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USE OF GEOPHYSICAL TECHNIQUES FOR ANALYSIS OF TRACE METALS IN A CEMETERY UNSATURATED SOIL ZONE

UTILIZAÇÃO DE TÉCNICAS GEOFÍSICAS PARA ANÁLISE DE METAIS TRAÇO EM ZONA DE SOLO NÃO SATURADO DE CEMITÉRIO

Francisco Carlos da SILVA, Francisco de Assis Cavallaro, Wagner França AQUINO, Emerson Rodrigo ALMEIDA, Paulo Sérgio TONELLO

Universidade Estadual Paulista – UNESP. Instituto de Ciência e Tecnologia. Avenida Três de Março, 511 - Alto da Boa Vista, Sorocaba – SP.

E-mails: fracarlos@hotmail.com; assiscavallaro@gmail.com; wagnergpr@gmail.com; emerson.almeida@ufu.br; paulo.tonello@unesp.br

Resumo. O objetivo desta pesquisa foi aplicar dois métodos geofísicos [Técnica de Imagem de Resistividade (RI) e Técnica Eletromagnética Indutiva (EM-31)] para verificar a eficiência desta ferramenta na localização em plumas de contaminação subsuperficial e/ou íons metálicos liberados pela decomposição de cadáveres e suas conchas na Necrópole Nossa Senhora Aparecida, Piedade, SP. Esta pesquisa foi realizada no período de outubro de 2015 a setembro de 2016. Na primeira fase, utilizamos a técnica de Resistividade Imaging e posteriormente aplicamos a técnica eletromagnética. Esse período entre uma investigação e outra foi útil para verificar se as anomalias mudaram durante esse período. Os resultados mostraram que as anomalias localizadas não se moveram e que os resultados de ambas as metodologias foram semelhantes, considerando as limitações de cada técnica.

Palavras-chave: Técnica de Imagem de Resistividade (RI). Técnica Eletromagnética Indutiva (EM-31). Cemitério. Metais potencialmente tóxicos. Geofísica.

ABSTRACT - The purpose of this research was to apply two geophysical methods [Electrical Imaging Technique (RI) and Inductive Electromagnetic Technique (EM-31)] to verify this tool's efficiency in locating in subsurface contamination plumes and/or metal ions released by decomposition of corpses and their shells at *Necrópole Nossa Senhora Aparecida*, Piedade, SP. This research was carried out from October 2015 to September 2016. In the first phase, we used the Electrical Imaging technique and later we applied the electromagnetic technique. This period between one investigation and another was useful to verify if anomalies changed during that period. Results showed that localized anomalies did not move and that results of both methodologies were similar, considering limitations of each technique.).

Keywords: Electrical Imaging Technique (RI). Inductive Electromagnetic Technique (EM-31). Cemetery. Potentially toxic metals. Geophysics.

INTRODUCTION

For decades, necropolises were addressed as mere deposits of lifeless bodies. Researches indicated that they were built distant from urban centers and in areas where it was difficult to build houses and/or commercial establishments; for example, *Vila Formosa* Cemetery in São Paulo city East region.

With population increase, these areas must be more carefully assessed, as part of these necropolises were established in areas not suitable for this type of facility as they are frequently close to springs, headwaters, rivers, aquifers, or soil improper for burial.

With publication of Resolution 335 of May 8, 2003 by CONAMA (Environment National Council), cemeteries are currently considered a source of environment contamination and all provisions of the Law must be complied with to build a cemetery. It is necessary to implement equipment to protect environment and preserve soil and underground water. Scientific studies indicate that lack of planning on disposal of lifeless bodies may bring harm to the environment (Silva, 2008). Necropolis *Nossa Senhora Aparecida*, located in the municipality of Piedade, São Paulo State, SP, is almost totally composed of graves and is around 200 years old. Therefore, it is necessary to detect areas with high concentrations of soil contaminants related to the presence of metals and possible concentrations of organic material.

In this context, application of geophysical tools as a strategy to locate anomalous areas permits a better use of financial resources for subsequent confirmatory investigation. According to CETESB (1999), “Geophysical methods are indirect techniques for investigation of subsurface structures through acquisition and interpretation of instrumental data, characterizing them as non-invasive or non-destructive methods.

Application of geophysical methods in the process of localizing metallic anomalies in the soil to verify if interred corpses, as well as their shells, contributed to such anomalies. In academic researches such as those of Silva & Malagutti Filho (2009), hotbeds were located of potentially toxic metal concentrations coming from coffins, as well as of formaldehyde and methane used for corpse embalming. According to Xavier et al. (2006), higher temperatures, high rainfall indices and higher microbial activity cause accelerated decomposition of organic material contained in the soil. Based on this assumption, years of existence, and the way corpses are buried, only argillaceous soils will adsorb metallic concentrations.

Electro resistivity technique is the technique mostly used in hydrogeological designs. Horizontal scrutiny methods at different depths (electrical imaging) provide mapping and demarcation of irregularities related to possible contamination anomalies, especially those linked to the presence of metallic ions; organic anomalies are also important as they increase underground water electrical conductivity. Gandolfo (2007) makes it clear that electric resistivity is an adequate geophysical technique for preliminary valuation of possible contaminants in cemetery soil.

As mentioned above, electrical resistivity is appropriate and at the same time provides a quick answer for a more decisive scrutiny. It would be ideal to have other techniques to provide us with tools to differentiate between organic material and inorganic material (Silva, 2018). In their research, Silva & Malagutti (2009) clarify that it is possible to carry out a precise valuation and offer possible solutions for the contamination issue. Considering this premise, we realize that this research is able to provide data for surveys in different locations.

The purpose of this article is to present environmental assessment carried out on research area and possible consequences in the medium and long terms, given the fact that this entrepreneurship has been in operation for a long time. To this end, geophysical tools were used to locate organic and/or inorganic anomalies; information thus obtained was evaluated to compose a study on preliminary environmental impact of necropolis under discussion.

MATERIALS AND METHODS

Method description

Inductive electromagnetic method (EM) is comprised of induction of a primary electromagnetic field (Hp) for subsurface through a transmitter coil, and generation of a secondary electromagnetic field (Hs) in the soil, which is detected by a receiver coil (Figure 1).

In this geophysical method, physical property involved is the environment electric conductivity, which is proportional to the ratio between primary field emitted and secondary field captured.

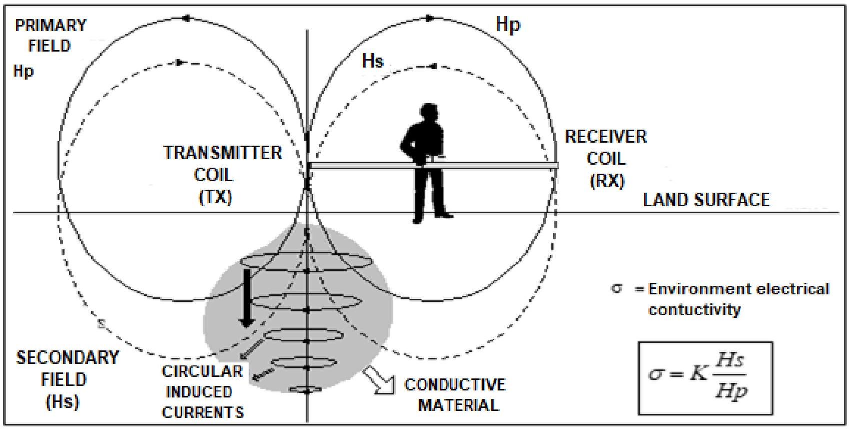

Figure 1 - Inductive electromagnetic method (EM) application principle (Adapted from Aquino, 2000).

Electric conductivity value obtained from measurement equipment is an integrated measurement of each soil portion conductivity, from the surface down to investigation depth reached by this method.

The other technique used in this research was the Electrical Imaging (RI), which is based on modification of spatial disposition of current and

ORP electrodes, providing an investigation of subsurface lateral variations at different depth levels.

In dipole-dipole array, A and B current electrodes are spaced just like M and N ORP electrodes. According to Figure 2, it is possible to see that X=AB=MN; investigation depth grows with separation of current and ORP electrodes (R), theoretically corresponding to ½R.

This lateral tracking originates pseudo-sections where plotted values of apparent resistivities measured are presented, both in magnitude and spatial position (horizontal and in-depth).

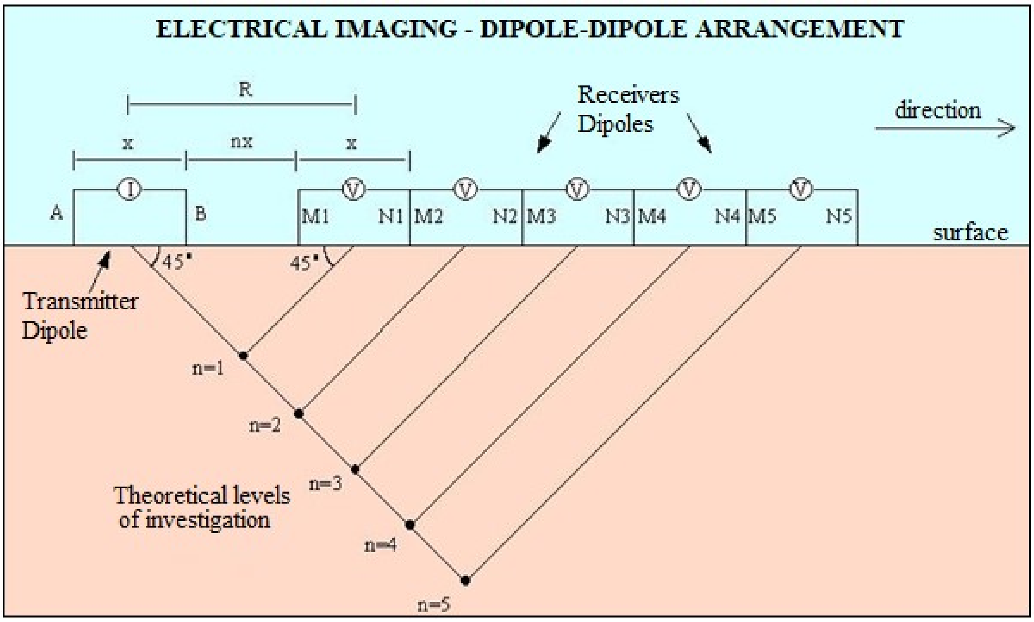

Figure 2 - Dipole-dipole array field disposition (Adapted from Braga, 2006).

Descriptions of the area and data collection procedures

The municipality of Piedade is located in *Embu* Domain, which, on its turn, is located in the South of *Taxaquara* shear Zone. This domain is comprised of supracrustal and granite and is divided into high metamorphic rocks of Embu Complex and Ibiúna and Piedade Batholiths.

As classified in IBGE (Brazilian Institute of Geography and Statistics) pedological map (2015), dominant soil in the region is the red-yellow argisol (PVA8). The main characteristic of this type of soil is the great increase of clay at depth.

Nowadays, the town has two public cemeteries: one of them is called *"Nossa Senhora Aparecida"* (Figure 3) and the other *"Jardim Eterno"*. Graves are numbered and shallow ones have an iron or wood framework, with permission to install crosses and grids, and to plant flowers and small bushes. Graves are made of reinforced concrete, and facilities that are harmful to public health are avoided.

According to the cemetery's manager and to information collected from church members, this cemetery is estimated to be approximately 200 years old and was expanded in the North-South direction. Cemetery *Nossa Senhora Aparecida* is now located in the town center with an area of approximately 17,000m² and occupation of 100%.

From October 2015 to August 2016, two different geophysical techniques were used (RI and EM) to locate anomalous concentrations of metals in the soil for the purpose of confronting them and verifying if obtained results are similar, which would characterize greater accuracy in soil collections for confirmatory analysis.

Electrical Imaging has the advantage of locating areas with metallic as well as organic anomalies, therefore, it is possible to locate necro-leachate, if any. Electromagnetic imaging has the advantage of providing faster results since readings are direct. Therefore, as time was a concern, geophysical techniques were applied with time distance of approximately 12 months.

First technique applied in above-mentioned research area was Electrical Imaging in October 2015, using multielectrode resistivimeter Syscal Switch Pro® (IRIS Instruments) model with 48 channels. This equipment has a data inclusion program denominated Electre II®, which permits assembling several field arrangements with the 48 channels.

Most trials were carried out in paved streets, therefore, we had to previously bore into the pavement with a drill to insert electrodes. Accordingly, 48 equidistant holes were previously drilled for introduction of electrodes with dipole-dipole array in those five profiles that were to be analyzed (Figure 4).

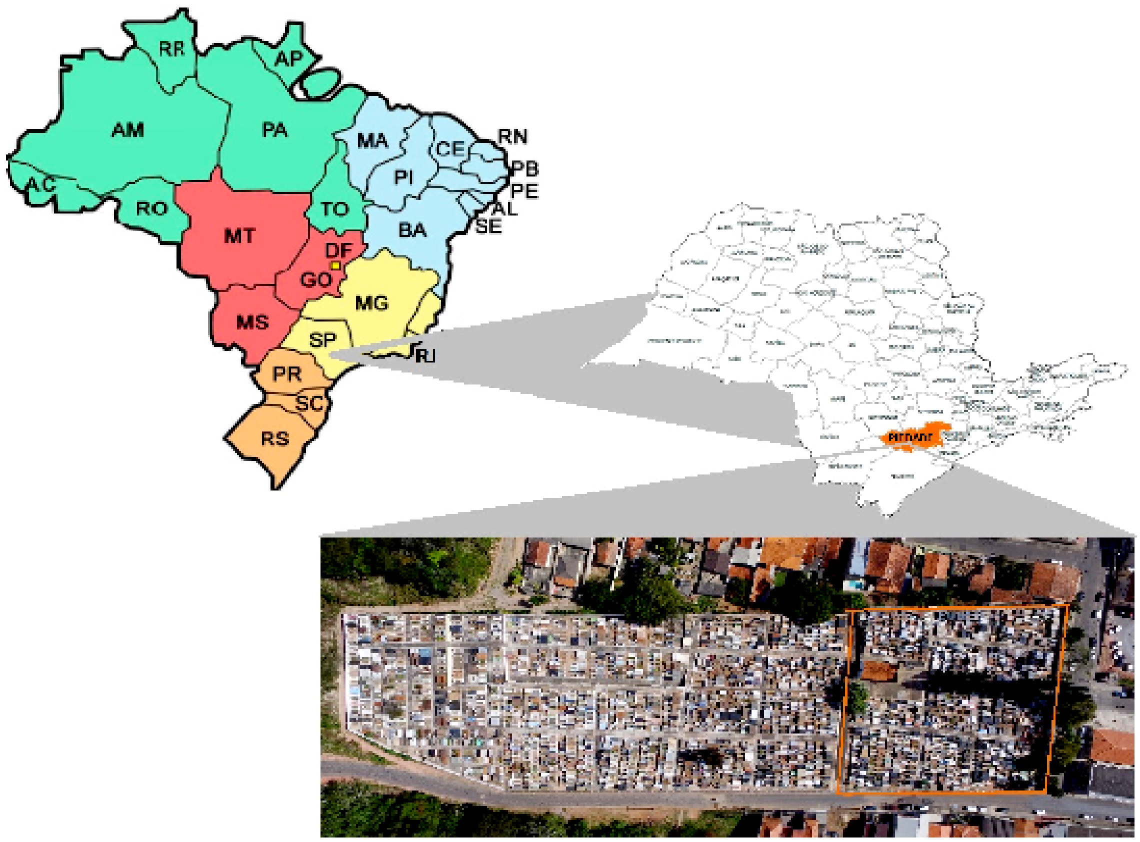

Figure 3 - Localization of *Nossa Senhora Aparecida* cemetery in the municipality of Piedade, São Paulo State, SP.

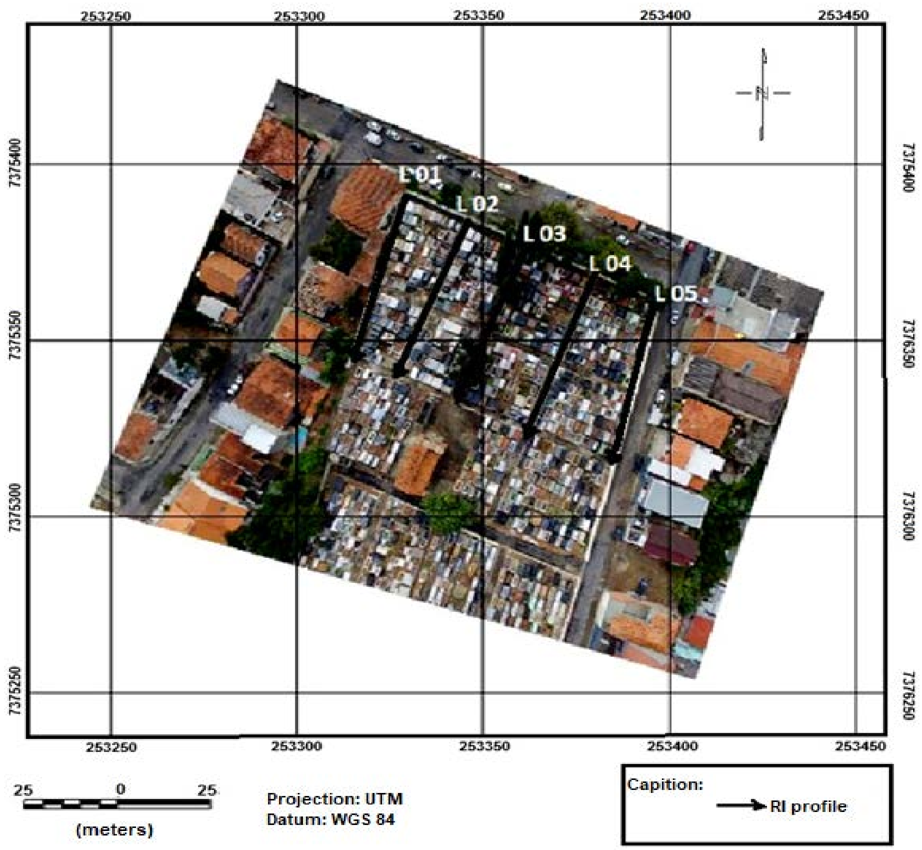

Figure 4 – Map with localization of RI profiles in research area of necropolis *Nossa Senhora Aparecida*, Piedade, SP.

The second technique was the electromagnetic resistivity imaging technique conducted in July 2016. Inductive electromagnetic method is based on induction of a primary electromagnetic field (Hp) to subsurface through a transmitter coil, and on generation of a secondary electromagnetic field (Hs) in the soil that is detected by a receiver coil. In this geophysical method, physical property involved is the environment electric conductivity and this is proportional to ratio between emitted primary field and captured secondary field. Acquisition was made with instrument EM-31 (Geonics), which is comprised of two coplanar coils assembled on a rigid tube at a fixed distance of 3.7 meters, and that can be carried and operated by a single person. This is an instrument with single operation frequency of 9.8 KHz, and this defines that to investigate two different depths, it is necessary to change disposition of magnetic dipole axis. Results from EM surveys are presented as in-depth maps and individual profiles where it is possible to observe lateral conductivity variations and that may indicate possible underground contamination. Contours of isovalue curves in conductivity maps were made by plotting reading points' coordinates and then interpolating measurement data through software Surfer, version 6.01 (Golden Software Inc.).

Successive measurements were made over preestablished profiles with measurement points at constant intervals of 5 meters to map possible lateral variations of electric conductivity. Measurement points were distributed in detail over interest area with a five-meter spacing between measurements (sampling interval) to make it possible to have a good detailing of executed lines. Field works were developed with parallel, diagonal and transversal EM profiles according to Figure 5.

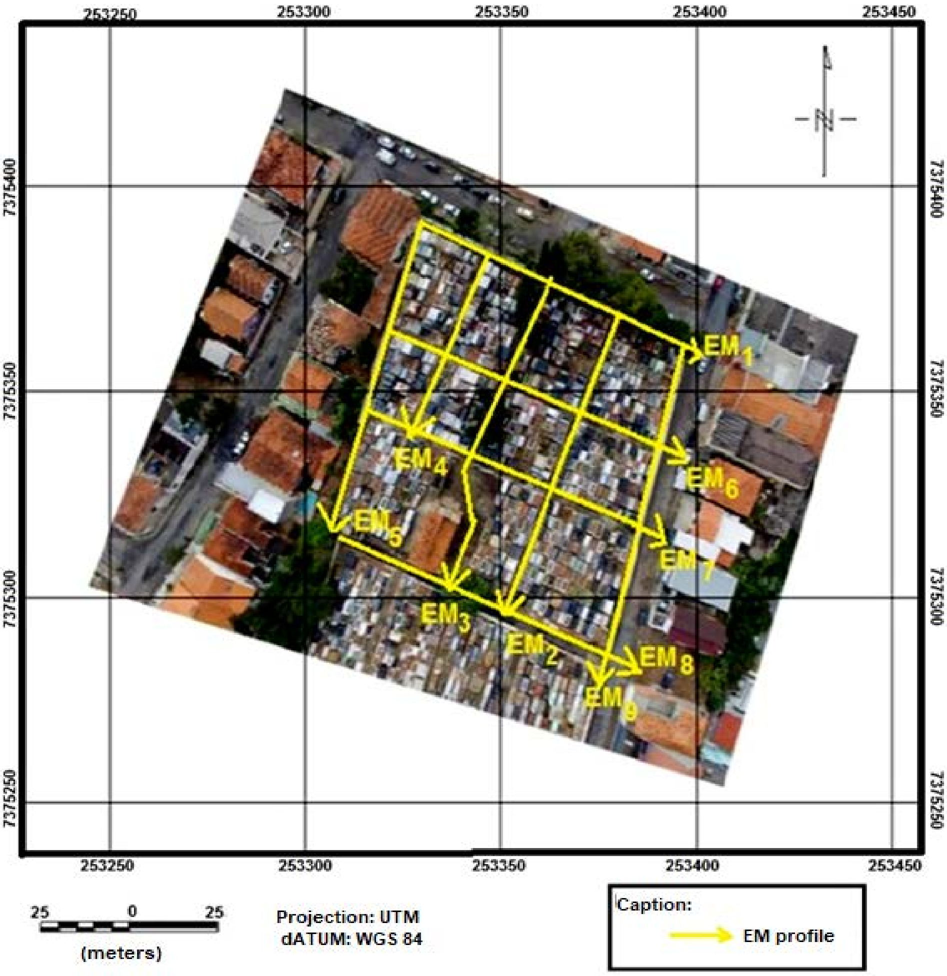

Figure 5 – Map with localization of EM profiles executed in research area of necropolis *Nossa Senhora Aparecida*, Piedade, SP.

RESULTS AND DISCUSSION

Results obtained using the Electrical Imaging technique applied to soil under discussion showed that there are points with anomalous concentrations of material in analyzed area that may be an indication of material not belonging to actual quantity of existing soil material (Figure

6). L1, L2, L3 and L4 profiles indicate low depths (0.5 to 3.0 m) in several low-resistivity sites. In profile L5, for example, this anomaly is also observed at great depths.

Results obtained in five analyzed profiles focused on obtaining data on relation between anomalous areas and possible materials deriving from decomposition of corpses and caskets are satisfactoryg since we found several anomalous points, except in profile L3, where only one anomaly point was identified. Results obtained in profile L5 also indicated an anomalous concentration at depths greater than 6 meters, which makes us believe that there is a possible flow of material to the outside of the necropolis, which indicates that "part of the waste is accumulated in lower slices" (Kemerich et al., 2012, p. 166-182).

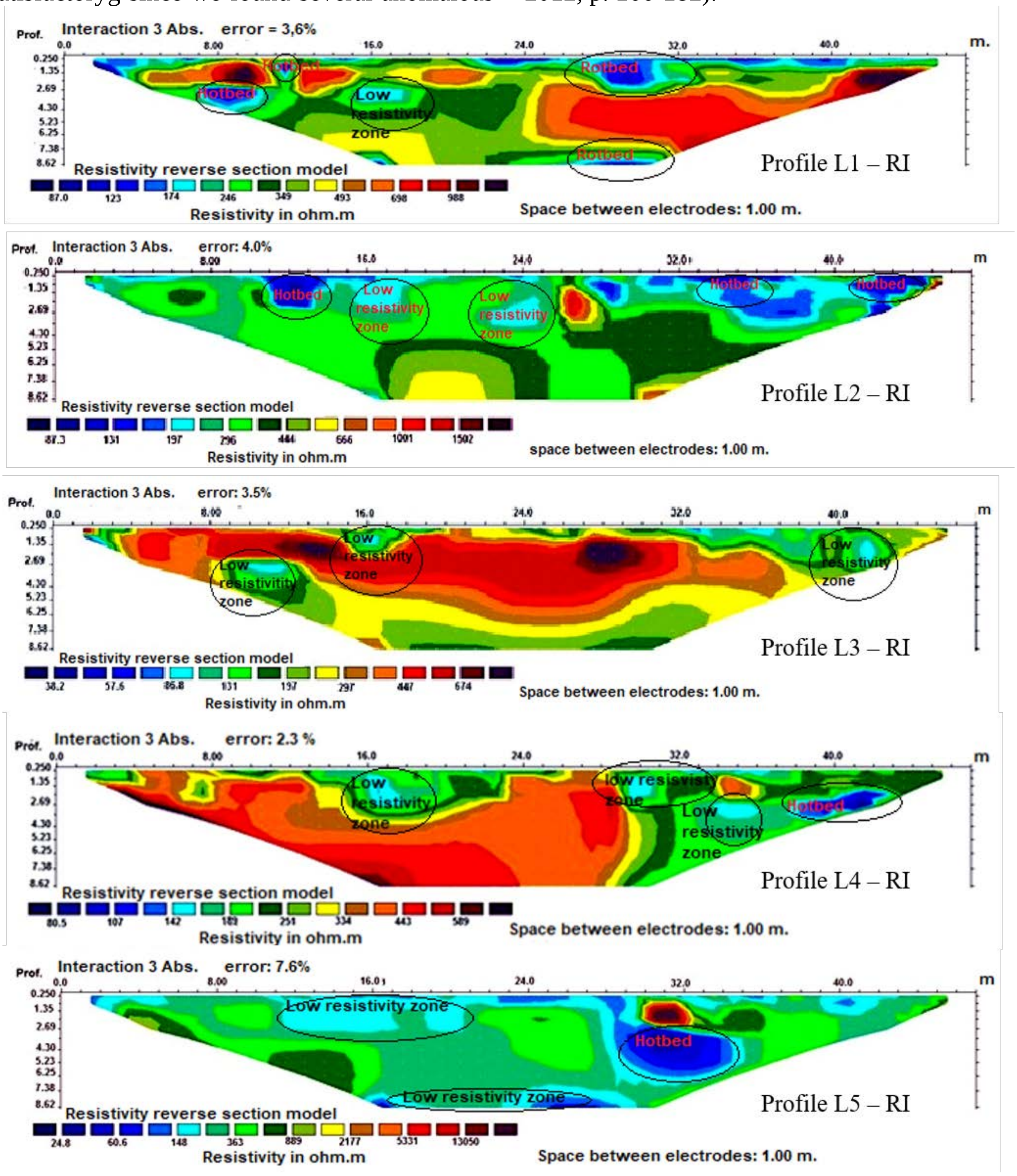

Figure 6 - RI (Electrical Imaging) pseudo-sections made in necropolis *Nossa Senhora Aparecida*, Piedade, SP.

Geophysical anomaly maps for exploration depths of 3.0 and 6.0 meters according to Figure 7.

To define contours of possibly contaminated (anomalous) zones in iso-conductivity maps (Figure 7), reference adopted for depths of 3.0 and 6.0 meters was the electric conductivity value of 5.2 mS m^{-1} and 13.6 mS m^{-1} respectively (background). Accordingly, anomalies were defined as values that extrapolate background. For this, values that are one and half times bigger than background conductivities were defined as anomalous values. However, to arrive at this result, an empirical procedure based on field work was used (Aquino, 2000).

In general, we can observe in iso-conductivity map of Figure 6 the presence of four anomalies, with three of them being common to iso-conductivity map of Figure 7. Anomalies occurring at both depths are denominated A1, A2, and A3, while anomaly occurring only at the three-meter depth is denominated anomaly B, and anomaly that is exclusive of six-meter depth was denominated anomaly C.

Iso-conductivity map of Figure 5 revealed the presence of more intense anomalies (A3 and B) in Northeast and East parts of investigated area.

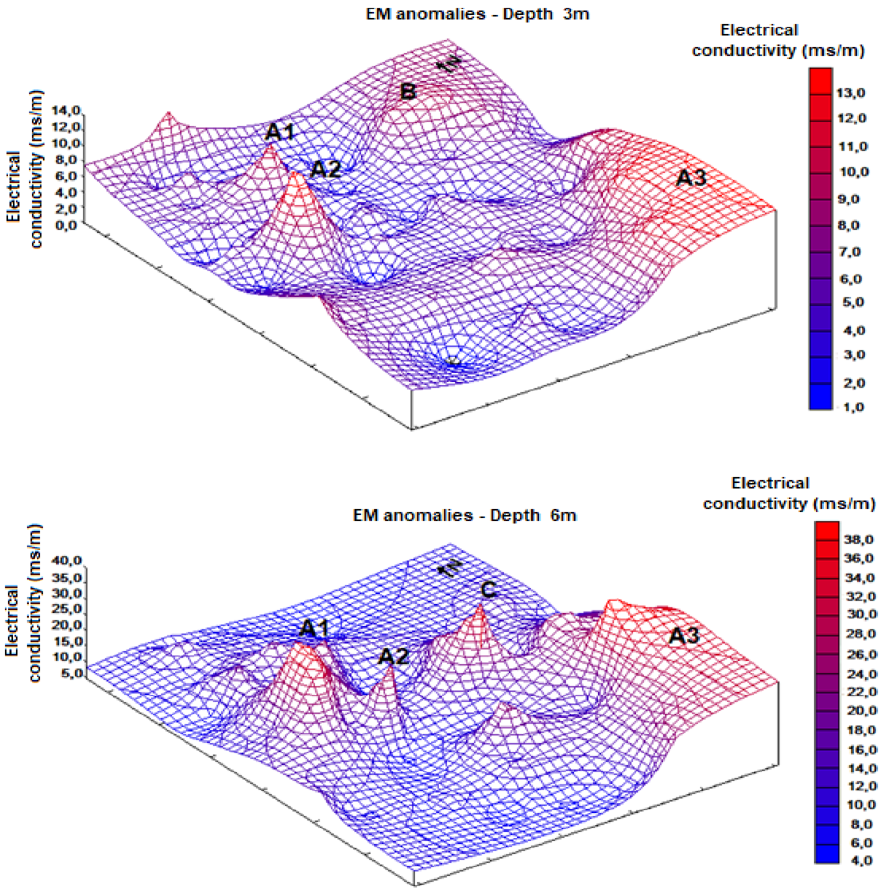

Figure 7 – Electric conductivity anomaly maps at depths of 3.0 and 6.0 m measured in mS m $^{-1}$ at necropolis *Nossa Senhora Aparecida*, Piedade, SP.

Anomaly A3 corresponds to a contamination plume, as it covers a considerable area and presents high conductivity (approximately 35 mS m^{-1}). This finding gives us indications that there is a possible preference zone of fluid accumulation and percolation that may correspond to contaminants. In that case, this preferred direction would tend to affect houses located West of the necropolis, exposing them to contamination.

Anomaly B is intense and extends over a considerable area. However, the fact that its occurrence is not verified at greater depths may indicate the presence of an impermeable material that prevents percolation of contaminants in this region of the necropolis, preventing the contaminant from reaching greater depths.

Anomalies A1 and A2 also appear at both depths. However, they are punctual, that is, they do not reach a significant volume when compared to anomaly B. In addition, for anomaly A, it is possible to observe a decline in intensity at the depth of six meters, which signals that its source was removed or was not enough to reach depths below six meters.

Like anomalies A1 and A2, anomaly C is punctual (Figure 8). However, as it is exclusive of the six-meter depth, it is not representative of the area's context, when we compare it to other anomalies in the necropolis.

Results obtained in all profiles with the electromagnetic technique indicated that, except for points highlighted in figures, which are in areas with greater declivity, we can affirm that there is soil homogeneity.

Results obtained with the Electrical Imaging technique indicate the same direction, as the highest point of the area under discussion is located in profile L3- RI. Anomalies are also found at lower points; therefore, we can deduce that anomalous substances tend to be carried to profiles with greater declivity.

Figures 8 A, B and C illustrate convergence points between results obtained from Electrical Imaging (RI) and electromagnetic (EM) imaging in analyzed profiles.

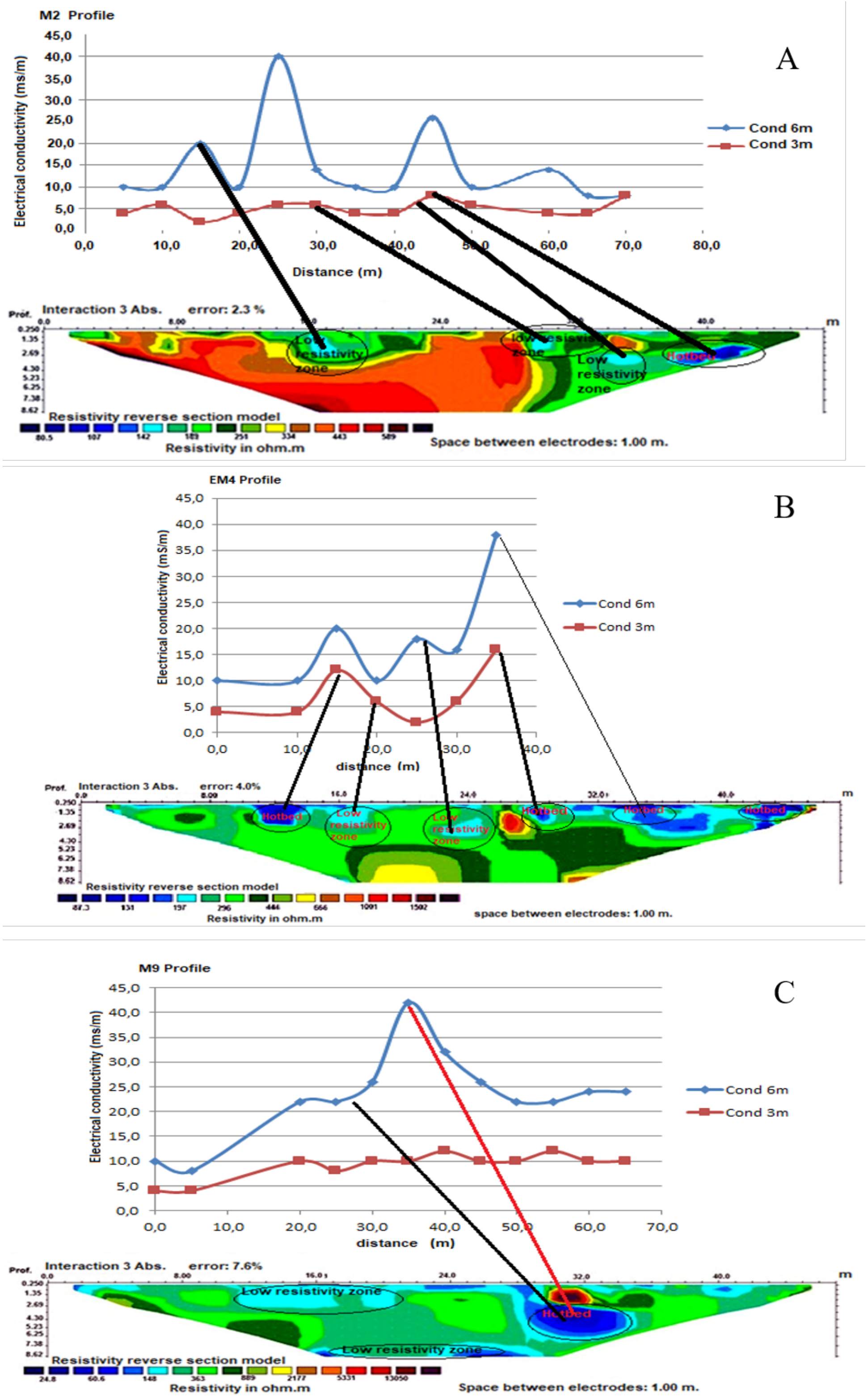

Figure 8. A – Comparison between EM-31 and Syscal results referring to point C discriminated in anomaly maps for 3 and 6 meters. B – Comparison of EM-31 and Syscal results referring to points A1 and A2 discriminated in anomaly maps for 3 and 6 meters. C – Comparison of EM-31 and Syscal results referring to point A3 discriminated in anomaly maps for 3 and 6 meters.

CONCLUSIONS

Both geophysical techniques used in this research yielded very close positions of anomalous concentrations. Considering that Electrical Imaging (RI) has the capacity of detecting both inorganic and organic substances and electromagnetic technique (EM-31) only metallic ions, some questionings arose.

1. Considering that this necropolis has approximately 200 years, that burials are carried out on a random basis, that the cemetery is basically comprised of vaults, it will be difficult to find contamination plumes deriving from corpses.

2. In Figure 8 B, concentration of "metals" is high, which is justifiable since this was a clay soil landfill. This type of soil has the capacity of retaining water, which, in most cases, causes preservation of corpses as there is no sufficient oxygen for proliferation of decomposing microorganisms.

We use this opportunity to make a warning about improper burials, as we may have corpse preservation (saponification) problems and/or we may have formation of a contamination plume in case there is a high number of burials in the same period.

In view of the above, it is possible to say that even with geophysical trial using Electrical Imaging technique, it is necessary to deepen studies on other techniques; at first, qualitative techniques and, after reaffirmation using other techniques to confirm anomalous sites, conduct confirmatory (chemical and biological) trials with these results in hand. Geophysical technique provides us with only location and possible dimension of anomalous area but we are not able to affirm that observed material is necro-leachate waste, potentially toxic metals, or both.

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