivity values automatically, which was then stored and processed with the RES2DINV software (Loke *et al.,* 2003). The fundamental idea behind obtaining the resistivity measurements is depicted in Figure 3.

The inversion procedure used a least-squares technique and was repeated until the Root Mean Square (RMS) error was less than 5%, confirming data trustworthiness. The final resistivity pseudo-sections was evaluated to detect low-resistivity zones that indicate potential contamination. Figure 4 illustrates the general process for creating a pseudo section in ERT.

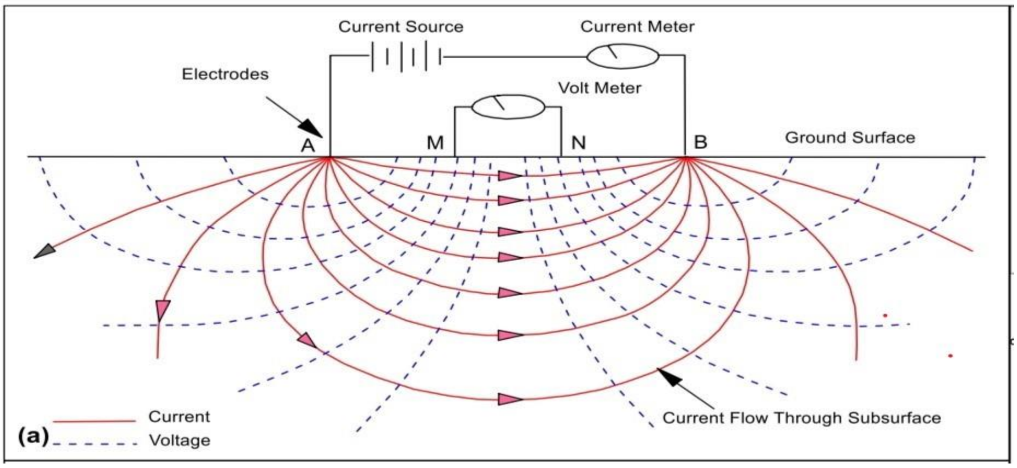

Figure 3: Fundamental conceptual model for resistivity measurement (modified after Todd and Mays 2005)

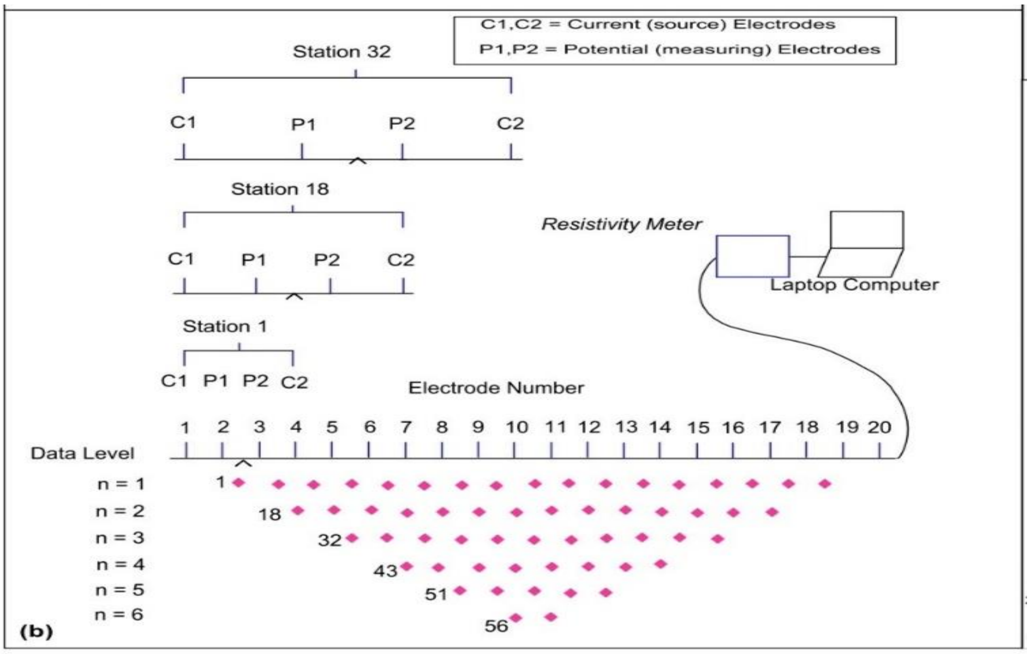

Figure 4: Principle diagram to generate a pseudo section in ERI

3.0. RESULTS AND DISCUSSION

Figure 5 show the 2D inversion model of Profile 1 (cultivated land) at Zobe dam irrigation farming site. A depth of 39.6 m was probe at a lateral distance of 200 m from N-S. The model has resistivity of 17-8629 Ωm. The top soil has a thickness of about 20 m with apparent resistivity between 17-50 Ωm. It is generally conductive. This indicates that the soil is mostly clay with high moisture content, less porosity, and relatively high organic. These regions of profile are considered to be saline, which could be as a result of fertilizer application during farming period. The near-surface region was dominated by low resistivity values represented by blue to green colours, while the deeper sections showed moderate to high resistivity values indicated by yellow to red colours.

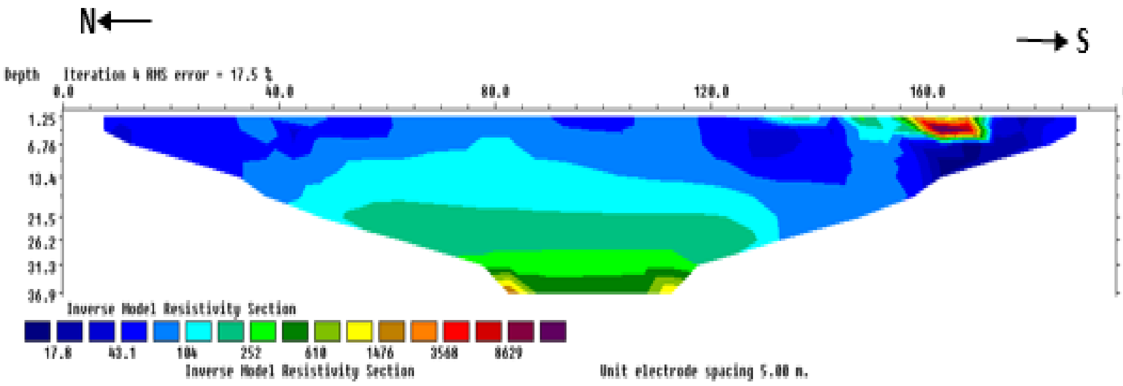

Figure 5: 2D Inversion Result of Profile 1

Profile 2 (Figure 6) shows a very low resistivity contrast (20 Ωm) which constitute the topsoil with a varying thickness between 16-10 m from N-S. The low resistivity contrast of about 17-50 Ωm indicates the presence of high saturated water/clay materials which is saline in nature especially in the northern part of the profile. This could be also as a result of excess application of fertilizer within the region. Underlie the topsoil is region of high resistivity (>200 Ωm) materials at a depth between 12-15 m. This is interpreted as sand.

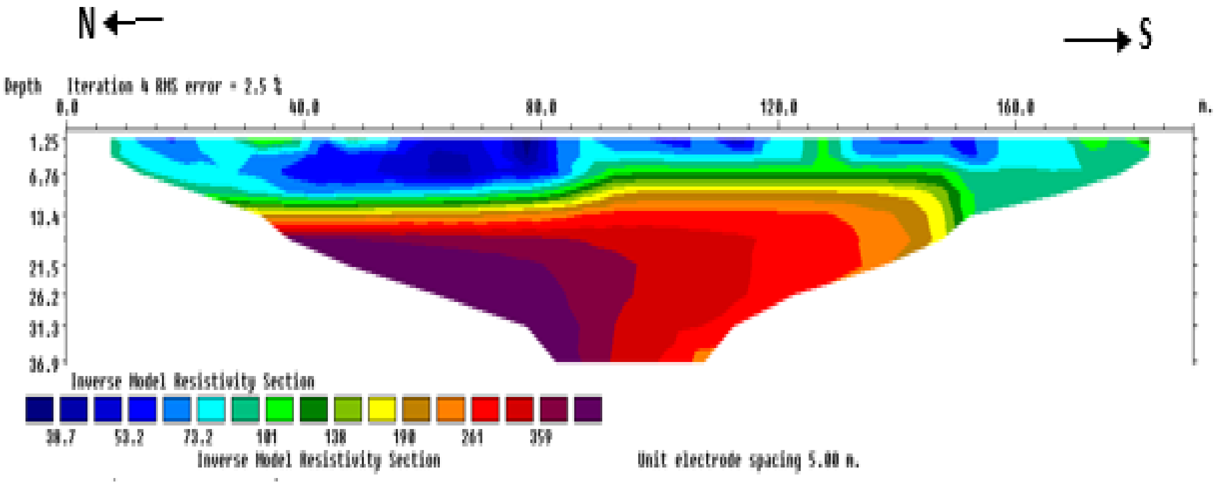

Figure 6: 2D Inversion Result of Profile 2

3.1. Discussion

The ERI results obtained from the Zobe Dam irrigation farming site revealed significant variation in subsurface resistivity, reflecting differences in lithology and fluid content.

The results of the study revealed three different subsurface layers classified as the topsoil layer, the intermediate layer and the subsurface layer. The topsoil layer in both profiles was characterized by low to very low resistivity values ranging from approximately 17-50 Ωm. This layer appeared as blue to green zones in the resistivity sections. These low resistivity values were interpreted as clayey soil with high moisture content and elevated electrical conductivity due to the presence of dissolved ions. Considering the irrigation activities at the study site, this condition was attributed to possible contamination from agricultural inputs such as fertilizers and other agrochemicals. This interpretation agreed with recent findings by Aizebeokhai *et al.* (2021) and Adagunodo *et al.* (2022), who reported that low resistivity values in agricultural environments are commonly associated with saline conditions and increased ionic concentration resulting from farming activities. An intermediate layer with moderate resistivity values ranging from approximately 100 to 200 Ωm was observed beneath the topsoil in both profiles. This layer corresponded to green to yellow colour zones. The layer was interpreted as a weathered zone composed of a mixture of clay and sand, indicating partial saturation and moderate permeability. This zone likely served as a transition layer and facilitated the downward movement of contaminants. Similar observations were reported by Oladunjoye *et al.* (2021) and Alabi *et al.* (2023), who described such layers as weathered formations that enhance fluid migration and contaminant transport in the subsurface.

The deeper sections of the profiles were characterized by high resistivity values greater than 200 Ωm, represented by yellow to red color zones. These zones were interpreted as sandy formations due to their relatively high resistivity and expected permeability. Sandy materials are known to have good groundwater storage and transmission properties, and were therefore identified as potential aquifer zones. This interpretation was consistent with recent studies by Akinlalu *et al.* (2022) and Abdullahi *et al.* (2021), who reported that high resistivity values are indicative of coarse-grained materials such as sand and gravel, which serve as groundwater reservoirs.

The contrast between the conductive topsoil and the resistive deeper layer suggested a typical hydrogeological setting in irrigation farming areas, where contaminants accumulate near the surface but may gradually infiltrate into deeper layers over time. The localized high resistivity zone observed in Profile 2 was interpreted as a compact or dry formation, which is consistent with findings from recent studies that associated such anomalies with consolidated geological materials (Alabi *et al.,* 2023).

4.0. CONCLUSION

Based on the results obtained from the ERI survey, it was concluded that the subsurface at the Zobe Dam irrigation farming site is composed of distinct lithological layers with varying resistivity characteristics. The low resistivity values observed in the topsoil layer suggested the presence of clayey and possibly contaminated materials influenced by irrigation and fertilizer application. The intermediate weathered layer was identified as a potential pathway for contaminant migration, while the deeper high resistivity layer was interpreted as a sandy aquifer capable of storing groundwater.

Although the subsurface layer appeared relatively protected, continuous agricultural activities and infiltration processes may pose a long-term risk of groundwater contamination. The study also demonstrated that 2D electrical resistivity imaging is an effective and reliable method for assessing subsurface conditions and identifying contamination zones in irrigation farming environments.

Based on the findings of this study, it was strongly recommended that regular monitoring of groundwater quality at the Zobe Dam irrigation farming site should be carried out to detect any changes in contamination levels over time.

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