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Geoelectrical Characterization of Subsurface Anomalies in a Controlled Landfill Near the Belo Monte Hydroelectric Plant (PA, Brazil)

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Abstract

This study investigates the subsurface conditions of a controlled landfill near Belo Monte, Pará, Brazil, using electrical resistivity tomography (ERT). Four dipole-dipole resistivity profiles, each 310 meters long, were acquired using the X6xtal 500 system. The method enabled the identification of low-resistivity anomalies (ZLR), typically associated with water-saturated zones, particularly in profile PM-01, where anomalies are closer to the surface. These results were integrated into a 3D geological model, highlighting potential zones of fluid migration and rock-fluid interaction. The findings demonstrate the effectiveness of the ERT method in environmental monitoring, particularly for detecting anomalies related to possible contamination and fluid pathways in sedimentary aquifers.

Introduction

Inadequate solid waste disposal remains a significant environmental challenge in developing countries. Although controlled landfills represent an improvement over open dumps, they often lack proper leachate and gas treatment infrastructure, posing serious soil and groundwater contamination risks. In this context, environmental geophysics plays a crucial role by providing non-invasive tools for subsurface investigation, helping to delineate contamination plumes, evaluate aquifer vulnerability, and characterize geological structures that may influence contaminant transport.

Among geophysical methods, electrical resistivity has proven effective for monitoring and assessing subsurface anomalies such as zones of low resistivity potentially associated with leachate migration. According to Araújo and Tancredi (2002), many alluvial aquifers exhibit high vulnerability to external contamination sources, making seasonal and spatial assessment of these resources essential for environmental management and protection.

The present study focuses on a controlled landfill near the Belo Monte hydroelectric plant in Vitória do Xingu, approximately 50 km from Altamira (Pará, Brazil). The site lies within the Maecuru Formation, which, according to da Silva et al. (2011), is composed predominantly of deltaic and neritic sandstones, pelites, siltstones, and shales. These lithologies were deposited in high-energy environments capable of sorting sedimentary grains efficiently. As highlighted by Silva (2018), the Maecuru Formation features interconnected pore systems within the rock matrix, which facilitates fluid movement and may enhance contaminant migration through the subsurface. This geological context underscores the importance of resistivity-based investigation to detect zones of potential concern related to landfill leakage and aquifer interaction.

Materials and Methods

This study employed the electrical resistivity method to investigate subsurface conditions near a controlled landfill site. Among various configurations, the dipole–dipole array was selected due to its high resolution for lateral heterogeneities and operational efficiency in field deployments. This configuration uses current electrodes (AB) and potential electrodes (MN) arranged with fixed spacing, where the separation between the dipoles (AB–MN) increases progressively at each depth level of investigation (denoted as NN), allowing for both vertical and horizontal resolution Braga (2016). Voltage readings were constrained to remain above local noise levels to ensure data reliability.

Field data were acquired using the X6xtal 500 resistivity imaging system (Auto Energia). Four pseudosections were obtained and labeled PJ-02, PJ-03, PJ-04, and PM-01, each consisting of 32 electrodes spaced over a 310-meter profile (Figure 1). The raw resistivity measurements were processed and inverted using dedicated software that applies a least-squares approach to reduce random noise and stabilize the inversion process, as described by Loke and Barker (1996).

The inverted resistivity sections were exported in ".xyz" format, including topographic corrections and subsurface resistivity values. These outputs were subsequently imported into geological modeling software (Leapfrog Geo) for 3D reconstruction of the subsurface. The model incorporated geophysical section data, Differential GPS (DGPS) coordinates, and interpreted resistivity measurements. Based on this integrated dataset, subsurface layers were analyzed and classified into low-resistivity zones (ZLR), defined as areas ranging from 0 to 550 $\Omega\,\mathrm{m}$, and high-resistivity zones (HRZ), with values above 550 $\Omega\,\mathrm{m}$. These classifications formed the basis for delineating target areas of interest within the study site.

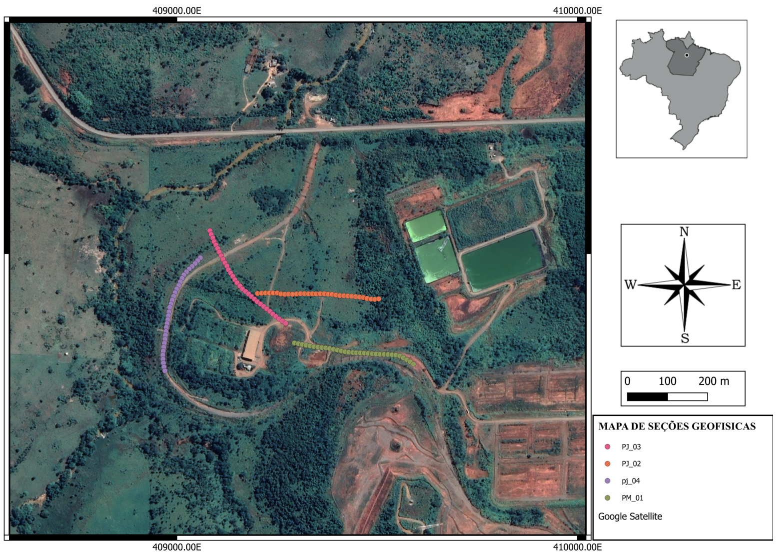

Figure 1: Acquisition map of the resistivity survey profiles conducted in the landfill area.

Results

All resistivity sections revealed distinct low-resistivity anomalies (ZLR), represented by blue tones interpreted as saturated rock zones. These anomalies are likely associated with pore spaces filled with conductive fluids. The PM-01 section displayed features closer to the surface than the others. This difference is attributed to topographic variation within the study area, as this section is situated at a higher elevation.

Figure 2 shows the inverted resistivity sections: PJ-02, PJ-03, PJ-04, and PM-01, each approximately 310 meters long. The spatial distribution of low-resistivity zones suggests potential contamination or water accumulation in specific subsurface regions.

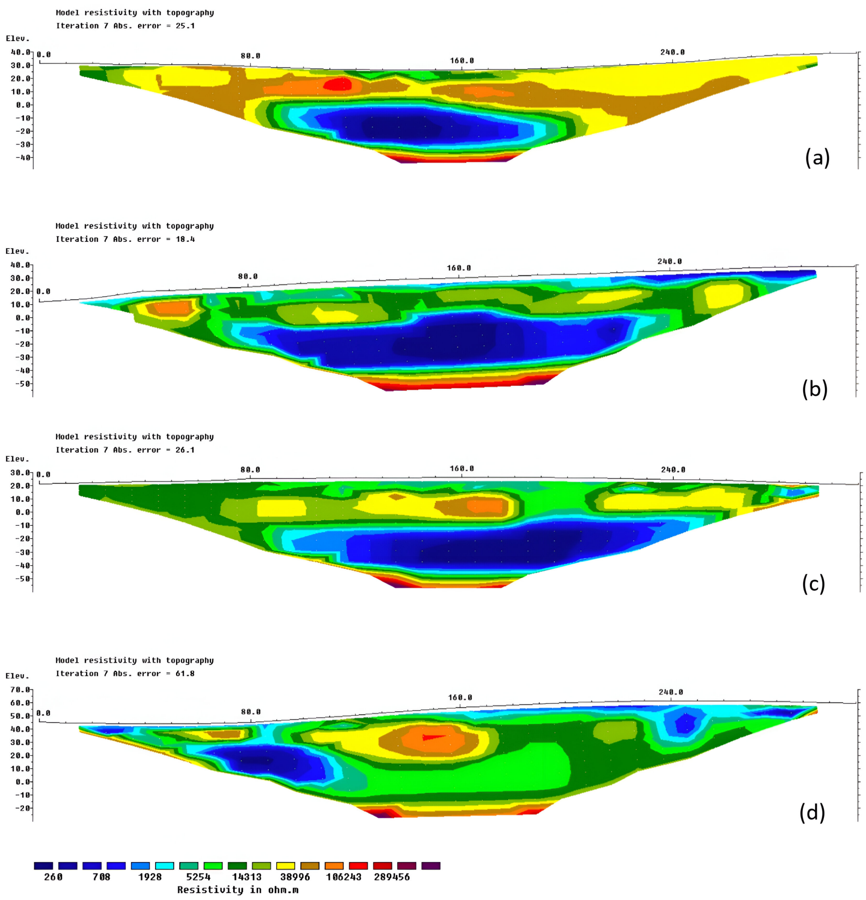

Figure 2: Inverted resistivity sections: (a) PJ-02; (b) PJ-03; (c) PJ-04; (d) PM-01. Low-resistivity anomalies (ZLR) are highlighted in blue and indicate zones potentially saturated with fluids.

Based on these sections, a 3D geological model was constructed by integrating the interpreted low-resistivity zones, mesh geometry, and surface topography. This model, shown in Figure 3, enabled the delineation of subsurface features and facilitated the identification of potential pathways for fluid flow and contaminant transport. The model provides an enhanced understanding of subsurface anomalies' spatial configuration and volumetric extent.

Conclusions

Applying electrical resistivity tomography using the dipole-dipole array proved effective in identifying subsurface anomalies near the controlled landfill in Vitória do Xingu. Zones of low resistivity (ZLR), interpreted as saturated or potentially contaminated areas, were consistently detected across all sections, especially in PM-01, where shallow anomalies were influenced by local topography. Integrating inversion results into a 3D geological model provided valuable insights into the spatial configuration of these anomalies, reinforcing the method's suitability for environmental monitoring of potentially vulnerable aquifer systems.

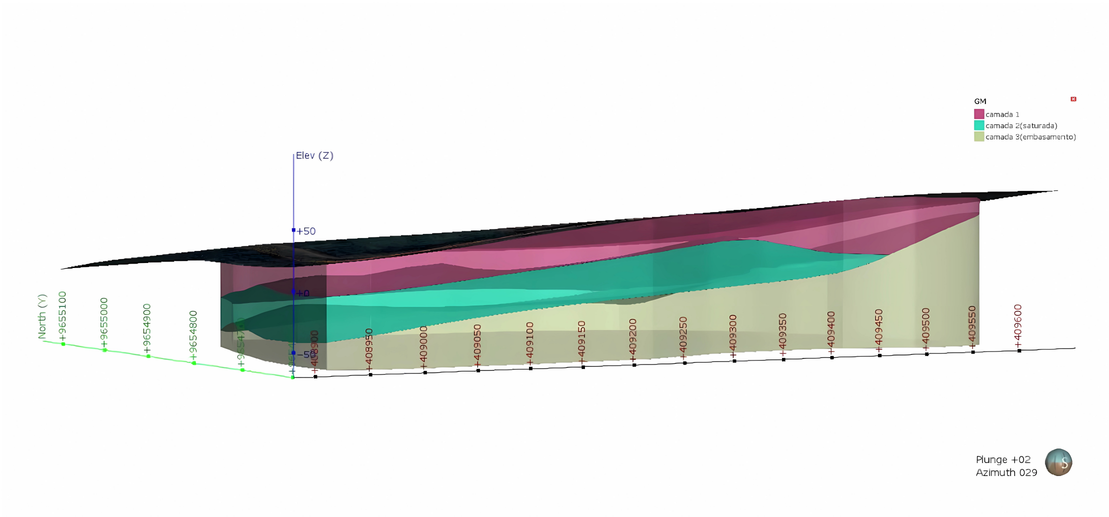

Figure 3: Three-dimensional geological model of the subsurface, constructed from the inverted resistivity data and interpreted based on resistivity contrasts and structural features.

Acknowledgments

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