Using Geophysics Methods to Analyze Evolution of Infiltration from a Tailing Storage Facility

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Abstract

Tailing storage facility (TSF) infiltration poses a significant environmental risk. This study investigates infiltration plume evolution from a TSF under investigation since 2016. Geophysical methods, specifically NanoTEM and electrical resistivity tomography, were used to characterize subsurface anomalies indicative of infiltration. These techniques offer high-resolution data and allow for temporal monitoring of the plume's migration. Results demonstrate the effectiveness of geophysics in delineating the infiltration's spatial extent, identifying areas of high concentration, and assessing groundwater potential contamination. Temporal analysis reveals contaminant migration rates, informing mitigation strategies and suggesting new control measures. This approach provides valuable insights for improved TSF management and environmental monitoring.

Keywords: Tailings, Infiltration, Geophysics, Groundwater Contamination.

Introduction

Tailings storage facilities (TSF) are indispensable components of modern mining operations. However, they also represent a significant environmental liability due to the potential for seepage and infiltration. One of the primary concerns associated with TSFs is the risk of tailings-derived water infiltrating underlying groundwater systems. This infiltration can introduce a range of contaminants, including pollutants and other potentially harmful substances, into aquifers, posing substantial risks to both water resources and sensitive ecosystems.

While modern TSF design incorporates various measures to minimize seepage, achieving complete elimination of infiltration is often a significant challenge. The complex and frequently heterogeneous nature of the foundation soils beneath TSFs, coupled with the evolving chemical and physical properties of the tailing's material itself, contributes to the complexity of predicting and effectively monitoring infiltration processes. These factors make it difficult to accurately assess the potential for contaminant migration and the long-term effects on groundwater quality.

Traditional monitoring methods, such as installation of monitoring wells, while providing valuable data, can be hard to implement, spatially limited in their coverage, and potentially disruptive to the TSF structure itself. These limitations highlight the need for alternative approaches that can provide more comprehensive and non-invasive monitoring of infiltration.

This study explores the application of geophysical methods, specifically geoelectrical techniques, as a non-invasive and effective approach to characterize and monitor the evolution of infiltration plumes emanating from a TSF that has been under study since 2016, providing a valuable temporal dataset for analyzing the long-term behavior of infiltration. The study aims to demonstrate the utility of geophysics in enhancing our understanding of infiltration processes and improving the management of potential risks associated with TSFs

Infiltration Monitoring Complexity

Monitoring infiltration from TSFs represents a complex challenge due to the interplay of numerous influencing factors. These factors include hydraulic properties of tailing's material, hydrogeological characteristics of the underlying soils (such as permeability, porosity, and degree of saturation), specific design and operational practices of the TSF, and climatic conditions. A thorough understanding of these factors and their complex interactions is crucial for effectively understanding and managing the infiltration process.

However, the unsaturated zone, where much of the initial infiltration occurs, poses a particular challenge for characterization. This zone, located between the ground surface and the water table, is notoriously difficult to investigate due to its dynamic nature and the complex interactions between water, air, and soil particles. Traditional methods, while providing valuable information, have inherent limitations. Soil sampling and laboratory testing, for example, offer insights into soil properties but are limited in spatial extent and can be disruptive to the TSF structure. Furthermore, these methods may not adequately capture the dynamic nature of the infiltration process, which can vary significantly over time in response to changing conditions.

These limitations have driven the exploration and development of more comprehensive and, importantly, non-invasive monitoring techniques. The need for methods that can provide continuous, spatially distributed information about infiltration processes without disturbing the TSF has led researchers and practitioners to investigate the potential of geophysical methods. These methods offer the promise of characterizing the subsurface in a non-destructive manner, providing valuable insights into the evolution of infiltration plumes and informing more effective management strategies.

Geophysical Methods: A Powerful Tool for Infiltration Analysis:

A Geophysical methods offer a non-invasive and cost-effective way to investigate the subsurface and identify anomalies associated with infiltration. This study focuses on the use of geoelectrical methods, specifically NanoTEM and ERT, to map the spatial distribution of electrical resistivity.

These methods are widely used in hydrogeological exploration contexts. Both ERT and NanoTEM are indirect and non-invasive methods that measure the variation of electrical resistivity in the subsurface. This property, electrical resistivity, will depend mainly on the porosity of the rocks, the degree of lithification and, in the case of sediments, granulometry (Telford *et al.* 1990). Furthermore, the relative water content in the rocks (i.e. saturated, partially saturated or unsaturated layers) and the chemistry of the groundwater (electrical conductivity) allow for significant variations in resistivity with depth (Telford *et al.* 1990). In this way, the layers with the highest water content will provide low resistivity values (< ~30 Ω-m), compared to those less saturated (between 30 and 250 Ω-m approx.) and unsaturated (> ~250 Ω-m). Some examples can be seen in works carried out in Northern Chile (Taucare, 2015; Ruthsatz *et al.* 2018; Viguier *et al.* 2018).

- NanoTEM (Transient Electromagnetic Method): NanoTEM measures the decay of an electromagnetic field induced in the ground. It is particularly sensitive to conductive materials at depth and can be used to map the overall extent of a conductive plume associated with infiltration.
- Electrical Resistivity Tomography (ERT): ERT involves injecting electrical current into the ground and measuring the resulting voltage differences. By analyzing these measurements, a 2D or 3D image of the subsurface resistivity distribution can be generated. ERT provides higher spatial resolution than NanoTEM and can be used to delineate the detailed structure of the infiltration plume.

Study Site and Methodology:

This study focuses on a specific TSF that has been monitored since 2016. Geological setting, TSF design, and operational history are important factors considered in the interpretation of geophysical data.

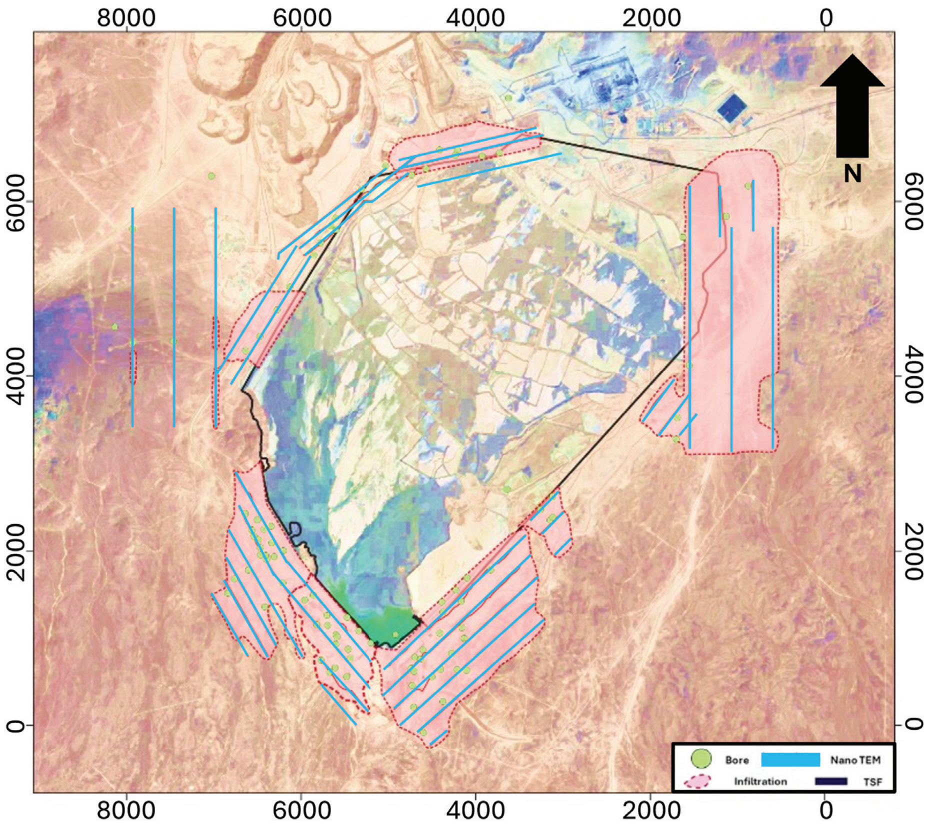

Figure 1 *Geophysical survey's locations around TSF area.*

The methodology involves repeated geophysical surveys using NanoTEM and ERT at key locations around the TSF (Fig. 1). Baseline surveys were conducted to establish background resistivity distribution before significant infiltration was observed. Subsequent surveys were conducted at regular intervals to monitor the temporal evolution of the infiltration plume. The data were processed and interpreted using specialized software to generate maps and cross-sections of resistivity. These results were then integrated with existing hydrogeological data, including information from monitoring wells, to develop a comprehensive understanding of the infiltration dynamics.

Results and Discussion:

Multiple geophysical surveys successfully delineated the spatial extent of the infiltration plume emanating from the TSF, with multiple interpretations of the resistivity (Fig. 2). NanoTEM data provided a regional overview of the conductive anomaly, while ERT data revealed the detailed structure of the plume, including areas of higher contaminant concentration.

Fig. 2 shows the delimitation of the plume based on the resistivity interpretation of one of the multiple surveys. Results of this interpretation were also compared with data from bores P4 and P4A, drilled and screened in the unsaturated zone, but their current situation shows presence of water that is associated with infiltration from the TSF. It must be noted that close to bore P4A there is a lack of data due to field complications. This same procedure was repeated with the different surveys shown in Fig. 1. With all this information it was possible to delimitate the areas of the infiltration as presented in the same figure.

Temporal analysis of the data showed the plume's migration pathways and its rate of advance. Results were compared with data from monitoring wells, confirming the effectiveness of the geophysical methods in detecting and characterizing infiltration. The study also revealed the influence of geological structures, such as faults or preferential flow paths, on the plume's migration. This was not the focus of the study and will be analyzed in future studies.

As shown (Fig. 2) this infiltration flows at the first 25 m to 50 m below ground surface, while regional water level in this area is currently at 200 m of depth or lower. The climate of the area is desertic, with less than 5 mm of precipitation per year in average, leading to the main conclusion that the only source of water that can produce this infiltration is the water contained in the tailings.

Implications for TSF Management:

The findings of this study have important implications for the management of the TSF. The comprehensive understanding of infiltration dynamics provided by the geophysical methods allows for the development of more effective strategies for preventing and mitigating groundwater contamination risks. For example, the identification of high-risk areas can inform the placement of additional monitoring wells or the implementation of targeted remediation measures. Temporal monitoring data can also be used to assess the effectiveness of existing mitigation measures and to optimize water management strategies.

Conclusions

This study demonstrates the effectiveness of geophysical methods, particularly NanoTEM and ERT, as valuable tools for monitoring the evolution of infiltration plumes from TSFs. These methods provide high-resolution data without the need for intrusive sampling, enabling the capture of both spatial and temporal dynamics of infiltration. The results of this research contribute to a better understanding of the complex processes governing infiltration and provide valuable information for developing improved TSF management strategies. Further research could explore the integration of geophysical data with hydrogeological models to enhance predictive capabilities and optimize water management practices.

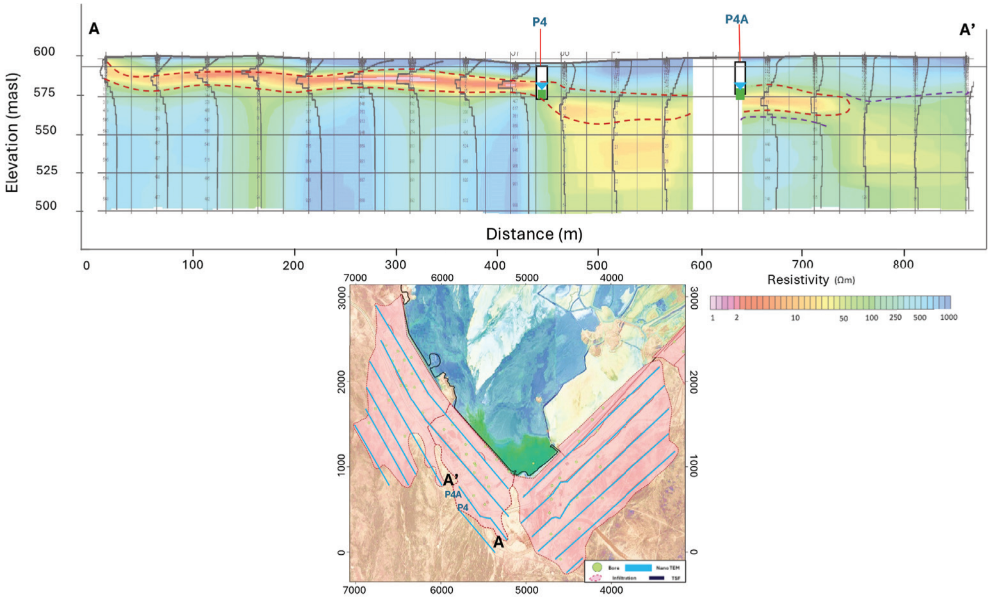

Figure 2 *Interpretation of resistivity for one of the geophysical surveys.*

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