Delineation of soil contamination plume in biodigesters through geophysical and geostatistical methods

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Abstract. Soil and groundwater contamination is a critical environmental issue, posing risks to human health and ecosystems. Accurate delineation of contamination plumes is vital for effective environmental management and remediation. Traditionally, this involved costly and invasive drilling methods, but geophysical techniques have revolutionized the approach. In this context, this study presents a case study of contamination on a Brazilian farm where a biodigester system collapsed due to geotechnical issues, leading to material infiltration and environmental contamination. The study showcases the effectiveness of geophysical investigations combined with geostatistical interpolation techniques in identifying and characterizing contamination plumes. The methodology involved in this project involved geophysical investigations using the electrical resistivity method. 2D resistivity profiling surveys were conducted around the affected area, utilizing non-polarized electrodes and a Dipole-Dipole array. Self-Potential (SP) data were collected to determine the contamination plume's flow direction, and geostatistical interpolations were performed to map the plume. Results revealed conductive anomalies in the subsurface, indicative of a highly saturated zone with characteristics resembling aqueous materials. These anomalies consistently occurred at an approximate depth of 7 meters. Data were processed and visualized, with geostatistical interpolation highlighting the lateral distribution of anomalies. The study confirmed that material from the biodigester pound infiltrated the soil to an apparent depth of 7 meters, as indicated by conductive anomalies.

Keywords. Subsurface Investigation, Soil and Groundwater Contamination, Environmental Management, Geophysical Investigation, IDW Interpolation.

1. Introduction

The Contamination of soil and groundwater by hazardous substances is a comprehensive enviromental concern, with significant implications of human health and ecosystem integrity [1]. To effectively manage and remediate contaminates sites, it is crucial to accurately delineate and understand the extent of contamination plumes – the areas where contaminants have migrated through subsurface enviroments. This understanding is critical for informaed decision-making and the sucess of the enviromental restoration efforts.

Traditionally, the characterizatio of contamination plumes has relied heavily on costly and invasive drilling techiniques. However, the development and application of geophysical methods has significantly transformaed the way we approach this issue.

Geophysical methods constitute a powerful and non-invasive set of techniques that have played a transformative role in the indentification and caracterization of contamination plumes in subsurface enviroments. These methods explore the physical properties of the subsurface, such as electrical resistivity, thermal conductivity, and magnetism, to contaminants in soil and groundwater [2].

In this context, this article presents a case study of subsurface contamination on a farm located in the Brazilian city of São Domingos, in the state of Goiás, where one of the lagoons in the biodigester system collapsad due to geotechnical issues, and the material that filled the lagoon infiltrated into the subsurface, causing soil instability and contaminating the enviroment. Thus, this work aims to demonstrate the efficiency of using geophysical investigation methods combined with geostatistical interpolation methods in the identification and characterization of contemination plumes.

2. Contextualization

This work aims to present the results of a field survey to identify the damege caused by the leakage of biodigester system that collapsed due to geotechinical issues. The context of this study is in a farm that developed a system of collecting animal waste and sending it to biodigestion ponds, where the material was processed ans used as biofertilizer in the farm's filds. However, due to the low soil resistence and some maintence process failures in the biodigesters, one of the pond's impermeable liners ruptures, resulting in the leakage of all the material that filled the pond, approximately 7 million liters of animal waste mixed with water.

All this content infiltrated the soil through the points where the impermeable liner ruptured abruptly, causing further soil instabilities. These instabilities manifested on the surface through cracks, subsidence, and the formatios of cavities in the soil.

3. Metodology

To identify and characterized the contamination plume generated by the leakage from the biodigester ponds, geophysical investigations were conducted using the electrical resistivity method. Nine 2D resistivity profiling were performed around the entire affected area.

The 2D resistivity profiling were conducted using non-polarizable electrodes containing a copper sulfate solution, with a spacing of 10 meters between them. Additionally, a Dipole-Dipole array withe 8 levels was chosen. This configuration allowed for subsurface investigation to a theoretical deth of approximately 25 meters.

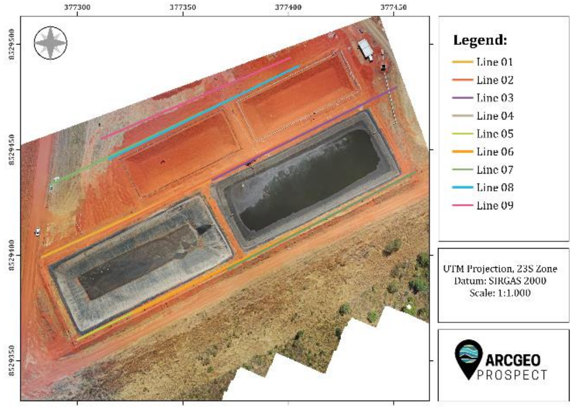
In addition to the 2D resistivity profiling, data acquisition was also carried out using the Self-Potential Method to identify the flow direction of the contamination plume.

Finnaly, to map the contamination plume in the subsurface, the field-collected electrical resistivity data were used for geostatistical interpolations, employing the Inverse Distance Weighted (IDW) interpolation method.

The tools used in this study were an electricalresistivimeter from the Brazilian manufacturer Auto Energia, model X6xtal 500. The geophysical data were processed using the RES2DINV software. Additionally, interpolations were carried out in the QGIS 3.28.5 geoprocessing Software.

3.1 Electrical resistivity method

Electrical resistivity relies on the subsurface material's ability to conduct electrical currents, and this tecnique has been widely applied in the identification of contamination plumes.



Electrical resistivity allows for the assessment of variations in the electrical resistivity of the soil, which can indicate the presence of contaminants and the extent of contaminantion plumes [2]. This non-invasice approach is particularly effective in areas where soil sampling is limited.

3.2 2D resistivity profiling

A 2D resistivity profiling is a geophysical techinique used to create a two-dimensional subsurface image of the electrical resistivity distribuition in the Earth [3]. It involves the measurement of electrical resistivity at various points along a profile, typically in a linear array, to assess subsurface variations in material and their resistivity values.

This method is particulary used for investigating subsurface structures, such as geological formation, growndwater flow paths, and the detection of anomalies, including contamination plumes [4]. It can provide valuable insights into the distribution of subsurface materials, helping researchers and environmental scientists in various applications.

3.3 Self-Potential (SP) method

The self-potential (SP) method is a peophysical technique that measures natual electrical potential in the Earth's surface [5]. This method is based on the principle that subsurface variations in electrical conductivity and electrochemical processes generate electrical potentials, which can be detected at the surface.

SP surveys are valuable tools in various geophysical applications, including mineral exploration, hydrogeology, and enviromental investigations [6]. The SP method can provide insights into subsurface structures, such as ore bodies and geological formations, as well as the moviment of groundwater and the identification of potential contaminant plumes.

3.4 IDW interpolation

The Inverse Distance Weighted (IDW) interpolation method is a widely used geoprocessing tool in spatial analysis and geostatistics [7]. IDW is a deterministic interpolation method that estimates values at unmeasured locations based on the weighted average of known values within the vicinity, with closer points receiving higher weights.

This method has found extensive application in various fields, including enviromental science, geography, and geology. IDW interpolation is particularly valuable for creating continuous surfaces from sparse data points, such as enviromental monitoring or sensor data.

4. Results

As mentioned earlier, to identify the contamination plume, nine 2D resistivity profiling surveys were conducted around the entire study area. Figure 1 shows the location of the geophysical acquisition liines.

Fig. 1 – Location map of the geophysical acquisition lines.

In this section, the results of processing all the fiel-acquired electrical resistivity data using the 2D resistivity profiling method will be demosntrated.

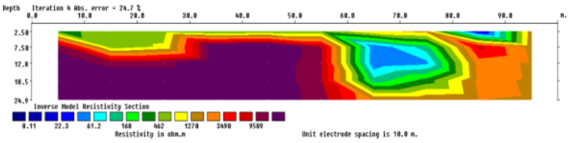


Fig. 2 – 2D resistivity profile from the line 01.

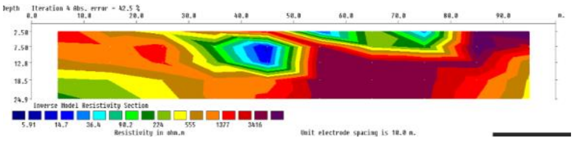


Fig. 3 – 2D resistivity profile from the line 02.

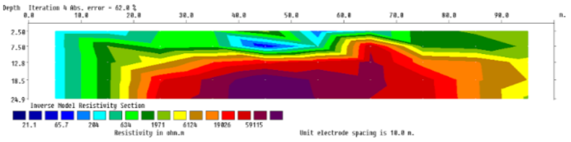


Fig. 4 – 2D resistivity profile from the line 03.

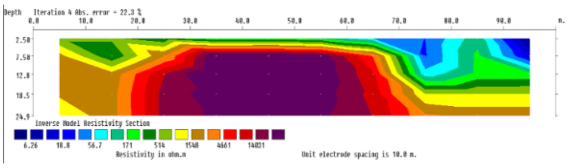


Fig. 5 – 2D resistivity profile from the line 04.

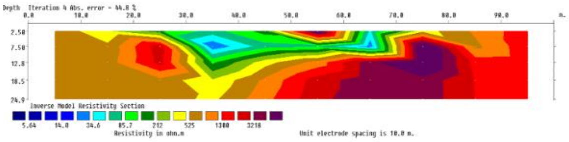


Fig. 6 – 2D resistivity profile from the line 05.

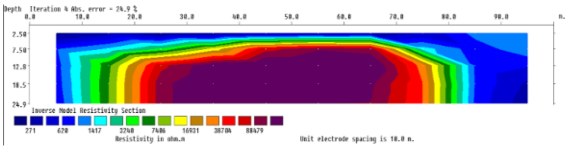


Fig. 7 – 2D resistivity profile from the line 06.

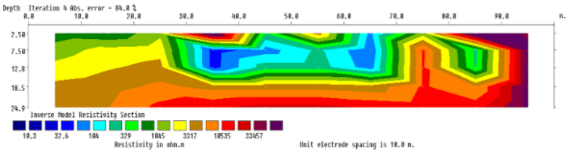


Fig. 8 – 2D resistivity profile from the line 07.

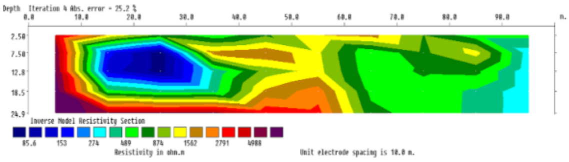


Fig. 9 – 2D resistivity profile from the line 08.

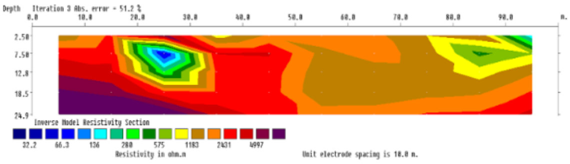


Fig. 10 – 2D resistivity profile from the line 09.

The geopysical profiles detected condutive anomalies with apparent conductivity values ranging from 5.6 to 100 ohm.m, indicating a highly satured zone in the subsurface with geoelectrical characteristics suggesting the presence of aqueous materials. All these anomalies were at a depth of appoximatly 7 meters. Consequently, data from all electrode measurements at this 7-meter depth in all profiles were collected. These values were plotted in the QGIS 3.28.5 software, alongside the self-potential (SP) data. Subsequently, IDW interpolation was performaed to generate a map illustrating the lateral distibuition of this conductive anomalies (figure 11), as the apparent electrical resistivity profiles had already demonstrated the vertical propagation of the anomaly.

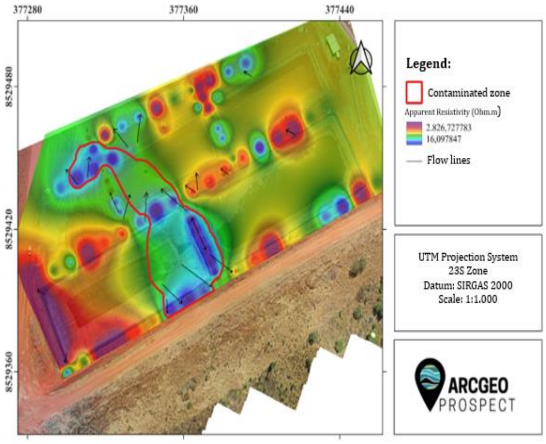


Fig. 11 – Map of IDW interpolation of the electrical resistivity values at the 7-meters depth.

5. Discution

The electrical resistivity profiles confirmed that the material from the biodigester pond infiltrated the soil to an apparent depth of 7 meters, as evidended by several conductive anomalies exhibited apparent resistivity values ranging from 5.6 to 100 Ohm.m. This resistivity range was interpreted as the contamination plume, as it displayed geoeletrical characteristics consistent with those of aqueous materials and constrated with the surrounding physical environment, characterized by higher resistivity values.

The results of processing the data collected from the self-potential (SP) acquisitios were visualized on the map in Figure 11 in the form of arrows, revealing that the contamination spread in two opposite directions, with a clear preference for the northwestern region of the area, while propagating to a lesser extent towards the southeast of the farm.

Furthermore, the data obtained through IDW interpolation provided a comprehensive spatial representation of the distribuition of electrical resistivity data across the entire area. Using this data, it was possible to accurately delineate the contamination plume that infiltrated the subsurface and estimate its size. Consequently, it was identified that the contamination from the biodigester pond had spread laterally over an area of approximately 2,143.151 m^2.

6. Conclusion

This study demonstrated the effectiveness of combining geophysical methods of electrical resistivity with geostatistical interpolation techniques, such as IDW, in the identification and characterization of contamination plumes. The application of this approach not only allowed for the determination of the vertical and horizontal extent of contamination in the subsurface but also revealed the preferred flow directions of contaminants. In this context, this methodology stands out as a powerful tool capable of making a significant contribution to the resolution of environmental issues related to soil and groundwater contamination.

7. Acknowledgement

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8. References

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