



Geophysical Evaluation of Cemeteries for Groundwater Contamination in Dutsin-Ma, Katsina State

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ABSTRACT

The increasing reliance on shallow groundwater sources in Dutsinma, Katsina State, has raised concerns about contamination risks from nearby cemeteries. This study applied 2D Electrical Resistivity Imaging (ERI) to investigate groundwater contamination around Dutsinma cemeteries. A total of six survey profiles were established using the dipole dipole electrode configuration with 5 m interelectrode spacing covering a total spread length of 200 m. ABEM SAS4000 terrameter was used for this survey, and inversion was performed using RES2DINV software to produce 2D resistivity models of the subsurface. All 2D resistivity models showed resistivity varying from 9.99 Ωm to 4226.0 Ωm to a maximum depth of about 21.5 m, interpreted as leachate plumes originating from the decomposition of buried remains. Regions with resistivity values < 20 Ωm suggest regions contaminated with leachate. These conductive anomalies extended beyond some of the cemetery boundary indicating lateral migration of contaminants controlled by the permeable weathered basement underlying the area. The findings demonstrates that 2D ERI is an effective, non-invasive geophysical tool for mapping cemetery-related leachate migration and assessing potential threats to shallow aquifers. The result revealed that the subsurface is composed of distinct lithological layers with the low resistivity values observed suggesting the presence of possibly contaminated materials influenced by decomposed remains and also provides valuable insights into the extent and possible pathways of contamination within the study area, which can support sustainable groundwater management and burial ground sighting in the study area. However, Electrical Resistivity Imaging (ERI)-based interpretation while powerful for mapping subsurface anomalies, has inherent limitations when used in isolation, it cannot confirm the actual chemical composition or concentration of pollutants, as such geophysical methods cannot fully capture hydrochemical dynamics without complementary validation. To strengthen contamination assessment, the result findings recommend that future investigations should adopt an integrated approach involving systematic groundwater sampling, detailed physicochemical analyses, seasonal monitoring and regular groundwater quality monitoring to protect water resources in Dutsinma and its environs.

Keywords: Groundwater Contamination, Leachate, Resistivity, Cemetery, Dutsinma

INTRODUCTION

Groundwater is one of the most valuable natural resources for human survival, providing a significant portion of drinking water, supporting agricultural, industrial, and domestic activities worldwide (Freeze & Cherry, 1979). Groundwater is an outstanding source of water as it is renewable and usually of greater quality than surface water (Aisha *et al.*, 2022). In many developing nations, including Nigeria, groundwater remains the most accessible and reliable source of potable water due to inadequate surface water supply and poor infrastructure for water treatment (Ocheri *et al.*, 2014). However, its quality is increasingly at risk and threatened by contamination from anthropogenic activities, including improper waste disposal, industrial effluents, agricultural chemicals, landfills, and cemetery leachates (Foster & Hirata, 1988). While agriculture and industry are commonly recognized as major sources of groundwater contamination, cemeteries are often overlooked despite their potential to release harmful substances into aquifers. Cemeteries, though perceived as passive land uses, can become significant sources of environmental contamination because decomposing human remains release a wide range of organic, inorganic, and microbial contaminants into the surrounding soil and groundwater (Rupanjana & Deep, 2025; Rodrigues & Pacheco, 2003). Cemeteries, though traditionally regarded as places of cultural and religious significance, have increasingly

become potential sources of groundwater contamination. As corpses decompose, they release fluids containing complex organic and inorganic compounds, microorganisms, and toxic elements, which can migrate into the surrounding soil and eventually leach into groundwater (Fiedler *et al.*, 2012). Decomposition products include ammonia, phosphates, chlorides, nitrates, and heavy metals, which may alter the physicochemical and microbiological properties of groundwater and make it unsafe for human consumption (Dent, *et al.*, 2004).

Globally, several studies have documented groundwater contamination beneath and around cemeteries, especially those situated on permeable soils with shallow aquifers. The processes governing the movement of cemetery leachates through the various zones and aquifers are complex, involving mechanisms such as adsorption, retardation, advection, microbial activity, and biological transformation (Dent, *et al.*, 2004). Critical factors influencing contamination include soil type, permeability, burial density, groundwater depth, and climatic conditions. In addition to decomposition by-products such as nitrates and pathogens, other sources of pollution arise from materials used in coffin construction and burial practices. Toxic substances such as preservatives, varnishes, sealers, embalming fluids, and metallic ornaments can leach into groundwater. Coffins often contain paints and wood preservatives with toxic compounds such as copper, arsenic,

naphthalene, mercury, cadmium, chromium, and lead, which are capable of long-term groundwater contamination (Spongberg & Becks, 2000; Jonker & Olivier, 2012; Katz & Salem, 2005). These pollutants not only degrade water quality but also pose significant health risks to populations relying on groundwater for domestic purposes. Given these concerns, the application of advanced investigative techniques has become crucial. Geophysical methods, particularly Electrical Resistivity Imaging (ERI), have proven effective in subsurface characterization and hydrogeological investigations. ERI provides high-resolution spatial datasets, enabling the mapping of subsurface heterogeneities, identification of preferential flow paths, and detection of contaminant plumes without invasive drilling (Martin, 2022). ERI enhances contamination assessments by correlating resistivity anomalies with actual water quality parameters. Such integrative approaches not only improve scientific understanding of groundwater vulnerability but also provide reliable data for environmental management and policy formulation.

In Nigeria, rapid population growth and urbanization have increased the demand for burial spaces, often leading to cemetery expansion in to residential areas or close proximity to groundwater sources such as hand-dug wells and boreholes (Oloso *et al.*, 2018). This practice raises significant environmental and public health concerns, especially in towns such as Dutsinma, Katsina State, where shallow aquifers serve as the main source of domestic water supply (Loke, 2004). Therefore, the method provides a reliable means of mapping contamination pathways. Moreover, policymakers and environmental managers currently lack sufficient local data to establish cemetery siting guidelines, groundwater monitoring frameworks, and aquifer protection measures. The absence of such data-driven management strategies means that urban expansion around cemeteries may continue to expose vulnerable populations to contaminated groundwater, with long-term socio-environmental and public health implications (Jonker & Olivier, 2012). This research therefore addresses an urgent need: to investigate the contamination potential of cemeteries on groundwater quality in Dutsin-ma, using 2D Electrical Resistivity Imaging (ERI).

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

$$V = I \times R \quad (1)$$

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

$$R = \rho \times (L / A) \quad (2)$$

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).

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.*, 2020).

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 & Kemna, 2005; Cassiani *et al.*, 2006).

MATERIALS AND METHODS

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 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).

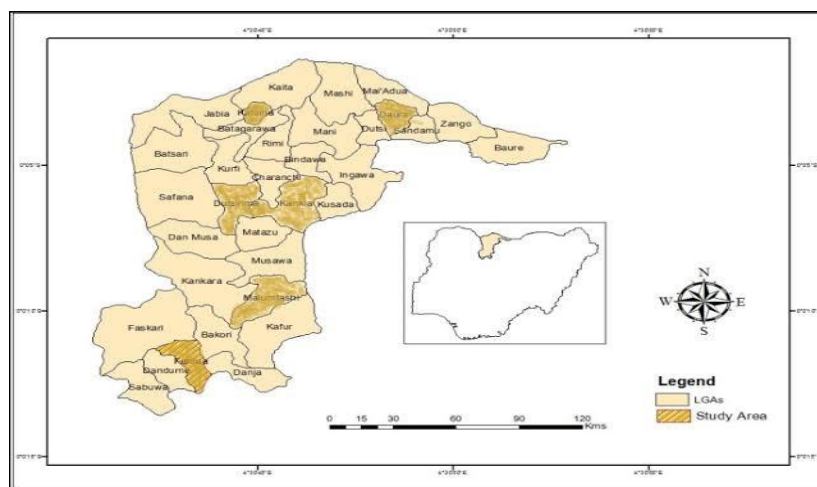


Figure 1: Katsina State Map Showing the Study Area (Source: Abaje *et al.*, 2016)

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

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

A 2D Electrical Resistivity Imaging (ERI) was carried out across three (3) cemeteries to identify subsurface differences and potential pollution caused by leachate migration. A total of six (6) traverses were carried out across the three (3) cemeteries namely; Tsaskiya road cemetery (traverse 1-3), Bani Adam cemetery (traverse 4-5) and Dogon Karfe cemetery (traverse 6), with an interelectrode spacing of 5 m. The ABEM Terrameter SAS4000 was used with stainless steel electrodes connected by multi-core cables. A dipole-dipole array configuration was chosen for its high lateral resolution and capacity to detect near-surface anomalies such as leachate movement (Loke *et al.*, 2003; Hassan *et al.*, 2020).

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.

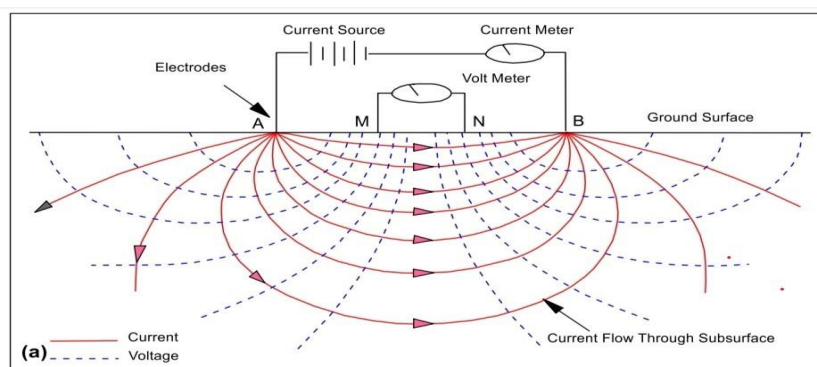


Figure 3: Fundamental Conceptual Model for Resistivity Measurement (modified after Todd and Mays 2005)

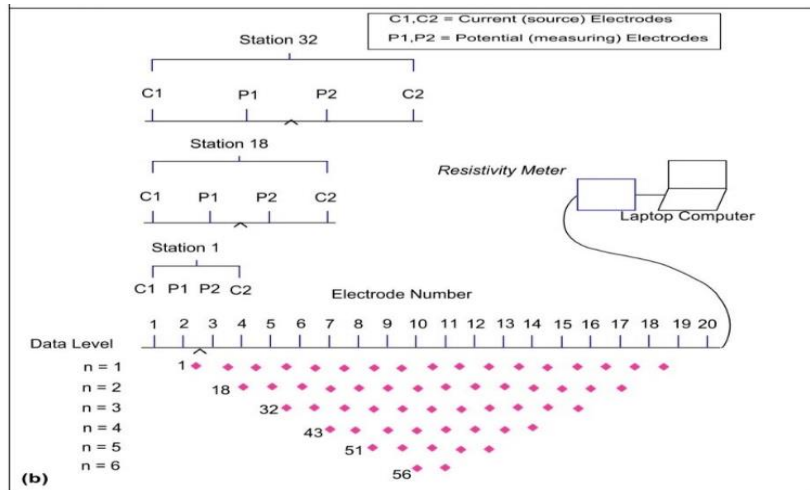


Figure 4: Principle Diagram to Generate a Pseudo Section in ERI

RESULTS AND DISCUSSION

Figure 5 shows the pseudo section and resistivity inversion result for profile 1 which is oriented SE-NW across the cemetery. The profile was taken in Tsaskiya road cemetery, it covers a total lateral length of 200 m. From the inversion model

there is little or nearly no Leachate plumes observed. The top soil at a depth of 4m has a resistivity between 20-90 Ωm which is interpreted as clay. The fresh basement which is shallow and almost intrudes the topsoil has a resistivity of between 1000-5000 Ωm.

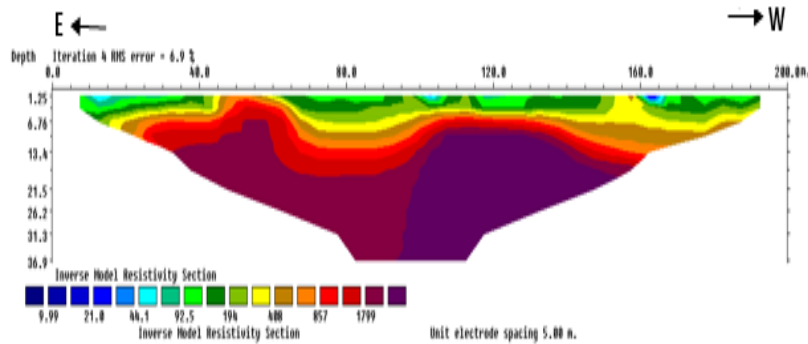


Figure 5: 2D Inverse Model Resistivity Section for Profile 1

Figure 6 shows the pseudo section and resistivity inversion result for profile 2 which is oriented E-W outside the cemetery. It was taken from Tsaskiya road cemetery. It indicates Leachate plumes at a depth of 6m from the surface and has a lateral distance between 90-105 m and 125-140 m

toward the SW part of the profile, with resistivity of about 20-60 Ωm. Beneath it is the weathered rock, at a depth of 10 m with resistivity of about 800 Ωm. The fresh basement is observed at a depth of 20 m and has a resistivity of 2500 Ωm.

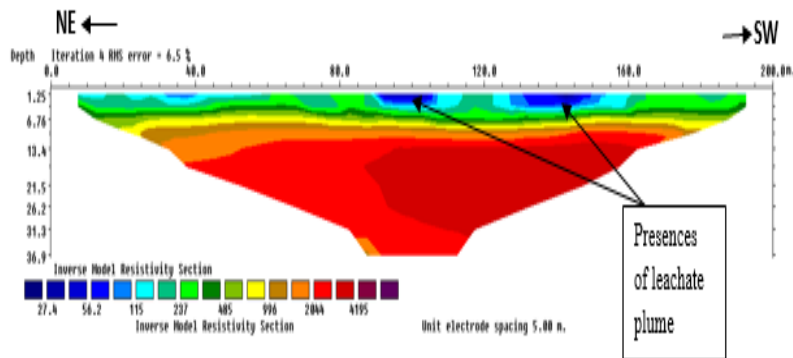


Figure 6: 2D Inverse Model Resistivity Section for Profile 2

Figure 7 shows the pseudo section and resistivity inversion result for profile 3 which is oriented SE-NW outside the cemetery. It shows a uniform distribution of low resistivity

contrast ranging between 15-90 Ωm, at a depth of 6 m approximately from SE-NW of the profile. This indicates contamination around this area. Beneath this layer is the

weathered rock with resistivity between 200-750 Ωm. The fresh basement at a depth of 14 m has a resistivity >4000 Ωm

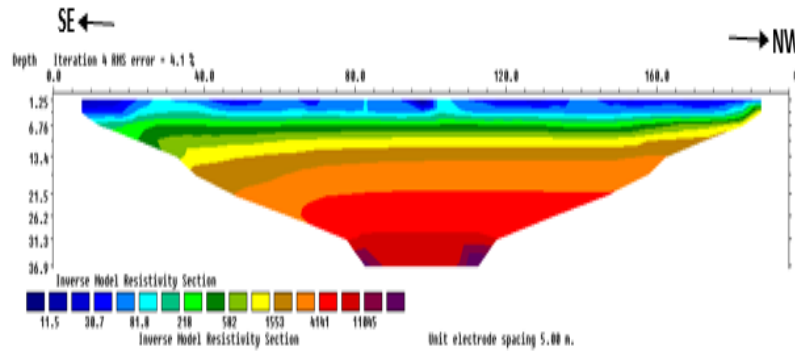


Figure 7: 2D Inverse Model Resistivity Section for Profile 3

Figure 8 shows the pseudo section and resistivity inversion result for profile 4 which is oriented W-E across the cemetery. This first profile in Bani Adam cemetery also indicates well significant leachate plume to the western and eastern part of the profile with resistivity between 25-50 Ωm

at a depth of 20 m from the surface, signifying high level of contamination in this area. The depth of contamination shows high decomposition of organic material. This is one of the oldest cemetery and has remain unused for the past ten years, as reported by the people living in the community.

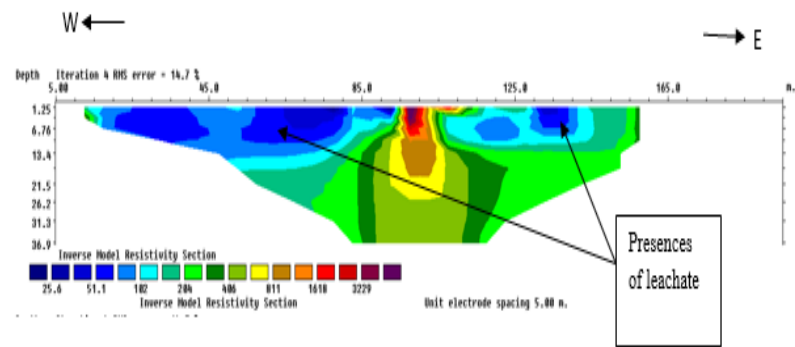


Figure 8: 2D Inverse Model Resistivity Section for Profile 4

Figure 8 shows the pseudo section and resistivity inversion result for profile 5. The result of the pseudo cross section revealed the presence of leachate plume indicating high to very high level of contamination both to the SE and NW of the profile. The depth of the plume is 18 m from the surface

with the resistivity ranging between 24-50 Ωm, beneath this layer is the weathered rock with resistivity between 200-500 Ωm, this could also serve as a path way for the contamination. The fresh basement was observed at a depth of 25 m with resistivity >2000Ωm

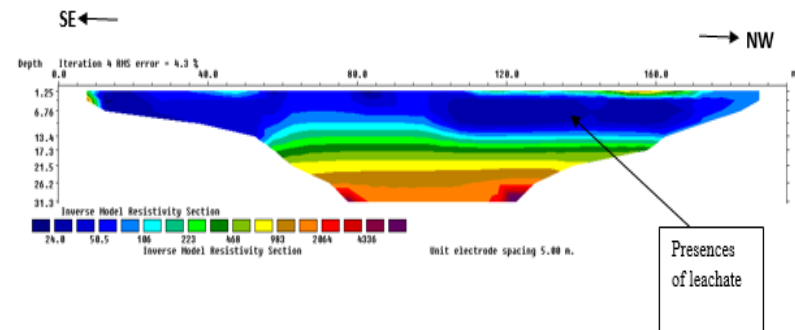


Figure 9: 2D Inverse Model Resistivity Section for Profile 5

Figure 9 shows the pseudo section and resistivity inversion result for profile 6 was taken outside Dogon Karfe cemetery. The result of profile 6 shows significant leachate plume at a depth of 6 m with resistivity of about 20 Ωm, which indicate

high contamination in this area. The significant contamination observed could be as a result of decomposition of organic material. The topsoil with high resistivity contrast between

250-650 Ωm , could be as a result of the consolidated lateritic soil observed in the study area.

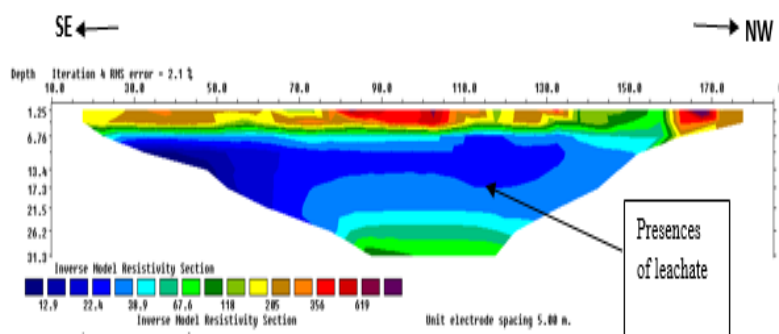


Figure 10: 2D Inverse Model Resistivity Section for Profile 6

Discussions

The geophysical investigation using 2D electrical resistivity imaging (ERI) across the six profiles at three different cemetery provides insight into the subsurface lithology and possible contamination due to leachate migration. The Electrical Resistivity Imaging (ERI) results obtained around the cemeteries reveal significant subsurface anomalies associated with contamination from burial activities. Variations in resistivity values reflect changes in moisture content, ionic concentration, and the presence of decomposition-derived leachates. All profiles shows pronounced low resistivity zones ranging from 9–25 Ωm at varying depth, indicating zones of high conductivity associated with leachate contamination. These low resistivity values are typically linked to the presence of decomposed organic matter, dissolved ions, and microbial activity. This observation agrees with findings that decomposition of human remains releases organic substances, salts, and microorganisms, which infiltrate the subsurface and reduce resistivity (Vava & Atangana, 2024).

Bani Adam cemetery despite being inactive for about a decade, the persistence of contamination at about 18 m depth indicates that decomposition products remain in the subsurface for long periods and continue to migrate, which supports earlier findings that leachates from cemeteries can persist and impact groundwater systems over time (Vaezihir & Mohammadi, 2016). The occurrence and movement of leachate plumes beyond some of the cemetery boundary indicate lateral migration of contaminants controlled by the permeable weathered basement underlying the area and suggests that contaminant migration follows subsurface flow patterns, controlled by hydrogeological conditions. This supports the assertion that contaminants from cemeteries migrate through seepage and are transported via advection and dispersion processes within the subsurface (Vava & Atangana, 2024).

The underlying weathered layer (200–500 Ωm) may act as a preferential pathway for contaminant movement due to its permeability. This aligns with findings that geological conditions such as permeability and hydraulic conductivity significantly influence contaminant transport and groundwater vulnerability (Vaezihir & Mohammadi, 2016). The presence of a fresh basement (>2000 Ωm) at greater depths suggests a relatively impermeable layer that may restrict further downward migration, although lateral spreading within the weathered zone remains possible.

CONCLUSION

In conclusion, the cemeteries constitutes a source of subsurface contamination that threatens groundwater quality in Dutsinma, the results of this study demonstrate that groundwater around Dutsinma cemeteries are susceptible to contamination arising from burial activities over a long period of time. The ERI method effectively identified low resistivity anomalies which may be associated with leachate plumes, particularly in areas characterized by permeable weathered materials that facilitate contaminant movement. Conversely, clay-rich zones showed limited contamination due to their low permeability, which acts as a natural barrier. The study further establishes that leachate migration can extend beyond the boundaries of the cemetery, posing potential risks to nearby groundwater resources. This highlights the importance of understanding subsurface geology when assessing environmental impacts. The findings are significant for environmental management, as they provide essential data for groundwater protection and sustainable land-use planning. To mitigate these risks, there is an urgent need for proper site selection of cemeteries based on hydrogeological studies, enforcement of sanitary buffer zones and regular monitoring of groundwater quality. However, Electrical Resistivity Imaging (ERI)-based interpretation while powerful for mapping subsurface anomalies, has inherent limitations when used in isolation. ERI provides indirect geophysical signals about resistivity contrasts, which can suggest zones of possible contamination, but it cannot confirm the actual chemical composition or concentration of pollutants when used in isolation, as such geophysical methods cannot fully capture hydrochemical dynamics without complementary validation. To strengthen contamination assessment, future investigations should adopt an integrated approach involving systematic groundwater sampling, detailed physicochemical analyses, and seasonal monitoring. This combined methodology will provide a more robust understanding of contamination pathways and temporal variations, thereby ensuring more reliable protection of groundwater resources in the study area.

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