We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Resistivity and Induced Polarization Application for Urban Waste Disposal Site Studies

Andréa Ustra and Vagner R. Elis

IntechOpen

Abstract

Environmental impacts caused by urban and industrial waste disposal are one of the greatest worldwide concerns, since contaminants may migrate to the local environment and contaminate soils and groundwater. Geophysical investigations have been widely used in environmental investigations of waste disposal contaminated sites, not only imaging the affected area but also evaluating the evolution of contamination plume in a timeframe. Geophysical studies in contaminated sites consist of detecting and mapping the area affected by a contamination source and providing information related to the groundwater flow and depth of saturated zone and bedrock. Particularly, electrical methods, such as resistivity and induced polarization, can identify the presence of contaminant and help to map and delineate the contaminated area and provide information related to contaminant mobilization and attenuation. Therefore, these methods are a powerful tool for noninvasive long-term monitoring of waste disposal contaminated sites. In this chapter, we will show case studies conducted in Brazil, over different types of municipal waste disposal sites.

Keywords: waste disposal sites, landfills, contamination plume, resistivity imaging, induced polarization

IntechOpen

1. Introduction

One of the greatest worldwide concerns is related to the increase and destination of waste volume produced by world's population. Waste disposal imposes a serious risk of contamination of groundwater by the migration of contaminants from the waste site to the local environment. To protect the environment from this type of contamination, waste disposal sites must follow regulation standards.

Modern landfill facilities are specially engineered for the disposal of solid waste. They operate to ensure protection of the environment from groundwater contamination and landfill gas produced by residue degradation. Municipal solid waste (MSW) landfills are areas properly prepared to receive household waste, as well as other types of nonhazardous wastes. Ideally, MSW landfill projects should ensure that landfills: are built in suitable geological areas away from faults, wetlands, flood plains or other restricted areas; include flexible membranes (i.e., geomembrane) overlaying compacted clay soil lining the bottom and sides; collect leachate (formed when rain water filters through wastes) for treatment and disposal; and operate according with standard practices (compacting and covering waste frequently with soil) [1].

IntechOpen

However, inadequate waste disposal activities were a frequent routine in many developing countries until recent years. The direct disposal of residues on the ground, without any selection of waste types and without any protection to avoid soil and groundwater contamination, had been a common practice for decades. Inactivated waste disposal sites can continue to contaminate the groundwater, especially when they are located in hydrological vulnerable areas.

Contamination plumes are formed when leachate reaches the local water table and contaminating the groundwater. **Figure 1** illustrates the formation of a contamination plume. Contaminants are diluted into groundwater and are carried through hydrodynamic dispersion along with the groundwater flow.

Leachate typically presents high concentrations of total dissolved solids (TDS), ammonia, organic carbon, chloride, and iron, among other organic and inorganic contaminants [2]. Even though the exact chemical composition of the leachates produced by MSW disposal sites, they can be associated with high electrical resistivity values. This makes geophysical electrical methods ideal to detect contamination plumes generated by waste disposal sites.

The advantages of employing noninvasive geophysical methods over direct sampling are cost and time consuming of analysis. Geophysical methods can therefore optimize investigation campaigns, maximizing the investigated area and minimizing drilling needs. Another important advantage is that geophysical data are real time measurements of the investigated system. However, due to the inherent ambiguity of geophysical methods, it is often necessary to use direct measurements to validate interpretation.

According with Sharma [3], geophysics can assist waste disposal problem by: locating geological features of interest (i.e., faults and contacts); locating aquifers and hydraulic active features for contamination plume detection; and detecting the waste volume and searching for areas appropriate for waste disposal. Electrical methods have been widely used as a tool for environmental investigations. Its application in contaminated site investigations consists in detecting and mapping the affected area and providing information about groundwater flow and saturated zone and bedrock depth. When detecting the impacted area, electrical imaging

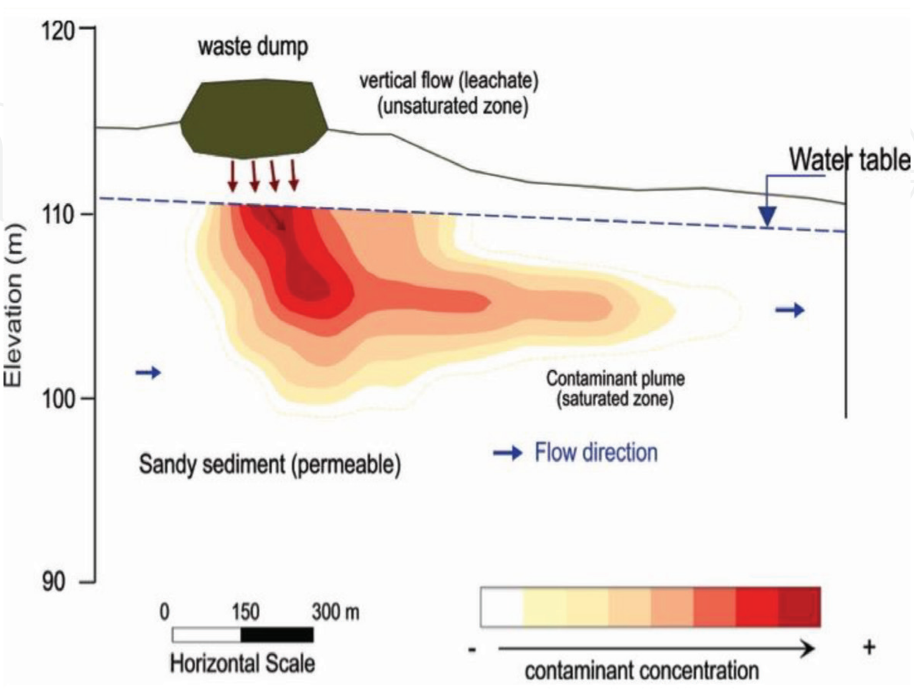


Figure 1.
Contamination plume formed by waste disposal site leachate.

techniques can not only map but also infer contaminant immobilization and long term monitoring.

The direct current (DC) resistivity method is frequently conducted simultaneously to time domain induced polarization (TDIP). In this measurement setup, electrical current is applied as a reversal square wave. When the current injection is "on," the observed voltage, V_c [mV], is measured. When the current injection is "off," the voltage decay curve, $V(t)$, is registered during a period of time [t_1,t_2], from with chargeability, m [dimensionless], can be computed:

$$m = \frac{1}{V_c}\int_{t_1}^{t_2} V(t)dt \tag{1}$$

In the frequency domain, resistivity and induced polarization (IP) methods consist in injecting an alternating current and measuring the amplitude and phase lag between applied current and measured potential, from which in-phase and quadrature components of resistivity, ρ^* [ohm.m], can be calculated: ρ' and ρ''. ρ' represents ohmic conduction (energy loss), whereas ρ'' represents media polarization (energy storage). While m is associated with the intensity of the polarization effect, normalized chargeability, $m_n = m/\rho$ [dimensionless], is considered a direct estimate of polarization, analogous to ρ'' [4].

Distinct mechanisms can generate the polarization response of the media. The IP phenomena are observed when metallic bodies and metallic dispersed particles are present in the subsurface, resulting from differences in ionic mobility in the metallic particles and ions in the pore fluid (electrode polarization). Another source of polarization is ion selective zones formed by clay particles and/or pore throats (membrane polarization). Charge motion along the electrical double layer (EDL) formed at the mineral surface also contributes to polarization (electrochemical polarization) [5, 6].

Resistivity is traditionally applied in waste disposal sites and contamination studies. However, resistivity does not separate different zones in these sites, and low resistivity zones are associated with the whole affected zone, both by wastes and leachate. Johansson et al. [7] and Leroux et al. [8] argue that this limitation can be suppressed by taking into account the normalized chargeability. Despite this seems to be efficient in environments poor in clay content which is not the case of Brazil [9]. According to Slater and Lesmes [4], normalized chargeability is highly influenced by clay content.

Several examples in the resistivity/IP literature report excellent applications of these methods for waste disposal site studies. Bernstone et al. [10] conducted a pre-remediation investigation over a MSW disposal site and identified preferential paths for the leachate. Gazoty et al. [11] obtained a 3D shape of the waste body of the former landfill in Denmark. Maurya et al. [12] investigated the migration of leachate from a landfill in Denmark by 2D and large-scale 3D electrical resistivity tomography. 2D profiles showed variations along the groundwater flow and the plume extension across the flow directions. The 3D model revealed low resistivity variation patterns corresponding to differences in the ionic strength of the landfill leachate.

In this chapter, we will present case studies conducted over municipal waste disposal sites in Brazil. We intend to show the ability of resistivity and IP method in providing useful and fundamental information for investigations of waste disposal and its impact on the environment.

2. MSW disposal site in Ribeirão Preto, SP, Brazil

Ribeirão Preto is a growing population city in Stet of São Paulo, and the water supply is almost completely provided by groundwater water. The quality of the

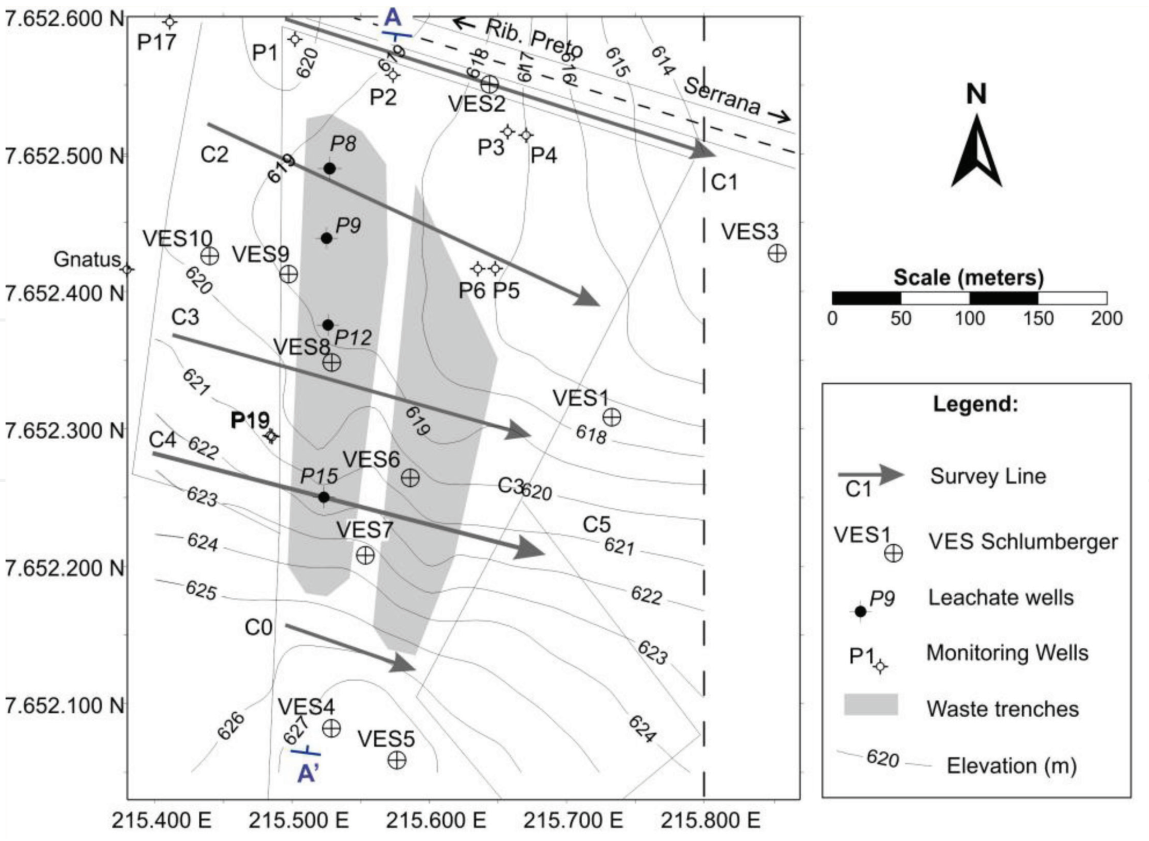


Figure 2.
Local map with survey lines.

groundwater in this region is therefore of critical importance. In this MSW disposal site that operated from 1974 to 1990, wastes were disposed inside two trenches of approximately 15-m deep. **Figure 2** shows the location of the trenches, geophysical lines and soundings, and groundwater wells. The area consists of a surface water divider, and the bedrock is Botucatu Formation sandstone, beneath unconsolidated material composed by sand residual soils and clayey material from Serra Geral basalts [13]. Decomposed basalt is observed at north and south from the trenches, between sandstones and colluvium. In the center, the trench base is in direct contact with the sandstones. The hydrogeological scenario is composed by a deeper aquifer (more than 30 m) within Botucatu sandstone and a shallow aquifer (~ 10 m) sustained by clayey materials originated from basalt alteration. Monitoring wells confirm contamination of groundwater and provide the groundwater flow direction as from southwest to northeast. **Figure 3** presents a geological session of the area, based on the geological wells and geophysical data. The suspended aquifer is assumed to form in the north portion of the trenches, being contaminated by leachate, and the main aquifer that is contaminated since the wastes were directly disposed above the sandstone.

In this site, resistivity and time domain induced polarization profile lines were carried out with dipole-dipole array (10 m of spacing and six investigation levels) using Syscal Pro (Iris Instruments). Metallic electrodes were used for current injection, and nonpolarizing electrodes ($Cu/CuSO_4$) for potential measurement. Current was injected in cycles of 2 s, and the IP measurements were recorded with 160 ms delay after current shut off. Data were inverted with the software RES2Dinv [14] generating 2D models that allowed a detailed analysis of the relationships between the natural materials and the trenches filled of waste.

Figure 4 presents the resistivity and chargeability models of line C4. The resistivity session clearly shows the two trenches filled with wastes and leachate marked by low resistivity values (<15 ohm m). Although the horizontal limits of the trenches

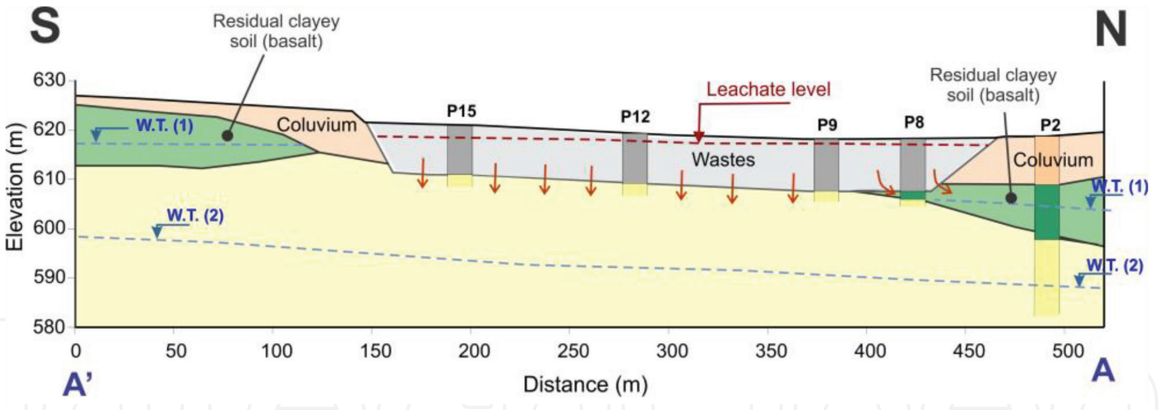


Figure 3.
Profile A–A'.

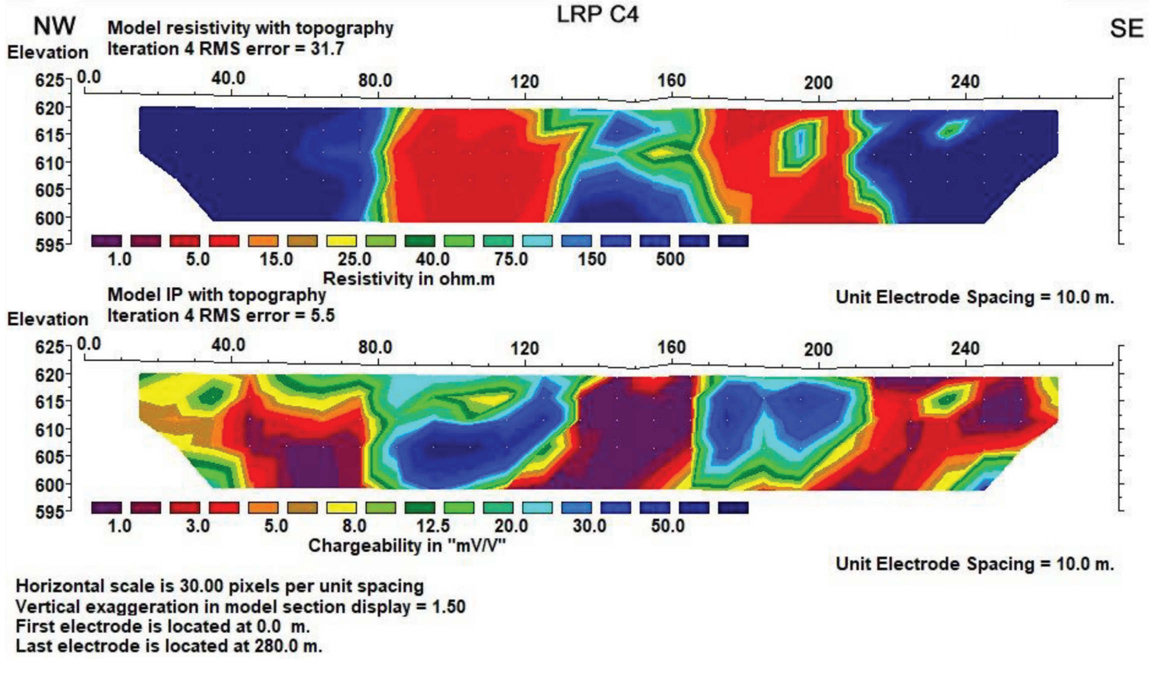


Figure 4.
Resistivity and chargeability sessions of line C4.

are well marked by resistivity, the bottoms of the trenches were not detected. We interpret these results as an indication that the permeable sandstones directly below the wastes as being filled by contaminated water, giving low resistivities. The chargeability session on the other hand, successfully detects the wastes bodies, marked by high chargeability values (>20 mV/V). The sandstone groundwater contaminated by highly saline leachate produces a low chargeability zone (<10 mV/V), identifying the trench base. The same geophysical fingerprint is observed for line C3 (**Figure 5**). The trenches are marked by low resistivity and high chargeability values, while the infiltration zone at the trench bases presents low resistivity and chargeability values. The high chargeability observed in the trenches is explained by the presence of metallic and polarizable material that composes the wastes, whereas the low chargeability signature of the contaminated groundwater is attributed to the decrease of ionic mobility due to increase of solution concentration [12].

Line C1 (**Figure 6**) is located outside and downstream from the trenches. The resistivity session detects the upper portion of the contaminated aquifer, identified by resistivity values lower than 50 ohm m. A polarization anomaly is observed in the position of 135 m along the survey line, produced by the metallic coating of part of the groundwater well P2. The contamination plume is not as well defined by

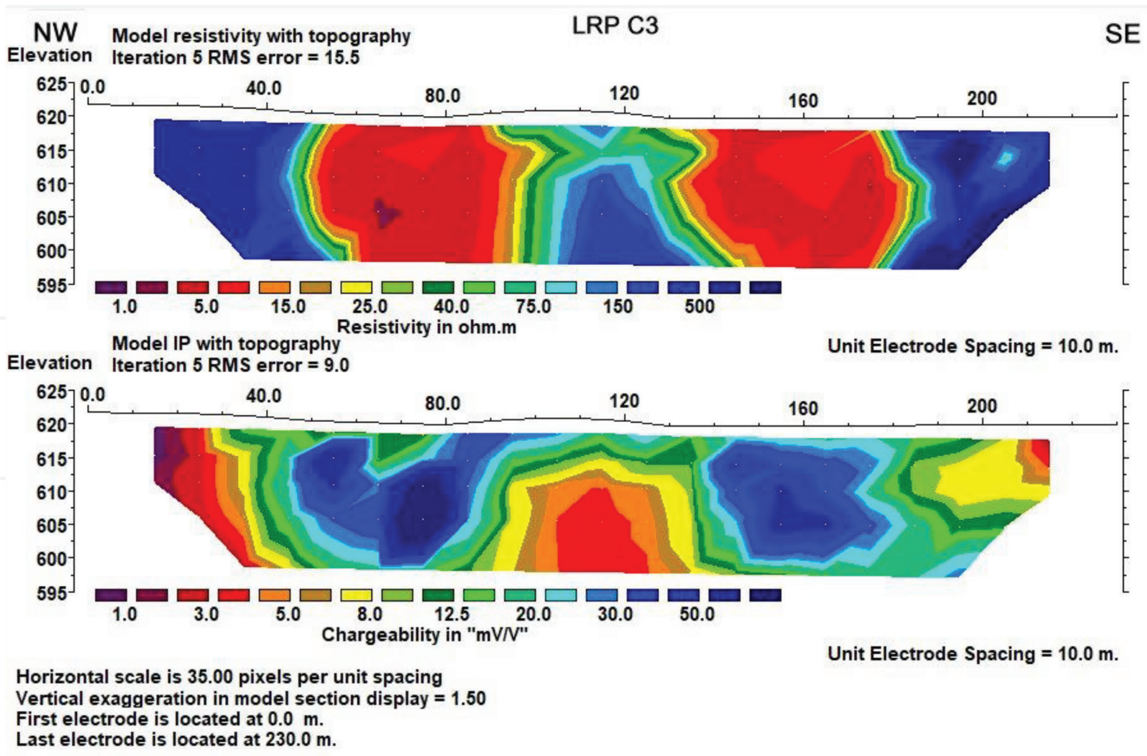


Figure 5.
Resistivity and chargeability sessions of line C3.

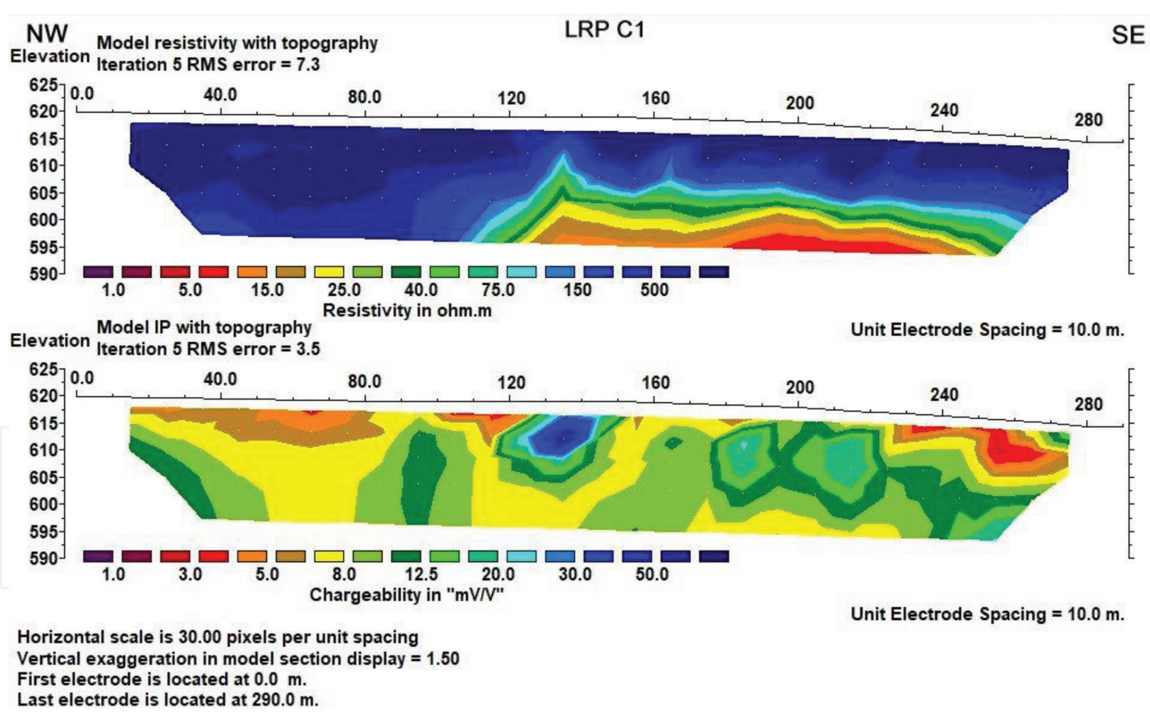


Figure 6.
Resistivity and chargeability sessions of line C1, outside and downstream from the trenches.

chargeability as it is by resistivity, but overall this region shows low chargeability values (8 mV/V). The behavior of chargeability against salinity (and clay content) does follow a linear trend, and its interpretation is not always straightforward. Lithological variations might also be affecting chargeability, competing with the salinity effect.

Table 1 presents chemical analysis of groundwater wells. High TDS values explain the observed low resistivity values inside the trenches. P2 TDS values confirm groundwater contamination. Well P19 (60 m deep) also present high TDS concentration, confirming the contamination of the deeper aquifer.

Monitoring well	Sampled fluid	Electrical conductivity (mS/m)	pH	TDS (mg/l)	COD (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
Maximum allowed value (water)		—	6.5–8.5	500.0	—	250.0	250.0
Gnatus	Water	2.7	6.2	12.0	ND	1.14	6.0
P2	Water	74.0	7.14	1828.0	51.1	—	—
P3	Water	5.4	5.82	26.0	11.0	4.91	3.8
P6	Water	19.5.	6.07	142.0	26.0	8.83	4.8
P17	Water	6.4	6.92	99.0	6.5	4.91	5.2
P19	Water	80.0	10.3	2505.0	130.0	19.0	924.0
P8	Leachate	129.0	6.97	1069.0	91.0	215.0	66.0
P9	Leachate	129.0	6.65	795.0	119.0	262.0	65.0
P12	Leachate	200.0	7.0	817.0	182.0	322.0	103.0
P15	Leachate	1520.0	7.9	9447.0	3640.0	3350.0	145.0

TDS—total dissolved solids, COD—chemical oxygen demand.

Table 1.
Important water parameters of monitoring well analysis.

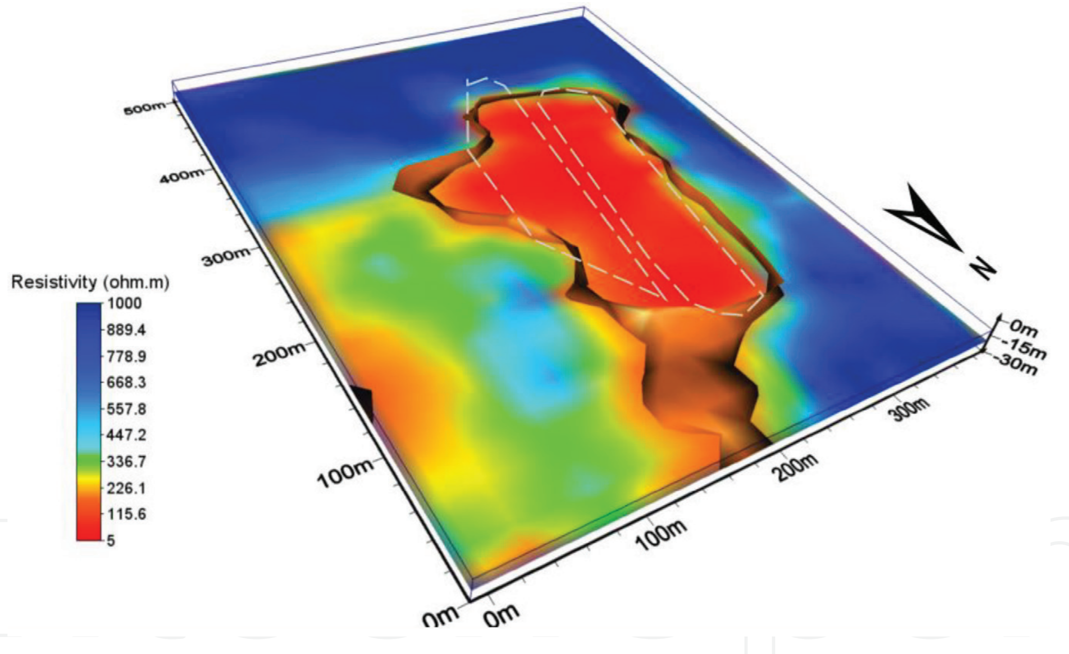


Figure 7.
3D resistivity model of the site, showing the source area (dashed lines) and contaminant plume flowing NE.

Figure 7 shows a 3D resistivity model obtained by the interpolation of all geophysical data. The obtained image shows the contamination source and a contamination zone flowing toward NE to the shallower aquifer.

3. MSW disposal site in São Carlos, SP, Brazil

This study site located in the city of São Carlos, São Paulo State, Brazil is an example of how choosing a disposal are without any consideration for environmental impacts can have disastrous consequences. Wastes were disposed at a natural depression zone produced by intense erosion. There was a small river in this site

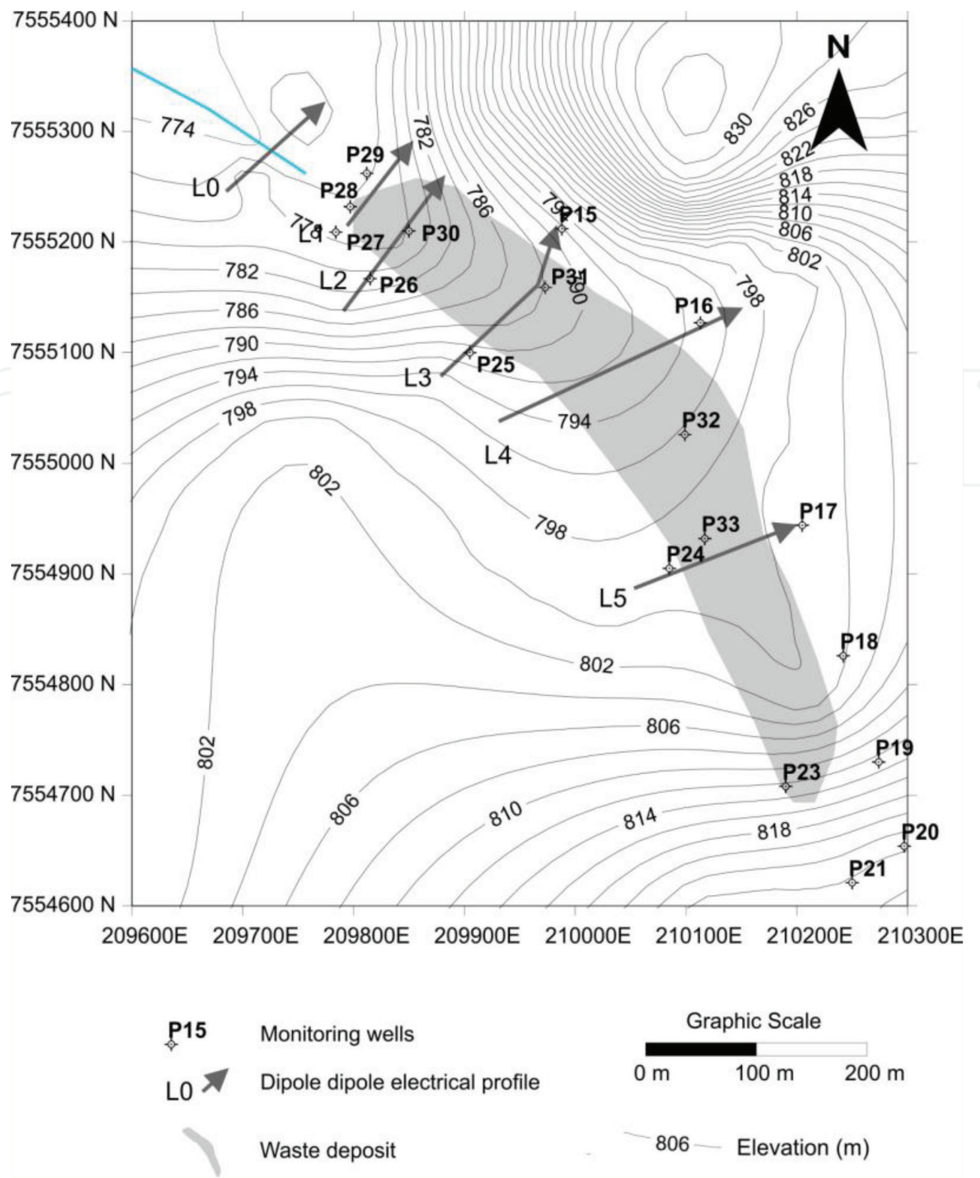


Figure 8.
Local map of waste dump in São Carlos, with geoelectrical survey lines and well positions.

that was covered by the waste dump. The area received industrial, domestic, and hospital wastes over 7 years, and it was then closed with the material being covered by soil in 1996. From the site's topography, the water drain to NW direction is expected, as well as the contamination plume flow in this same direction. Parts of the wastes are deposited in dry soil (above saturated zone), and in the NW part, the trenched bottom is in direct contact with the aquifer.

The site location is at Paraná Basin's east board, where the sandstones of Botucatu Formation occupy most of the study area. Botucatu Formation is the main geological unit of the most important water reservoir in Brazil, the Guarani Aquifer. The sediments from the area are characterized predominantly as fine sand, punctually more clayey or silty.

For mapping this site were performed five resistivity/IP lines across the deposit and one external to it. Data were collected with Syscal Pro (Iris Instruments). Metallic electrodes were used for current injection, and nonpolarizing electrodes ($Cu/CuSO_4$) for potential measurement. Current was injected in cycles of 2 s, and the IP measurements were recorded with 160 ms delay after current shut off. Data were inverted with the software RES2Dinv.

Figure 8 shows the positions of monitoring wells and geoelectrical sessions in the site. The combination of resistivity and time-domain induced polarization (IP)

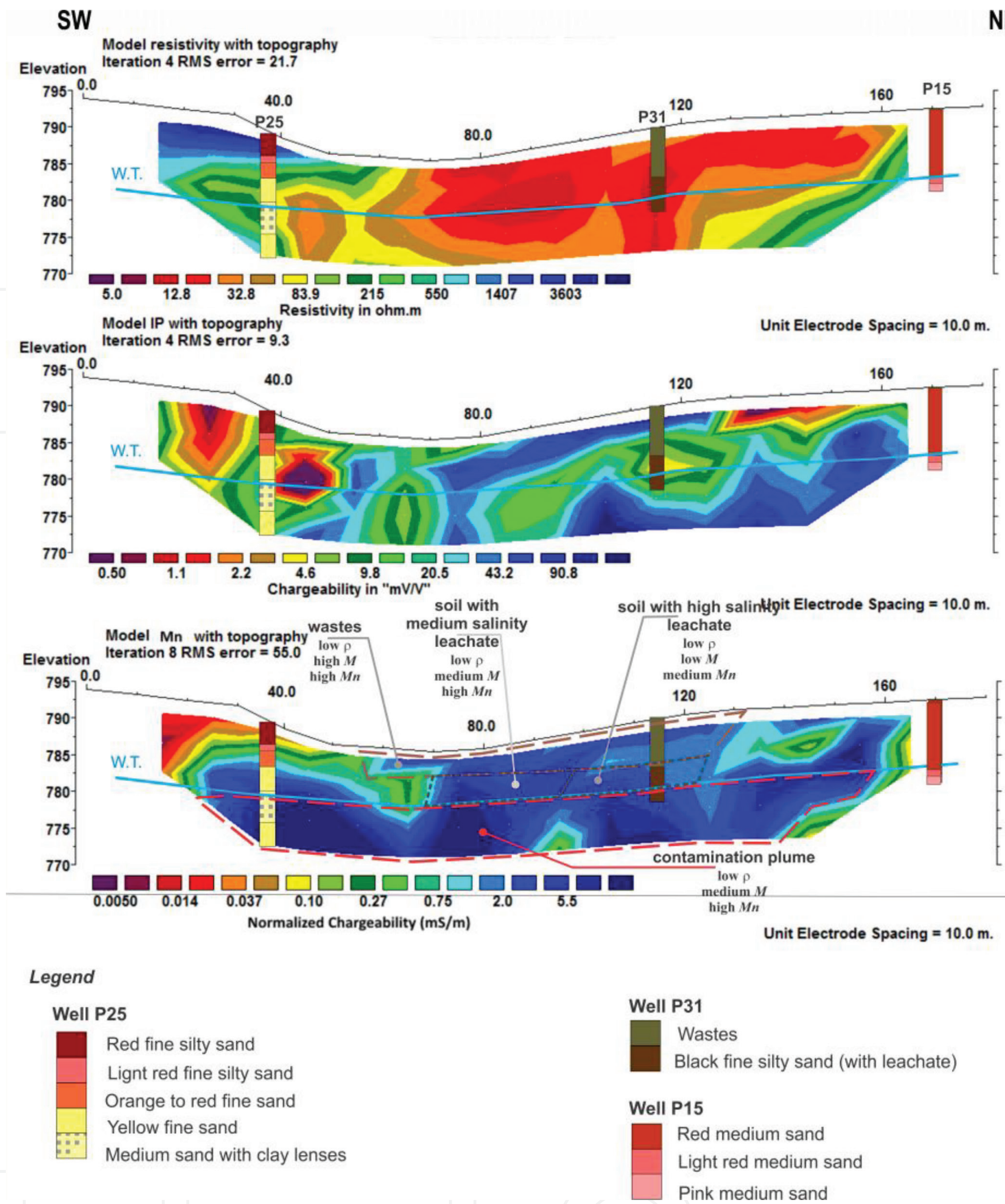


Figure 9.
Resistivity (top), chargeability (middle), and normalized chargeability (bottom) sections of L3 with monitoring wells P25, P31, and P15.

improved the site investigation. We will present results from lines L3 (across the wastes trench), L1 (at the boundary of the trench), and L0 (outside the trench).

Line L3 (**Figure 9**) identifies the area affected by the wastes and leachate, characterized by low resistivity values (<30 ohm m). The waste trench, the contaminated soil, and the contamination plumes are characterized by low resistivity values, and it is not possible to distinguish these different zones. The chargeability session shows the influence of the upper part of the trench (from 60 to 130 m) characterized by high values (>40 mV/V). The leachate attenuates chargeability values, due to its high salinity confirmed by groundwater well Pm31. The contamination plume dilution in the saturated zone produces higher chargeabilities. Normalized chargeability, a direct measurement of polarization, clearly marks the horizontal limits of the trenches and the contamination plume, by high Mn values (from 60 to 130 m, confirmed by visual inspection in the field). Both ρ and Mn show the horizontal spread of the contamination plume.

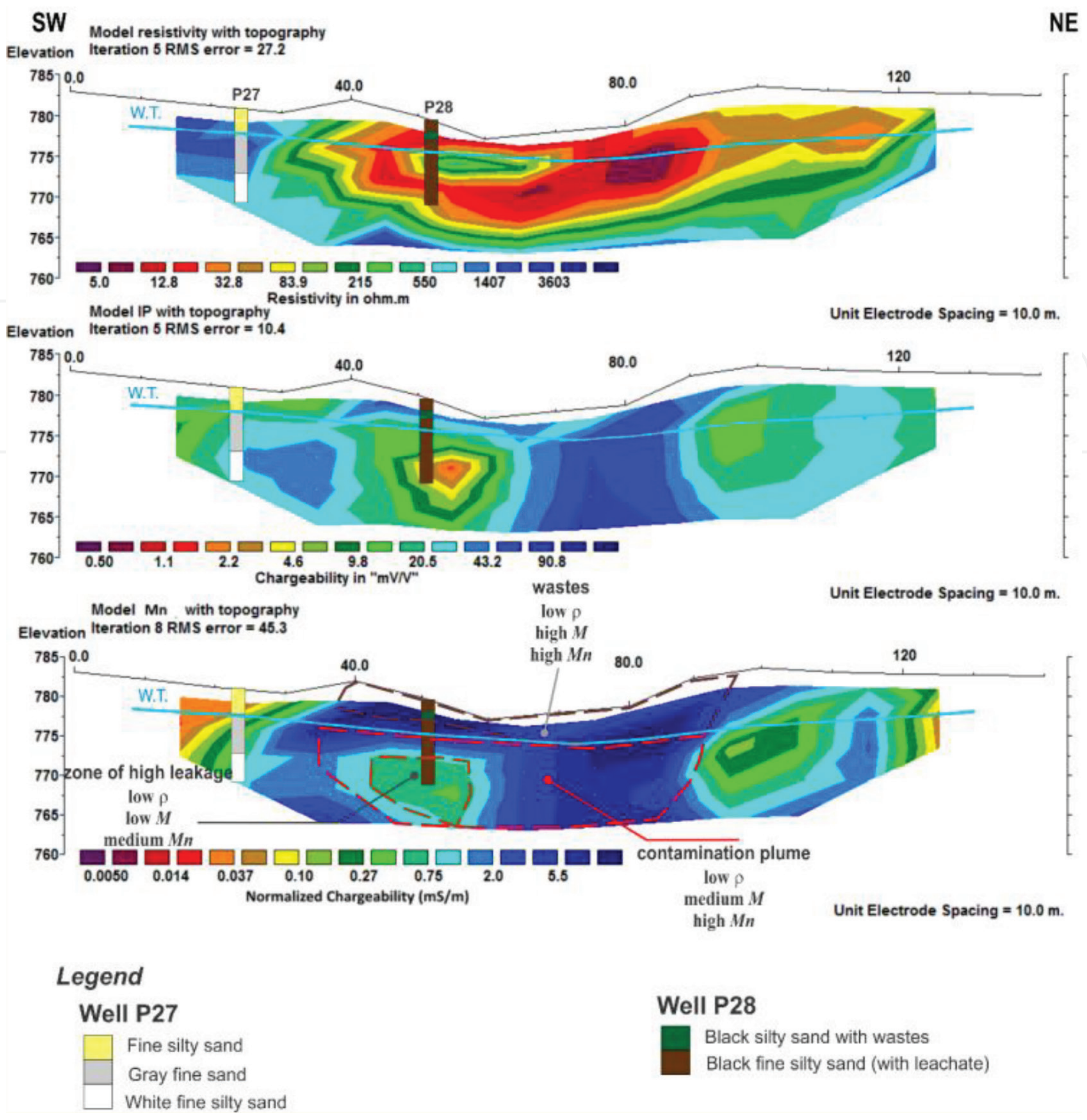


Figure 10.
Resistivity (top), chargeability (middle), and normalized chargeability (bottom) sections of Line 1 and monitoring wells P27 and P28.

Figure 10 presents the results for L1. The resistivity session shows the trench, the contaminated soils, and the contamination plume. Chargeability can limit the wastes between 40 and 90 m and a leachate concentration zone detected by the groundwater well Pm28. Normalized chargeability also identifies the wastes and the contamination plume. In this session, the contamination plume does not spread laterally as L3, which is confirmed by chloride concentrations found in the groundwater well Pm27 (11 mg/l). In the groundwater well Pm25, located in a low ρ and high Mn at L3, the chloride concentration found was 133 mg/l. The line L0 (**Figure 11**) crosses a small river raised from the erosion where the wastes were deposited and the leachate tends to be lixiviated by surface water flow. For this reason, no groundwater wells were installed along this line. The resistivity session shows the water table level very close the surface and low resistivity (50–100 ohm m) in the stream region, characterizing the contamination zone. Normalized chargeability identifies the water table and shows the zones of higher Mn in the stream region. Water sample collected from a small river 50 m always showed a chloride concentration of 64.4 mg/l and an electrical conductivity of 102.8 mS/m. The background values from the stream are to be 0.6 mg/l for chloride concentration and 5.7 mS/m for electrical conductivity.

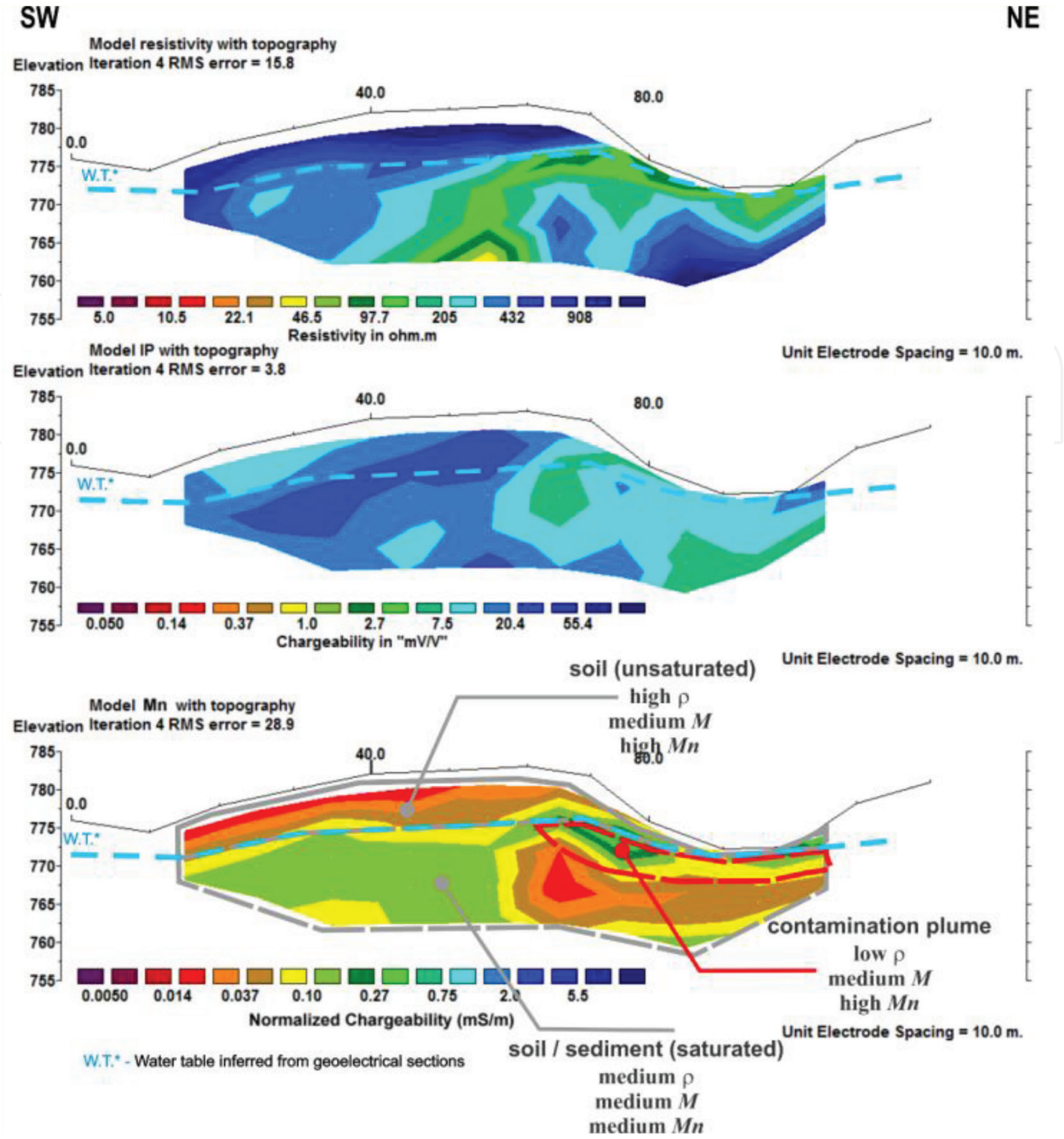


Figure 11.
Resistivity (top), chargeability (middle), and normalized chargeability (bottom) sections of Line 0.

Results from this study show that resistivity successfully identifies the wastes, the contaminated soil, and the contamination plume, being efficient in mapping the affected area. Chargeability is very sensitive to wastes and leachate, but its dependence upon salinity makes its interpretation sometimes complex. Normalized chargeability on the other hand was a more efficient parameter: it increases with fluid conductivity within the fluid conductivity range observed in this study.

4. MSW landfill in ditches in Luiz Antônio, SP, Brazil

In Brazil, sanitary landfills are considered ideal domestic waste disposal sites that are concepted to minimize public health hazard [13]. However, in small towns that produce less than 10 tons of domestic waste per day, waste final destination remains a challenge to the government. In an attempt to improve this situation, São Paulo State Environmental Agency (CETESB) proposed a financial and environmental low cost alternative to waste disposal for towns with less than 25,000 habitants. Landfill in ditches is a technique accepted by the environmental agency

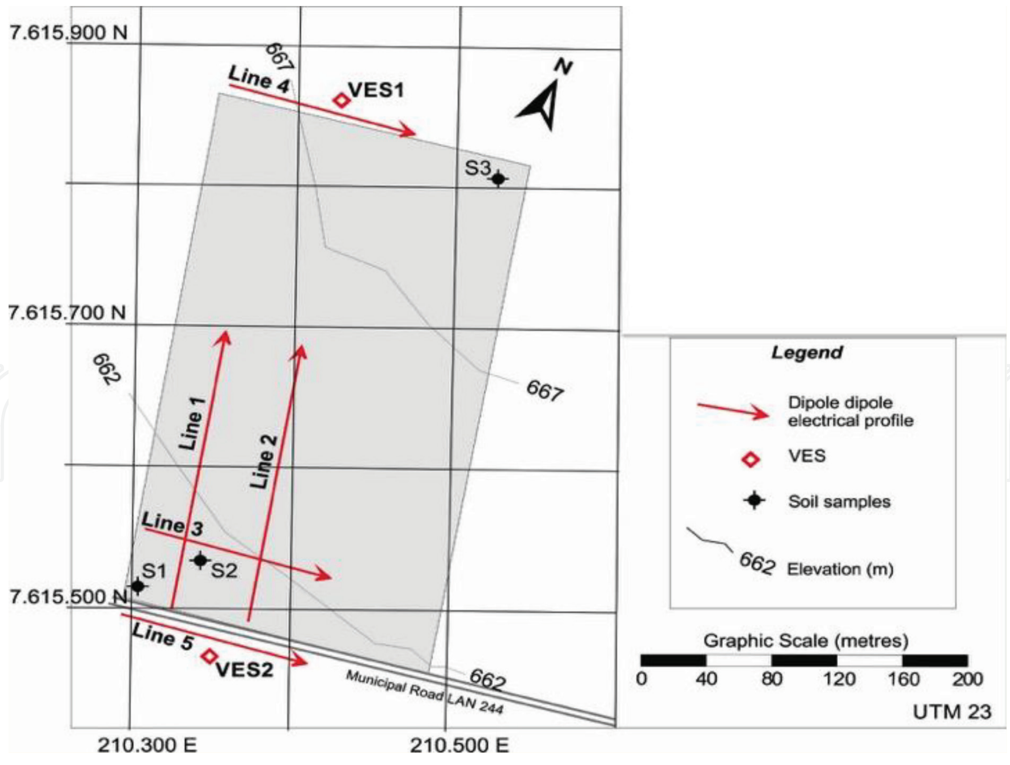


Figure 12.
Local map with survey lines and sample points.

and has been applied for more than 10 years in the São Paulo State, Brazil. The technical concept of landfill in ditches takes into account the natural attenuation capacity of the soil to minimize the environmental impact.

Nowadays, there are a great number of landfills in ditches in São Paulo State, whose simple implementation has been highly contested, making environmental investigation an important task to evaluate this activity impact on the environment. This work investigates the geoelectrical response of a landfill in ditches as an environmental impact evaluation tool. Geoelectrical surveys can help to evaluate the impact on soils and groundwater, leachate migration, and contaminant concentration attenuation. The MSW landfill in ditches in Luís Antônio is active since 1999 and operates in ditches of approximately 70 m long, 8 m wide, and 6 m deep.

Due to project designs, compacted soils are not used as impermeable base for the ditches. Therefore, this type of landfill requires favorable permeability soils and the water table at least 3 m below the ditch base. Luiz Antônio landfill was built on soils of 1×10^{-5} cm/s, and the water table depth is about 12 m.

The geophysical survey was conducted over the waste disposal area (two sessions) and upstream and downstream the ditches (**Figure 12**).

The field survey was conducted with resistivity and time domain induced polarization using dipole-dipole array (5 m of spacing and six investigation levels). The Syscal Pro (Iris Instruments) resistivity meter was used to collect resistivity and chargeability data. Metallic electrodes were used for current injection, and nonpolarizing electrodes ($Cu/CuSO_4$) for potential measurement. IP data were acquired with 2 s integration time with 160 ms delay after current shut off. Data were interpreted with the software RES2Dinv.

Figure 13 shows the line crossing the ditches. Low resistivity (<30 ohm m) and high chargeability (>40 mV/V). No signs of leachate infiltration are observed with the geophysical data. The chargeability value distribution looks complex, but this pattern is a reflex of the waste heterogeneity, and overall, the observed chargeability values are higher than 15 mV/V.

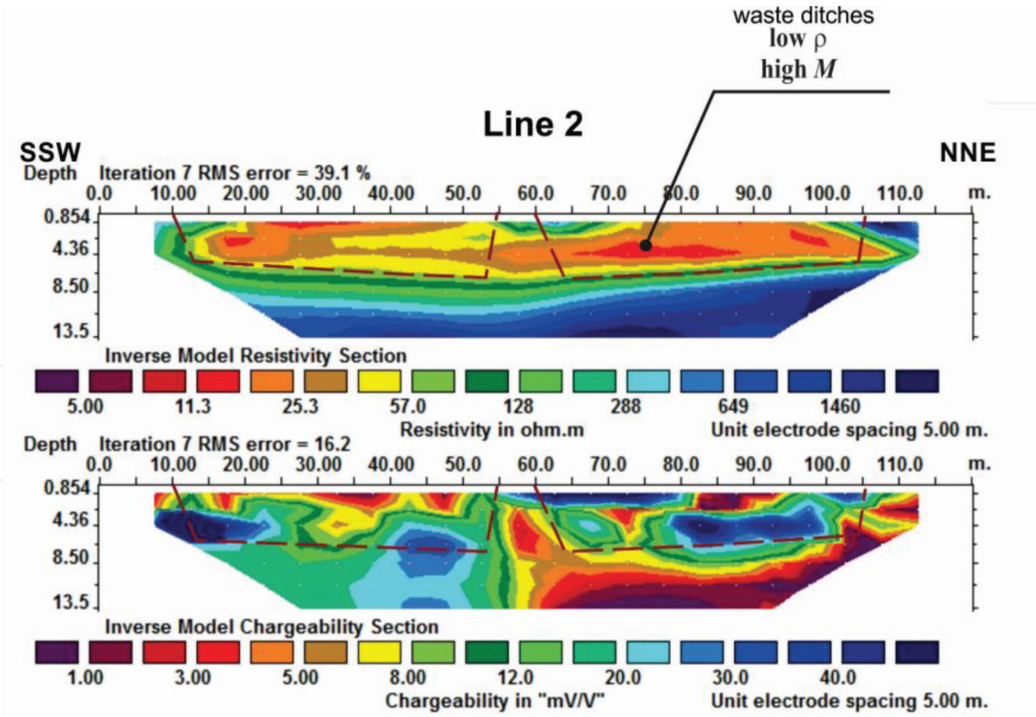


Figure 13.
Resistivity and chargeability sessions of Line 2.

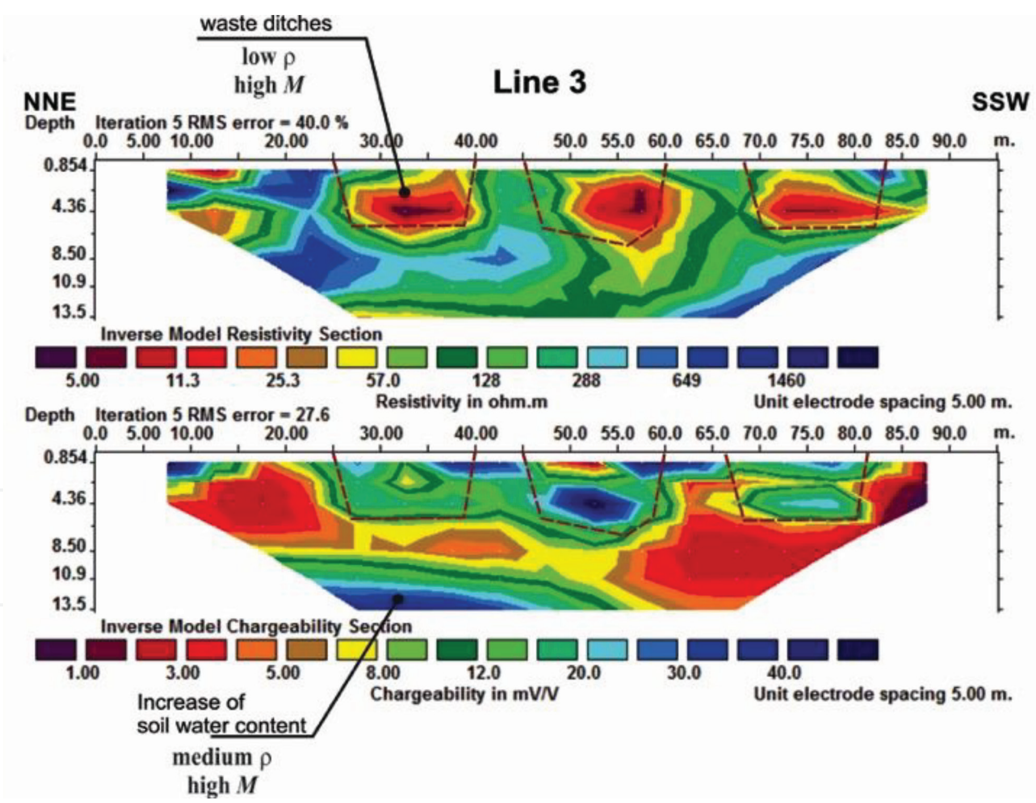


Figure 14.
Resistivity and chargeability sessions perpendicular to the landfill ditches.

Figure 14 shows the resistivity session perpendicular to the three ditches. Each ditch is clearly identified by low resistivity and high chargeability values. A low resistivity continuous feature beneath the ditches is observed, suggesting leachate migration.

To verify the contamination plume, another geophysical line was conducted south, 10 m from the ditches. This line does not show low resistivity features that could suggest a contamination plume. Medium resistivity and chargeability values shown in **Figure 15** are interpreted as higher water content in the porous media.

Soil sampling detected concentration within the legislation limits, even though close to the contamination threshold. Vertical electrical soundings characterized soil horizons, altered and unaltered rock, but the saturated zone was not identified (**Figure 16**).

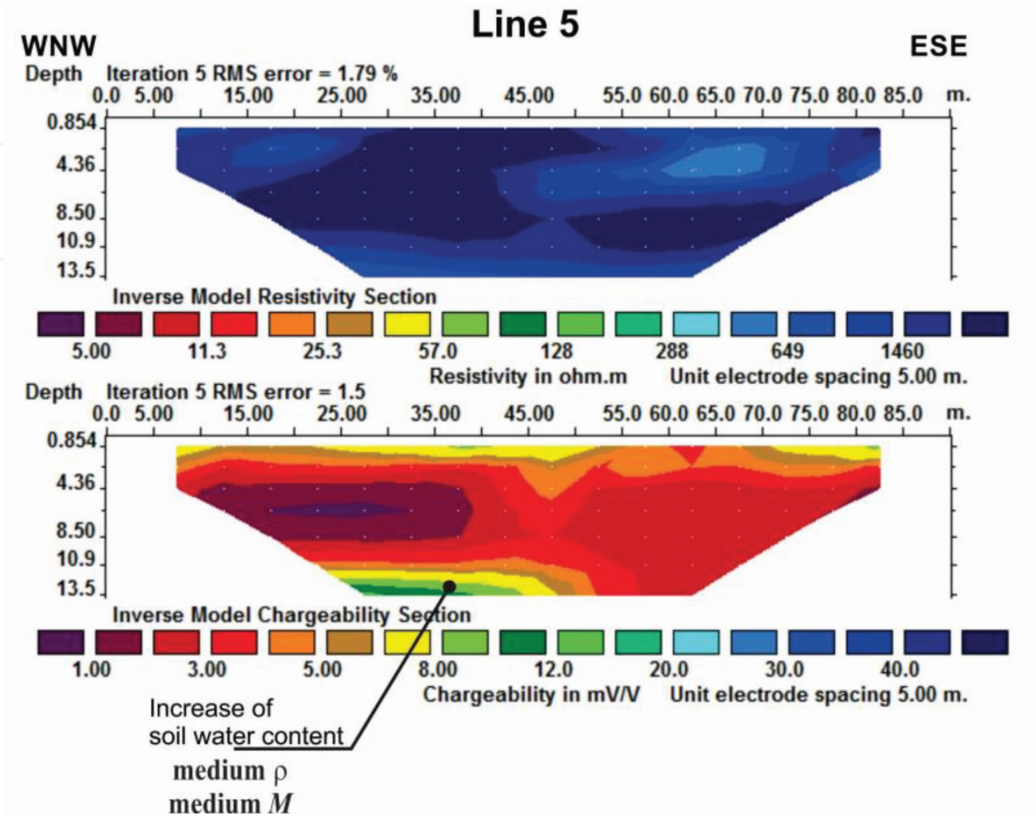
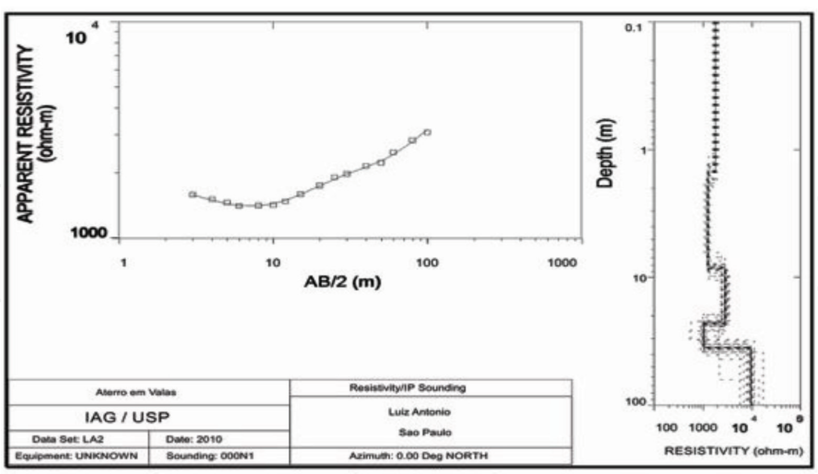


Figure 15.
Resistivity and chargeability sessions south from the trench landfill.



Layer	Depth (m)	ρ (ohm.m)	Interpretation
1	0 – 1.5	1790	top soil
2	1.5 – 8.4	1246	eluviated soil
3	8.4 – 22.4	2836	soil / saprolite
4	22.4 – 34.4	1020	soil / saprolite (increased water content)
5	34.4 –	9550	Basalt

Figure 16.
Interpretation of VES2.

5. MSW sanitary landfill in Bauru, SP, Brazil

The MSW disposal site in Bauru, São Paulo State, Brazil, is the biggest disposal site presented in this chapter, occupying an area of 270,000 m^2. It is a concept like a landfill, and the wastes are disposed in three layers of, approximately, 4 m height. Its bottom has an asphalt emulsion layer above compacted local soil. Digital topographical models show that wastes are disposed over an old valley.

The local geology consists of alluvium, colluvium, alteration soils, and sandstones (Bauru Group). The alluvium is characterized by silt-clayey fine sand and the colluvium by clayey sands. The landfill soil is fine to medium clayey sands. Groundwater flow is from east to northwest, reaching shallow water table depth of 5 m at the base of the landfill [15].

Ustra et al. [16] conducted a geophysical survey over the landfill area and suggested the formation of a contamination plume, based on the resistivity imaging. To investigate the contamination plume, the authors conducted a geophysical survey in the area downstream from the landfill, shown in **Figure 17**.

Chemical analysis data of groundwater sampling from monitoring wells (locations shown in **Figure 17**) showed that the downstream wells (P1, P2, P3, P5A, P5B, P7, P8, and P9) have the highest chloride concentration (12.5–30.5 mg/L, except P9), which is a clear sign of waste disposal leachate contamination. Anomalous sulfate, nitrate, nitrite, and iron (Fe) concentrations in some well downstream groundwater flow are below their maximum permitted value, established by the National Environment Council from Brazil, suggesting that this contamination is in its initial state (low contaminant concentration) and diluted into the aquifer. These parameters, when compared with the natural aquifer values, are considered anomalous even though.

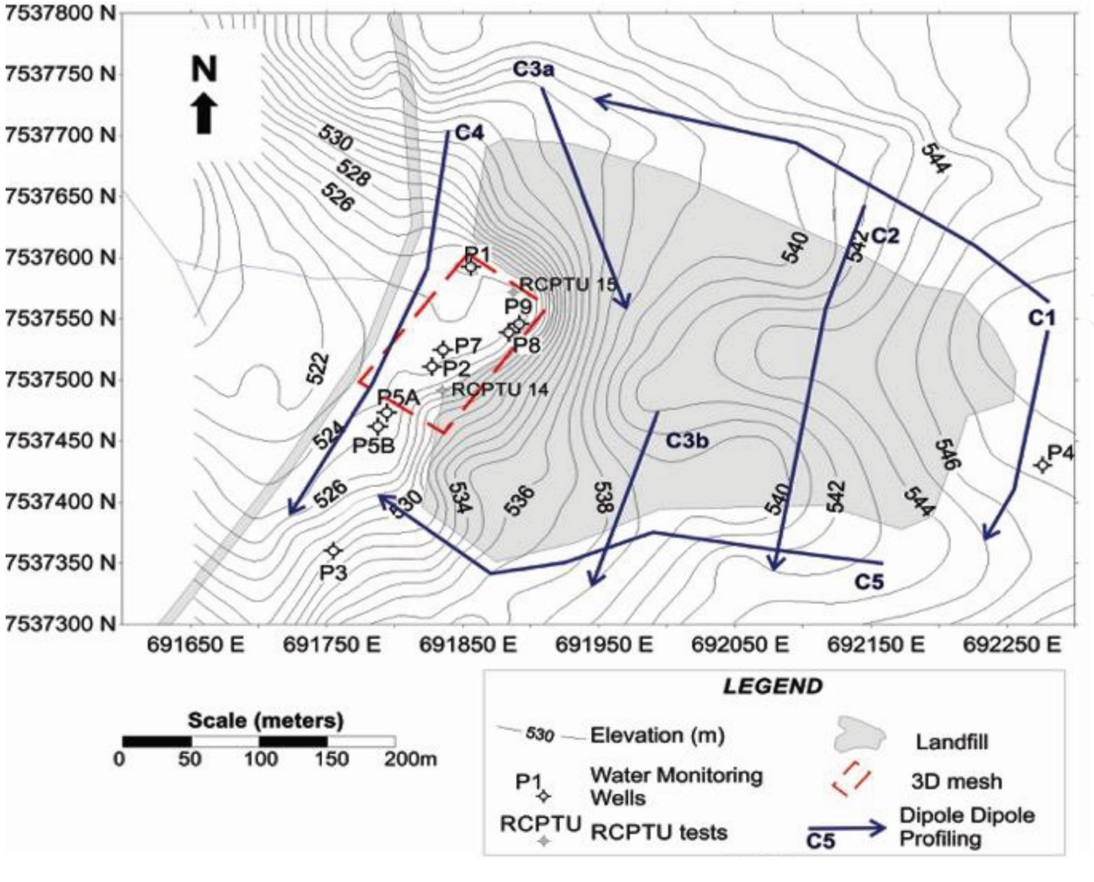


Figure 17.
Topographical map of the landfill with the location of monitoring wells, soundings, and the 3D geophysical survey mesh.

The 3D resistivity model (**Figure 18a**) show resistivity values lower than 100 ohm.m at 10 m deep, known to be n the saturated zone. A conductive feature is observed to start in the landfill (ρ < 20 ohm.m), propagating along the groundwater flow direction. Resistivity values lower than 20 ohm m observed outside landfill are interpreted as contamination plume supported by P2, P7, and P8 chloride anomalous values (mostly in conductive anomaly). However, according to chemical analysis of groundwater contamination, it can only be considered as low contaminant concentration plume. Highest chargeability (~33 mV/V) values are observed in the wastes but also at other regions in the saturated zone (**Figure 18b**). This feature is interpreted as a low salinity contamination plume. Despite low chargeabilities are usually associated with inorganic contamination plumes, the results from this study are in good agreement with Griffiths et al. [17], who observed the increase of chargeability with salinity, over a certain salinity range. The salinity range investigated by Griffiths is exactly the salinity range found in the monitoring well water conductivity. The groundwater flow is best marked by normalized chargeability (m_n > 0.3 mS/m) as shown in **Figure 18c**.

Ustra et al. [16] suggest that the increase of normalized chargeability outside the wastes is a signature of the local contamination plume. This interpretation is in good agreement with Viezzoli and Cull [18] who suggested that in high salinity environments, normalized chargeability is enhanced by clay content. In the case of the landfill, the distribution of the clay content is homogeneous (according with direct sampling), and there is no clay enrichment zone. Ustra et al. argued that in this case, salinity enhancement could highlight the clay content, enhancing the polarization in higher salinity zones that is the contamination plume.

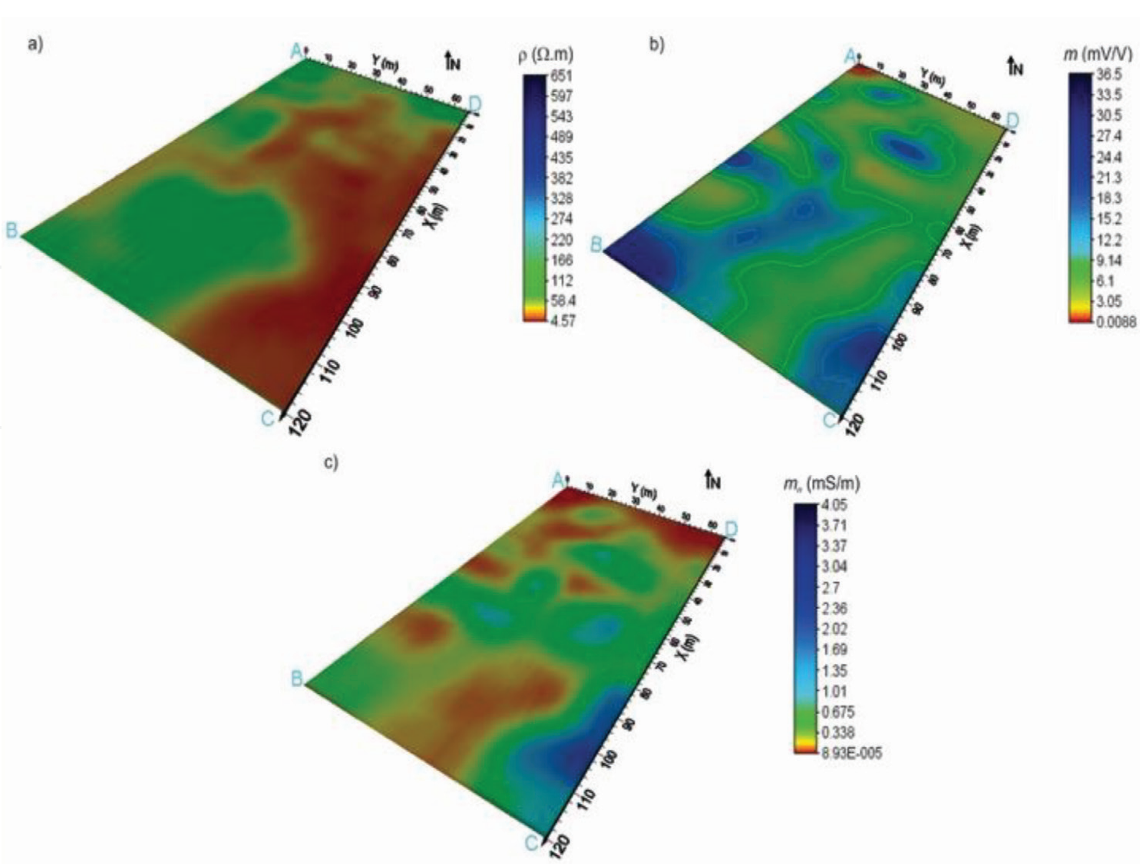


Figure 18.
(a) Resistivity, (b) chargeability, and (c) normalized chargeability models at the depth of 10 m, downstream the landfill.

6. Conclusions

We presented geophysical case studies conducted at MSW disposal sites in Brazil, to show the usefulness of resistivity and IP methods in characterizing these contaminated sites. The examples showed here show different types of waste disposal practice worldwide: direct disposal of wastes on the ground in geologically unfavorable and favorable conditions and proper landfills. We demonstrated that electrical methods are a powerful tool in identifying the presence of wastes in the subsurface and the boundary of the waste volume. Contamination plumes can also be detected with electrical methods, even for low contaminant concentration. Chemical analyses of groundwater are always needed to confirm contamination according to the environmental regulation. When the geophysical signature waste disposal sites are well defined and confirmed, geophysical methods can be used to monitor the temporal evolution of the contamination at the site.

Notes/thanks/other declarations

Thanks to town hall departments from Ribeirão Preto, São Carlos, Luiz Antônio and Bauru, which supported the scientific geophysical investigations at the MWS disposal sites.

Acknowledgements

We thank technicians and graduate and undergraduate student who help the series of surveys presented in this chapter. We also thank Sao Paulo State Funding Agency (FAPESP grant#08/25888-7), National Council for Scientific and Technological Development (CNPq grant #477330/2009-6), and Graduate Support Funding agency CAPES for funding parts of the studies presented here.

Author details

Andréa Ustra* and Vagner R. Elis
University of São Paulo, São Paulo, Brazil

*Address all correspondence to: andrea.ustra@iag.usp.br

IntechOpen

© 2018 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] United Stated Environmental Protection Agency. Available from: https://www.epa.gov/environmental-topics/land-waste-and-cleanup-topics [Accessed: 08-08-2018]

[2] Mirecki JE, Parks WS. Leachate geochemistry at a municipal landfill, Memphis, Tennessee. Ground Water. 1994;**32**(3):390-398

[3] Sharma PV. Environmental and Engineering Geophysics. Cambridge, UK: Cambridge University Press; 1997. 475 p

[4] Slater L, Lesmes D. IP interpretation in environmental investigations. Geophysics. 2002;**67**(1):77-88. DOI: 10.1190/1.1451353

[5] Pelton WH, Ward SH, Hallof PG, Sill WR, Nelson PH. Mineral discrimination and removal of inductive coupling with multifrequency IP. Geophysics. 1978;**43**(3):588-609. DOI: 10.1190/1.1440839

[6] Leroy P, Revil A, Kemna A, Cosenza P, Ghorbani A. Complex conductivity of water saturated packs of glass beads. Journal of Colloid and Interface Science. 2008;**321**:103-117. DOI: 10.1016/j.jcis.2007.12.031

[7] Johansson B, Jones S, Dahlin T, Flyhammar P. Comparisons of 2D and 3D inverted resistivity data as well as of resistivity and IP surveys on a landfill. In: Near Surface 2007—13th European Meeting of Environmental and Engineering Geophysics. Istanbul

[8] Leroux V, Dahlin T, Rosqvist H. Time-domain IP and resistivity sections measured at four landfills with different contents. In: Near Surface 2010—16th European Meeting of Environmental and Engineering Geophysics (Near Surface); 6-8 September 2010. Zurich, Switzerland: Expanded abstracts. P09

[9] Elis VR, Ustra AT, Hidalgo-Gato MC, Pejon OJ, Hiodo FY. Application of induced polarization and resistivity to the environmental investigation of an old waste disposal area. Environmental Earth Sciences. 2016;**75**:1338

[10] Bernstone C, Dahlin T, Ohlsson T, Hogland W. DC-resistivity mapping of internal landfill structures: Two pre-excavation surveys. Environmental Geology. 2000;**39**(3-4):360-371

[11] Gazoty A, Fiandaca G, Pedersen J, Auken E, Christiansen AV. Mapping of landfills using time-domain spectral induced polarization: The Eskelund case study. Near Surface Geophysics. 2012;**10**(6):575-586

[12] Maurya PK, Rønde VK, Fiandaca G, Balbarini N, Auken E, Bjerg PL, et al. Detailed landfill leachate plume aping using 2D and 3D electrical resistivity tomography—With correction to ionic strength measured in screens. Journal of Applied Geophysics. 2017;**138**:1-8

[13] Pejon OJ, Zuquette LV. Importância de estudos geológico-geotécnicos para a disposição de rejeitos urbanos. II Simpósio sobre Barragens de Rejeitos e Disposição de Resíduos. Rio de Janeiro-RJ: CBGB; 1991. pp. 367-377

[14] Loke MH. RES2DINV ver. 3.4—2D resistivity and IP inversion. Penang: M.H. Geotomo Software Users Manual; 2007

[15] Elis VR, Lago AL, Ustra AT, Mondelli G, Giacheti HL. Utilizacão de mapas de resistividade e cargabilidade para posicionamento de sistema de monitoramento geoambiental. In: International Congress of Brazillian Geophysysical Society, CISBGf 2007; Rio de Janeiro, Brazil. 2007

[16] Ustra AT, Elis VR, Mondelli G, Zuquette LV, Giacheti HL. Case study: A 3D resistivity and induced polarization imaging from downstream a waste disposal site in Brazil. Environmental Earth Sciences. 2012;**66**(3):763-772. DOI: 10.1007/s12665-011-1284-5

[17] Griffiths DH, Barker RD, Finch JW. Recent applications of electrical resistivity and induced polarization methods to hydro-geological problems. In: A Survey of British Hydrogeology. London: The Royal Society; 1980. pp. 85-96

[18] Viezzoli A, Cull J. Electrical methods for detection and discrimination of saline groundwater in clay-rich sediments in northern Victoria. Exploration Geophysics. 2005;**36**(3):294-300. DOI: 10.1071/EG05294

IntechOpen

IntechOpen