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ELECTRICAL RESISTIVITY METHOD APPLIED TO STUDY GROUNDWATER CONTAMINATION AROUND THE ALAGOINHAS CEMETERY, BAHIA, BRAZIL

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ABSTRACT. To investigate the subsurface geological and hydrological conditions around the area of the Alagoinhas county cemetery – Bahia State, Brazil, 38 vertical electrical soundings using Schlumberger electrode array were performed to a maximum AB/2 spacing of 300 m. The electrical resistivity data were automatically inverted by computer, using a least square fit criterion to the error of the model with respect to the observed data and the help of public domain softwares RESIST V1.0 and RES1D. Geological constraints of lithological well logs were used to control the data interpretation, by fixing the number of layers and an initial model suggested by the interpreter. Represented as maps, sounding curves and geoelectrical cross-sections, the results allow: (i) to map the static water table depth, which in the more plain areas, are around 27 m depth; (ii) to suggest that the subsurface zones of low true resistivity ($<300\ \Omega$.m) are contamination plumes above the aquifer top, whose sources are related to the cemetery; and (iii) to detect electrical heterogeneities in the aquifer vadose zone, indicatives of the travel of the invading contamination.

Keywords: electrical methods, resistivity, Alagoinhas, water contamination.

RESUMO. Para investigar as condições geológicas e hidrológicas da subsuperfície na área do entorno do Cemitério Municipal de Alagoinhas, Bahia, foram realizadas 38 sondagens elétricas verticais centradas em pontos acessíveis da área. As sondagens foram executadas usando o arranjo Schlumberger de eletrodos, até espaçamentos máximos de eletrodos de corrente AB/2 de 300 m. Os dados de resistividade elétrica foram invertidos automaticamente em computador usando critérios de ajuste de mínimos quadrados para o erro do modelo com respeito aos dados observados, usando os programas de domínio público RESIST V1.0 e RES1D. Informações geológicas de poços foram usadas no controle da interpretação, efetuada com o envolvimento do intérprete através da fixação do número de camadas e de um modelo inicial para a inversão. Apresentados na forma de mapas, curvas de sondagens e seções geoelétricas transversais, os resultados permitiram: (i) mapear o nível estático da água subterrânea que, nas partes mais planas da área, situa-se em torno de 27 m de profundidade; (ii) indicar que as zonas subsuperficiais de baixas resistividades verdadeiras ($<300\ \Omega$.m) são plumas de contaminação na parte superior do aquífero, cuja fonte é associada ao cemitério; e (iii) detectar heterogeneidades elétricas na zona vadosa do aquífero apontando feições indicativas de rotas de invasão do contaminante.

Palavras-chave: métodos elétricos, resistividade, Alagoinhas, contaminação da água.

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INTRODUCTION

Questions related to environmental protection and preservation has occupied the world scenario, especially after the Copenhagen Conference in 2009, where sustainability or sustainable development has become a target requirement for the signatory countries. Brazil has an advanced legislation concerning the responsibilities of those causing environmental pollutions, yet the environmental liability is large and originated from various human interventions.

Among the developments that are likely to cause impacts to the environment are the cemeteries. The technical norm L1.040 (CETESB, 1999) regulates its licensing for the State of São Paulo. In Brazil, the requirement for licensing cemeteries began with resolutions from the National Council for Environment, a consultative organ from the Ministry of Environment. The Law N. 335 of April 3, 2003 and the Resolution 368 of 2006 regulates the essential aspects of licensing cemeteries.

The generation of contamination plumes may be due to the infiltration of industrial and hospital wastes, or even from the decomposition of organic materials (garbage or corpses) that infiltrate the soil and reach the water table. These plumes deteriorate the water quality and may extend the environmental problem to the sphere of public health.

Several authors (Cavalcanti, 1999; Gallas et al., 2005) have demonstrated the efficacy to use geophysical methods in environmental investigations. In the specific case of cemeteries, the work of Silva & Malagutti Filho (2009) and Castro (2008) demonstrate the use of geophysics in the identification and delineation of necro-leached plumes. In the presents work, the source of contamination was related the municipal cemetery Jardim Paraíso da Saudade, Alagoinhas, Bahia. However, other environmental geoelectrical researches were also conducted in the same county (Pereira & Lima, 2007; Porciúncula, 2011).

The water supply for Alagoinhas city is of excellent quality, being pumped from the São Sebastião aquifer. This quality has attracted the interest of industrial brewers, as Schincariol and Ambev groups, bringing many investments to the city. Thus, knowing that the mortuary activity can, locally, compromising the water quality in its neighborhood, a geoelectrical survey has been conducted around the area of the cemetery, in order to characterize and evaluate its hydrogeological impact. The geophysical work comprises the execution of 38 vertical electrical soundings (VES), which were interpreted using RES1D and RESIST V1.0 softwares, to characterize the subsurface area around the cemetery.

Characterization of the Study Area

Alagoinhas is a county of Bahia, located between the coordinates 11°55'51" and 12°08'08" latitude south and 38°25'09" and 38°35'00" longitude west, with a territorial extension of 752 km^2, and a population of 142,160 inhabitants (IBGE, 2010). The city of Alagoinhas has an altitude of 132 m above sea level, and a distance of 107 km from Salvador. Road access is made by the BA-093 and BR-101 (Fig. 1). It has north border with the municipality of Inhambupe, south borders with Araçás and Catu, east borders with Entre Rios and Araçás, and the west borders with Aramari and Teodoro Sampaio.

The local climate, according to the Thornthwaite classification, is a transition from wet to sub-humid, with average annual rainfall of 1469 mm, with the highest rates recorded in autumn and winter. Daily temperature variations are irrelevant, keeping the annual isotherms at 24°C to 25°C. The natural vegetation of rainforest is quite uncharacteristic due to massive deforestation linked to agro-pastoral activities and extensive eucalyptus plantations. The predominant soils are deep, acids, unsaturated, sandy and of low fertility.

The water supply for Alagoinhas and for its districts and rural communities is controlled by the Autonomous Water and Sewage System (SAAE – Serviço Autônomo de Água e Esgoto), which uses as source the aquifer system formed by Marizal and São Sebastião sandstones. As a result, it is essential a continuous evaluation and water quality monitoring of this groundwater source.

The Jardim Paraíso da Saudade cemetery is located away from Alagoinhas urban center, and is in operation since June 10, 1979. It has undergone three expansions in the years 2002, 2009 and 2010, and has more than 12,500 buried bodies. Currently, the cemetery is approximately 172 m in length and 179 m in width. The cemetery is not subdivided into square blocks, and has built 5,895 boxes. The burial mostly occurs by the technique of burying the boxes directly in the soil pits.

Alagoinhas's county is situated in the Recôncavo sedimentary basin occupying a broad structural depression (the Alagoinhas low). His upper sedimentary cover, composing the explored aquifer system, is composed by Barreiras, Marizal and São Sebastião formations.

The Barreiras Formation of Tertiary age (Pliocene) has an average thickness of 50 m, and represents a system of fluvial and alluvial deposition. It consists of fine to coarse grained sandstones, interlayered with reddish-gray, purple and yellow claystones. The sandstones have a kaolinitic matrix, are slightly consolidated and poorly selected. Occurs as extensive sand bodies,

Figure 1 – Geographic map and Google images showing location and access to the study area, and the VES centers distribution around the cemetery.

inclined toward west, and resting with an erosive unconformity over Cretaceous deposits (Marizal and São Sebastião formations).

The Marizal Formation, of Lower Cretaceous age, was also deposited in fluvial and alluvial systems, composing a sub-horizontal section of coarse sandstones and conglomerates, interlayered with siltstones, shales and limestones. It is exposed around the study area, along road cuts of approximately 5 to 12 m in height, and from 30 to 18 m in length. Overlie, also with erosive discordance, the deposits of São Sebastião Formation.

The São Sebastião Formation occupies the entire municipal area, outcropping only in areas of low topography. In the Recôncavo, contains the second larger freshwater reservoir of Bahia State. It consists of coarse to fine grained sandstones, interlayered with shales and claystones. This configuration allows the occurrence of multi-confined sandstone bodies in which water is stored under pressure (Lima, 1999). It is covered, with an unconformity, by Marizal and Barreiras formations. It has been subdivided formally into three Members: Paciência, Passagem dos Teixeiras and Rio Joanes (Viana et al., 1971; Ghignone, 1979).

The Recôncavo aquifer system consists of two components: (i) a water table component, formed by the hydraulic combination of sandstone bodies of Marizal and Barreiras formations, which can reach up to 100 m in thickness; and (ii) a multi-confined component, composed by sandstone layers of São Sebastião Formation. This component accounts for about 70% of the total volume of potable water resources existing in the Recôncavo basin (Lima, 1999).

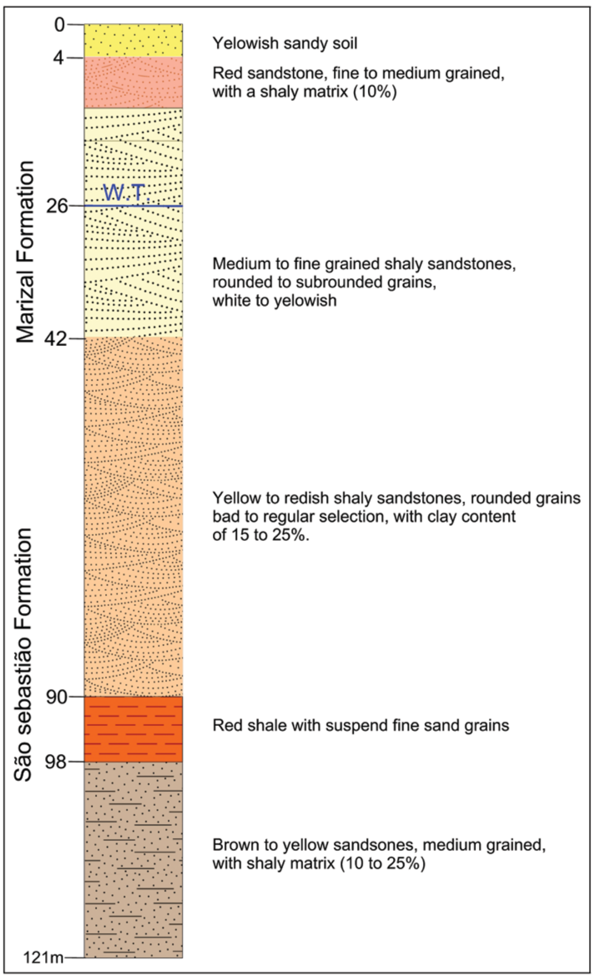

Figure 2 – Lithological log from well P-3 supplied by SAAE of Alagoinhas.

The SAAE of Alagoinhas released the lithological log of well P-3 (Fig. 2), with a depth of 121 m, located near the cemetery. Based on this log, we find that:

(i) the dominant lithology in Marizal Formation, up to 42 m depth, is a slightly consolidated sandstone, of rounded to sub-rounded grains, with clays disseminated in the matrix;

(ii) from 42 to 90 m, there is a thick sandstone body of São Sebastião Formation, characterized as a succession of fine-grained sandstones of good to regular selection, with clays dispersed in the matrix. The shaliness of this formation appears to be greater than that of the Marizal Formation;

(iii) the static water level at this site is found at a depth of 26 m;

(iv) between 90 and 98 m, there is a layer of reddish shale separating a second sandstone body, probably with water under confined conditions.

METHODOLOGY

The geophysical methods are characterized as being non-invasive technologies. They constitute indirect means to investigate the subsurface geological structure, through the acquisition and interpretation of data obtained to characterize the contrast of the physical properties of the subsurface materials. In the case of the electrical method, used in this paper, the property involved is the electrical resistivity.

The success of geoelectrical methods in environmental studies is attributed to the fact that they reveal the natural subsoil conditions as a function of changes in the quality of their interstitial waters. The electrical methods are typically used in investigations of aquifer contaminations and shallow prospecting in general. In this work the geoelectrical method was used through the technique of vertical electrical sounding.

The geoelectrical method is based on measuring the electrical impedance of the underground terrain through its coupling with the four electrodes used for data acquisition. By means of two electrodes, a direct or an alternating electric current of low frequency is injected into the ground; using two other electrodes, the potential difference caused by this current is measured (Ward, 1990).

In the resistivity method we have performed the VES using the Schlumberger electrode array. The VES technique was developed to obtain the resistivity distribution at different depths, using surface measurements made at different AB/2 spacing (Fig. 3). The depth of current penetration is increased as the spacing of the electrodes increases.

In the Schlumberger array, A and B are responsible for injecting the electric current into the ground, while M and N, are used to measure the electrical potential difference. Equation (1) is the base for constructing an electrical sounding curve. It was obtained by superposing solutions of Laplace's equation for a point current source over a homogeneous half-space of resistivity ρ. The electric potential difference ΔV is measured between the potential electrodes, K is the geometric factor of the array,

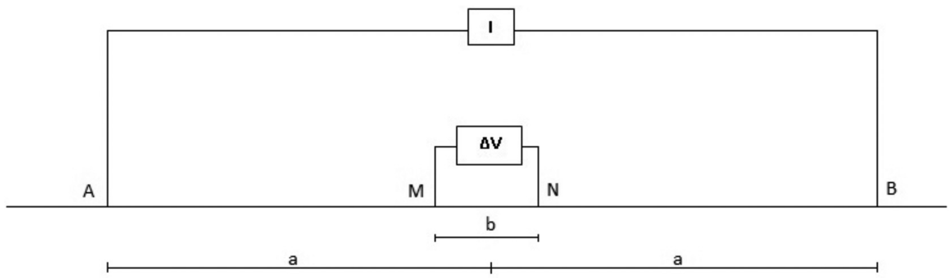

Figure 3 – Sketch of the Schlumberger electrode array.

given by Equation (2), and I the electrical current injected into the ground.

$$\rho = \frac{K\Delta V}{I}, \quad (1)$$

where,

$$K = \frac{2\pi}{\left[\left(\frac{1}{AM}\right) - \left(\frac{1}{BM}\right) - \left(\frac{1}{AN}\right) + \left(\frac{1}{BN}\right)\right]}. \quad (2)$$

For Schlumberger array the geometrical factor is giving by

$$K = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right), \quad (3)$$

in which $a = AB/2$ and $b = MN$.

For heterogeneous and anisotropic media, Equation (1) may be yet applied to compute a mathematical function, called apparent resistivity function, from which the geophysicist can infer the resistivity distribution within the subsoil geology.

The equipment used for the electrical acquisition was a SYSCAL-PRO, manufactured by *Iris Instruments*, from CPGG/UFBA. The SYSCAL-PRO comprises an integrated transmitter/receiver unit, configured to perform simultaneous readings of apparent resistivity and chargeability, from the injection of electric current through copper electrode bars. The device features a 10-channel system that allows up to 10 simultaneous readings of potential differences. A 12V battery is used as power source to the equipment.

We have performed 38 VES distributed preferentially in the vicinity of the cemetery, although six of them where set up inside the area, due to obstacles present on the outside. The obstacles that hampered the implementation of some VES at large spacing AB/2 were the asphalt from the road, the presence of dense vegetation zones, fences and walls around the cemetery (see Figs. 1 and 4).

This geophysical survey was conducted in two stages: the first one, from October to November 2011, during the rain period, where we performed 22 VES; in the second, from March to April 2012, we survey 16 additional VES. The rains have modified only the top layer resistivity, but were helpful in reducing the electrodes/earth contact resistances. During the summer, however, we have to use large amounts of salt-waters to implement the earth/electrode contacts. The VES were performed with current electrode spacing AB/2 progressively increased from 1 to 300 m.

Since the SYSCAL-PRO system operates with a DC-current source we expected only small noise interferences due to anthropogenic causes, such as air fences or transmission power lines. During the field work, the quality control on the acquired data was performed through the following procedures: (i) assuring a low contact resistance between the electrodes and the ground ($<$3k Ohm), as measured by the used instrument; (ii) constructing a VES curve during the field acquisition to avoid bad data points caused by break line connections, current cable leaks, or lateral effects near the measuring electrodes.

The geoelectrical data was inverted using the free computer programs RES1D from Geotomo Software (Loke, 2001), and RESIST 1.0 (Vander Velpen & Sporry, 1993). The first was used in the automatic mode, to obtain an adjusted model in which the number of layers is equal to the number of points in the VES. The second one was used for the final inversion, from an initial model proposed on basis of the first inversion having a small, selected, number of layers. Obtained the resistivity and true thickness for each VES, we constructed pseudo-resistivity sections and true geoelectrical profiles for the five transverse lines crossing the area.

In constructing the pseudo-resistivity sections, the distances AB/2 were converted to pseudo-depths using the conversion factor of 0.191, valid for the Schlumberger array (Loke, 2013).

RESULTS AND DISCUSSION

Two maps and five geoelectrical sections were constructed from the observed apparent resistivity values. The locations of the profiles are shown in Figure 4. The distribution of VES centers

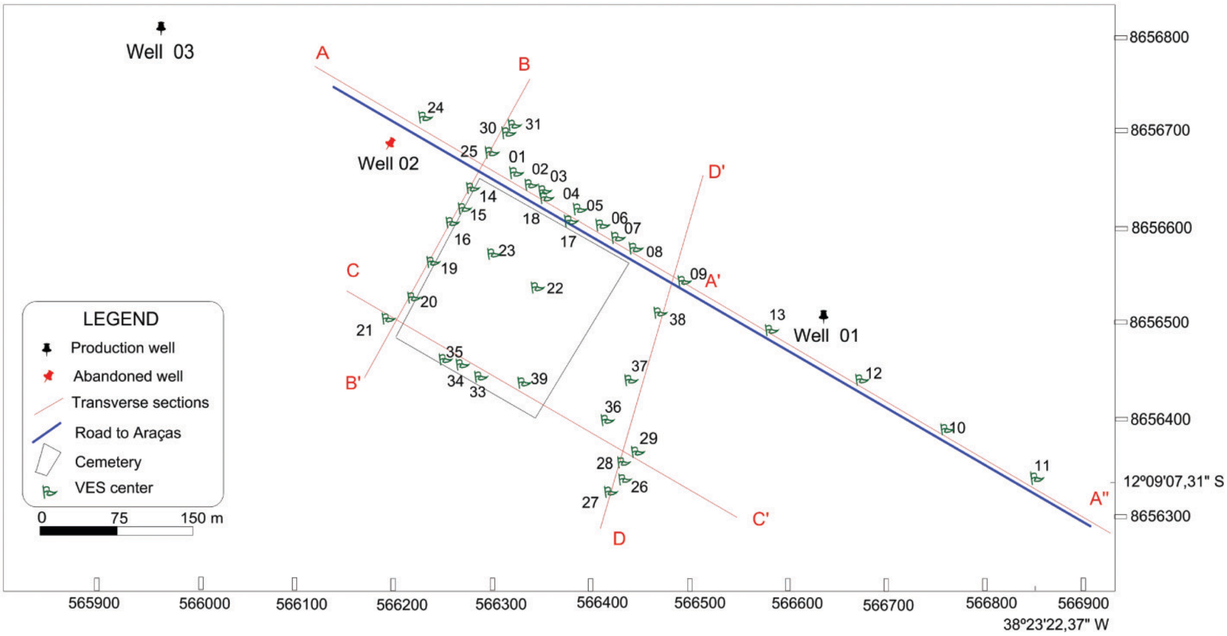

Figure 4 – VES center distribution and the four transverse lines used to depict geoelectrical cross-sections.

around the cemetery was defined to attain a probe separation convenient to investigate the vadose zone and the top of the aquifer in the area.

Apparent iso-resistivity contour maps were used to obtain qualitative environmental information about the subsurface geology in the study area. Two maps were constructed for AB/2 spacing of 30 m and 50 m, investigating approximately to a depth ranging from 15 to 25 m. Inside the cemetery area, the apparent resistivity values vary from less than 100 to almost 2000 Ohm.m. The more conductive levels are interpreted as near surface, low permeability zones with necro-leached contamination, whereas the more resistive host body, are representing the thick aerated, more pervious portions (vadose zone) of the local water table aquifer.

In the maps of Figure 5 the apparent resistivity contours below 800 Ohm.m, depicted by an orange to reddish colors, are interpreted as resulting from the rainwater infiltrated through the cemetery area, washing and dissolving the upper necrochorume zone. The presence of elongated lens-shaped conductive anomalies suggests the existence of less permeable zones intercalated within the Marizal sandstones.

In Figures 6 and 7 we show some examples of sounding curves obtained along the studied area. The curves, in general, are smooth and locally compatible with horizontally layered earth models. The final inverted results, obtained using RESIST are also shown in the graphics. For all VESs it was observed that the static water level is between 20 and 30 m depth.

The apparent resistivity pseudo-sections and the true geoelectrical sections of line A-A' (see map of Fig. 4 for location) is shown in two segments (A-A' and A'-A", as shown in Figs. 8 and 9). Interpolating the one-dimensional models for the VES that composes the sections we generated the true resistivity sections. In the first, located in front to the cemetery (Fig. 8) the resistivity distribution pattern with depth shows a remarkable decrease, within a limited lateral extent, directly below the cemetery terrain. In the true resistivity interpreted section, it is defined the water table position, in good accordance with the data of P-3 producing well. Two low resistivity zones directly below the cemetery, one at the top and another below the water table, suggest contaminations by fluids infiltrated vertically through the cemetery subsoil.

In the second segment of A-A" (Fig. 9) a similar pattern of resistivity reduction with depth is repeated, only with a more regular pattern through the profile. In the aquifer zone, the true resistivity values are higher than in the first segment, indicating native non-contaminated waters along the investigated extension.

The sections related to line B-B' (Fig. 10) also shows a limited lateral abnormality generated by the necrochorume, characterized as an upper conductive body near the surface, a middle resistive zone of low saturation, followed by a sharp decrease of electrical resistivity with depth, below the groundwater level. Some VES centers belonging to this profile are less than 1 m away from the cemetery boundary.

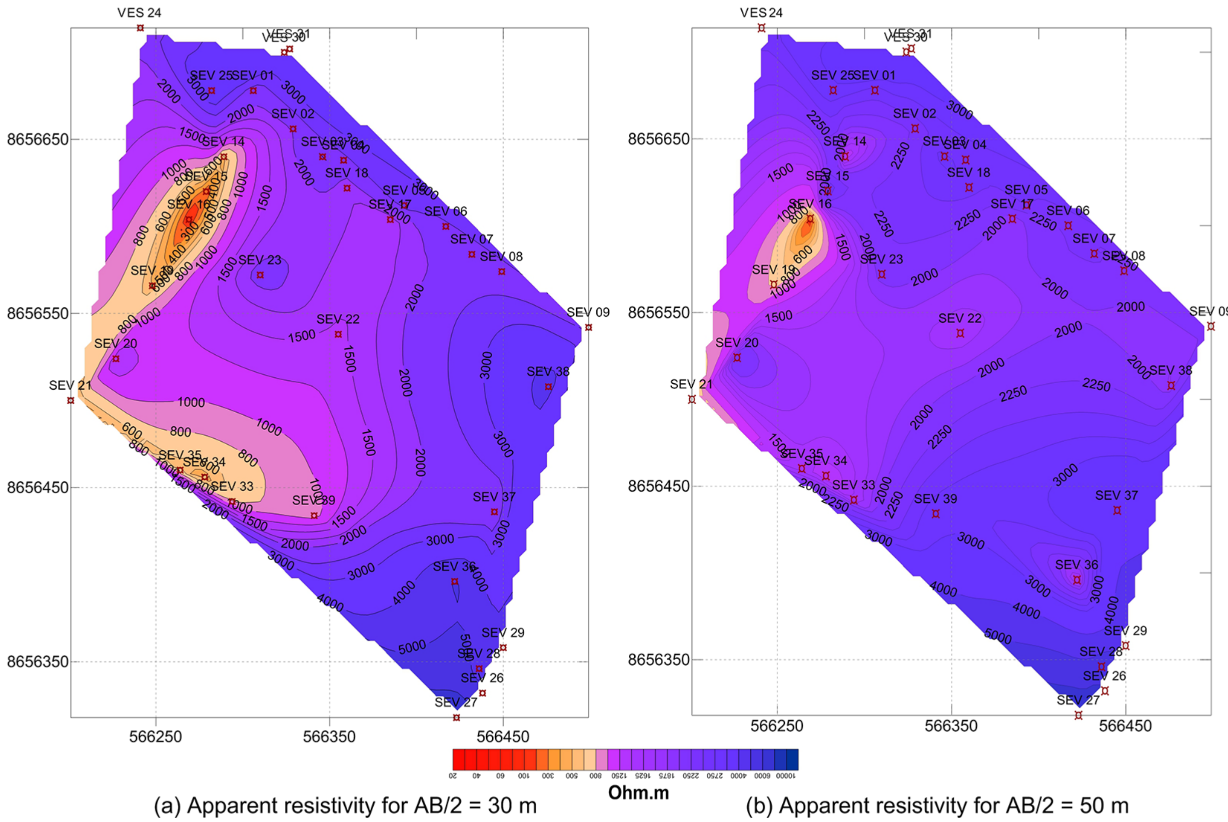

Figure 5 – Apparent resistivity maps for AB/2 = 30 m and AB/2 = 50 m, showing the near-surface anomalies due to rain-infiltration through the study area.

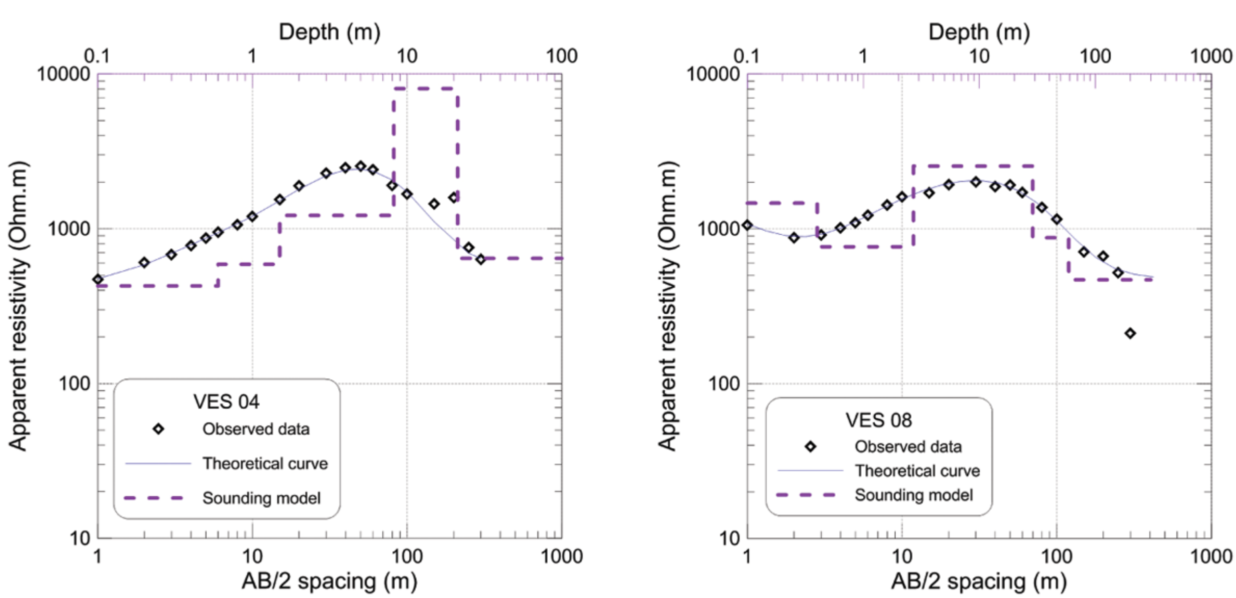

Figure 6 – Examples of representative electrical soundings obtained in this case study.

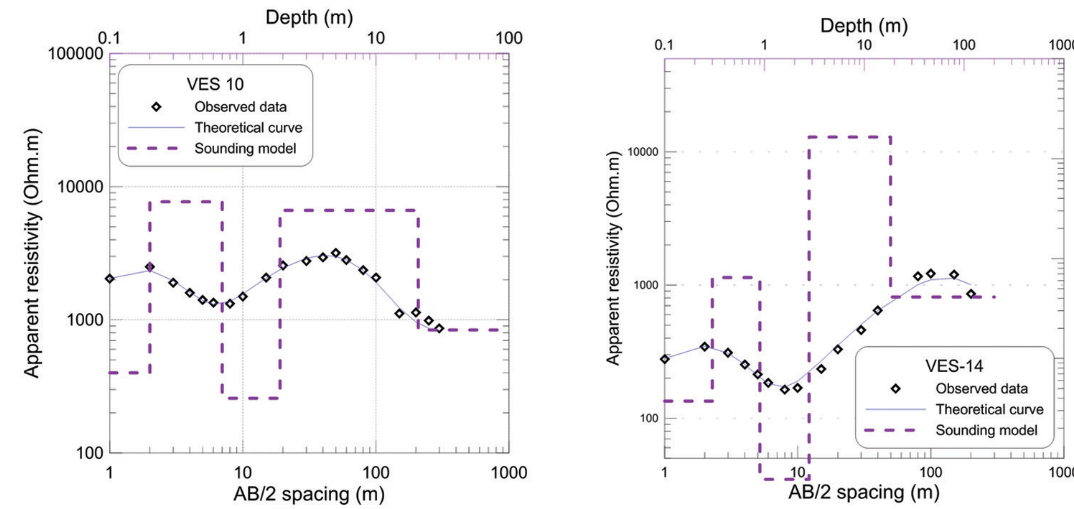

Figure 7 – Examples of representative electrical soundings obtained in this case study.

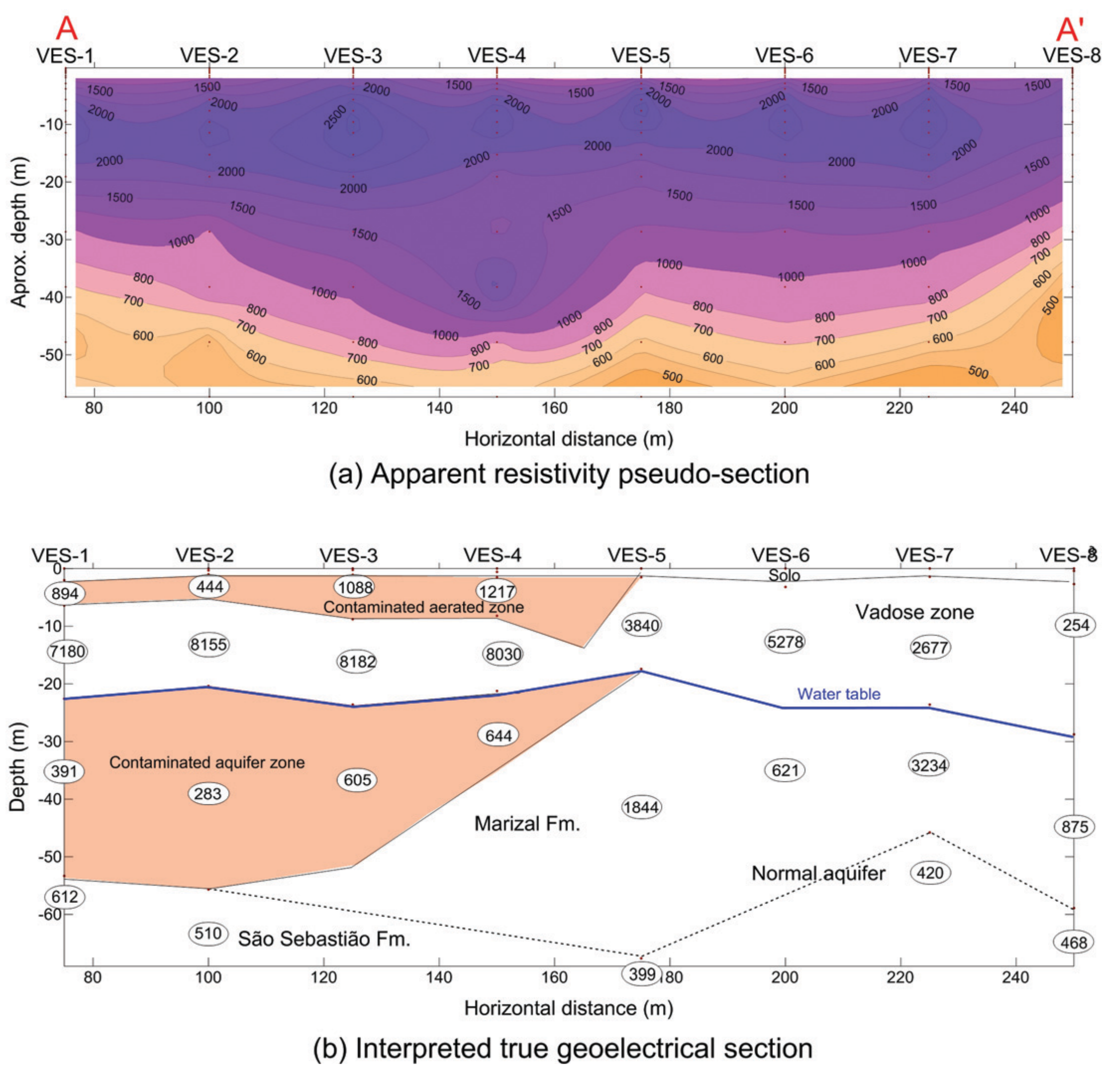

Figure 8 – Apparent resistivity pseudo-section and interpreted geoelectrical section along transverse A – A'.

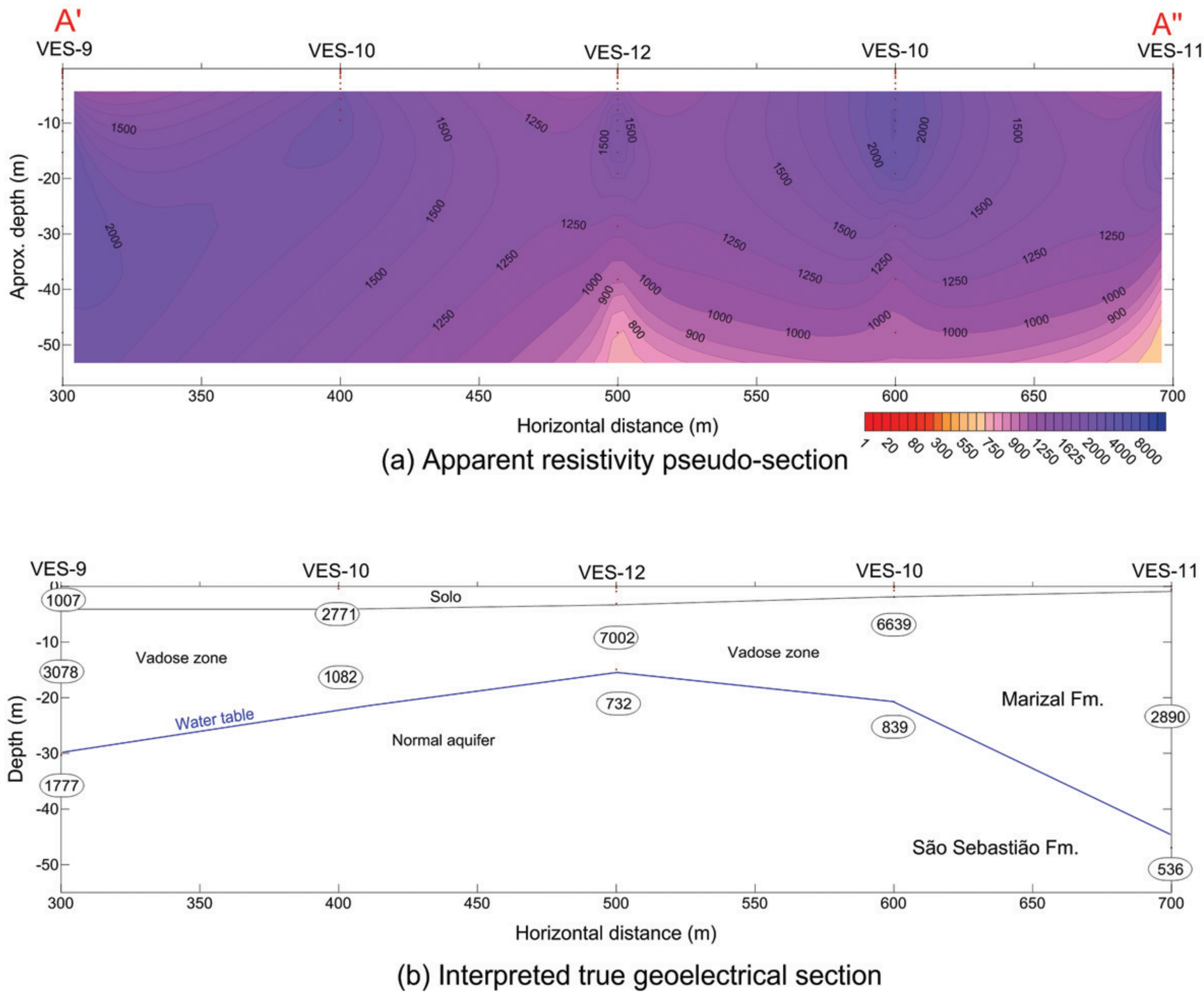

Figure 9 – Apparent resistivity pseudo-section and interpreted geoelectrical section along transverse A' – A".

The pseudo-resistivity section and the true resistivity section of C-C' transverse line (Fig. 11), located at the back of the cemetery, contains some VES centered within the burial area. Note the limited extension of the electrical anomaly characterized by a decrease in apparent resistivity with depth. However, unlike section A-A', the upper section is much more conductive. The true resistivity distribution indicates the presence of concentrated zones of necrosis in the most superficial underground slurry.

The data and results for line D-D' (Fig. 12), similar to the second segment of A-A', also shows a condition of normal aquifer saturation, without any contamination related to the cemetery.

CONCLUSION

The collected geological and geophysical data show that the area surrounding the Alagoinhas cemetery is represented by the water table aquifer component of the São Sebastião aquifer system, with about 90 m of thickness. It consists, largely, of thick shaly sandstone packages of Marizal and São Sebastião formations. On the site, this component has a thick vadose zone, which can vary from 25 to over 30 m thick.

The geoelectrical survey results allow defining underground contamination zones within the aquifer and in its vadose zone, with an extent limited to the area of the cemetery. The presence of a low resistivity layer of higher saturation near the surface represents a layer of necrochorume diluted by the rains, infiltrated before and during the geophysical survey. A thick vadose zone, having low saturation index, can help in reducing the deleterious effects of this contamination, by retaining metals and microorganisms at the clays surfaces disseminated in the sandstones. In the aquifer, the recharge by infiltrating produced a more conductive liquid plume, with an estimated thickness of about 30 m.

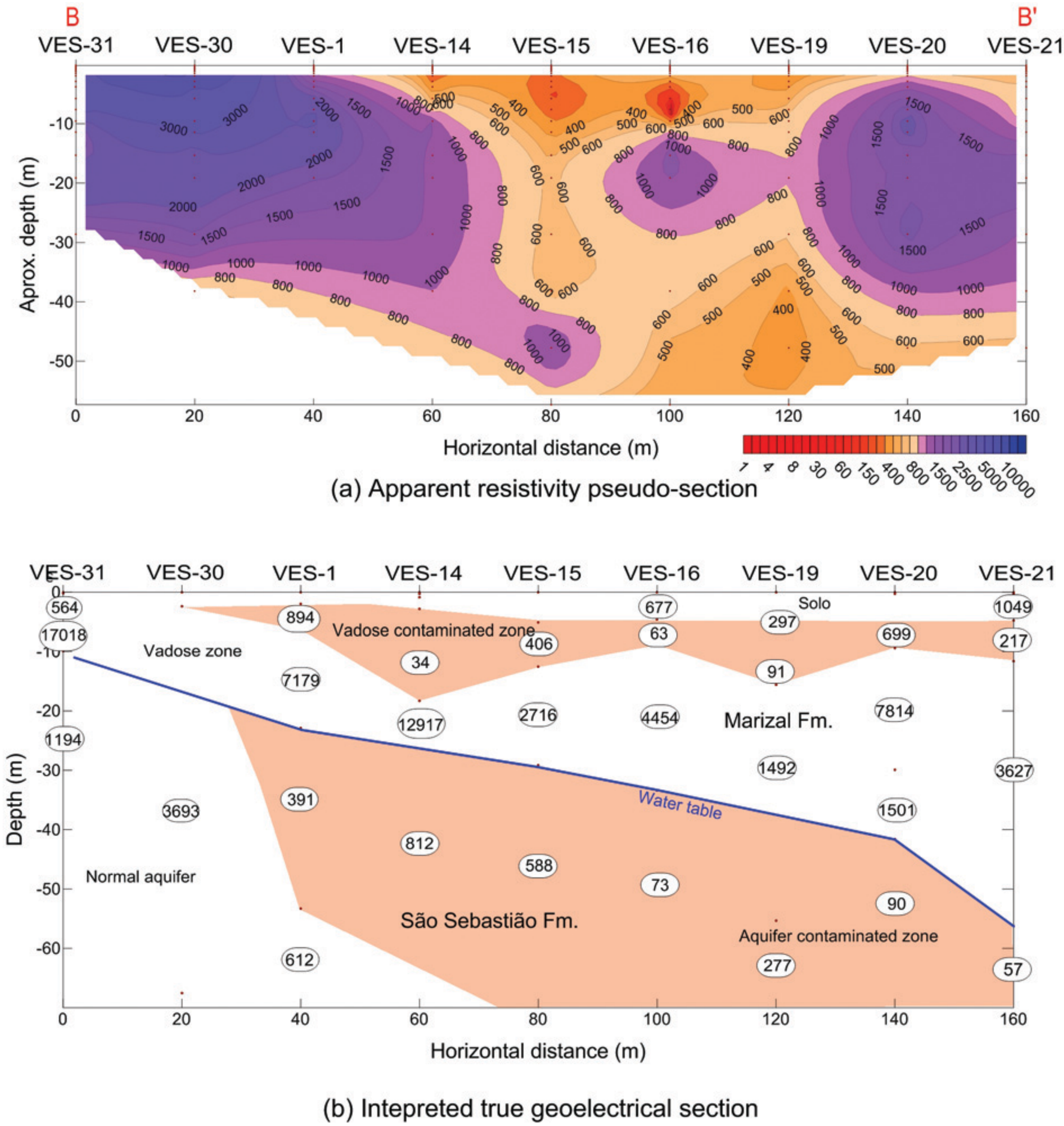

Figure 10 – Apparent resistivity pseudo-section and interpreted geoelectrical section along transverse B – B'.

No physic-chemical data are available to evaluate the intensity and dangers of this contamination. However, based on Archie's law and assuming the water as a NaCl solution, the electrical resistivity data suggest an increase in the water salinity by a factor of 4, in the contaminated nucleus.

The water table variation observed in some profiles are, in part, related to terrain topographic changes, but some may be attributed to lateral facies changes within the Marizal sandstones, causing local variations in the sandstone permeability.

Since there are two production wells yet exploiting the aquifer in the vicinity of the cemetery it is recommended to perform a systematic monitoring of the water produced by measuring physical, chemical and biological properties as a function of time. This is required because, in continuous operation, the expansion in the

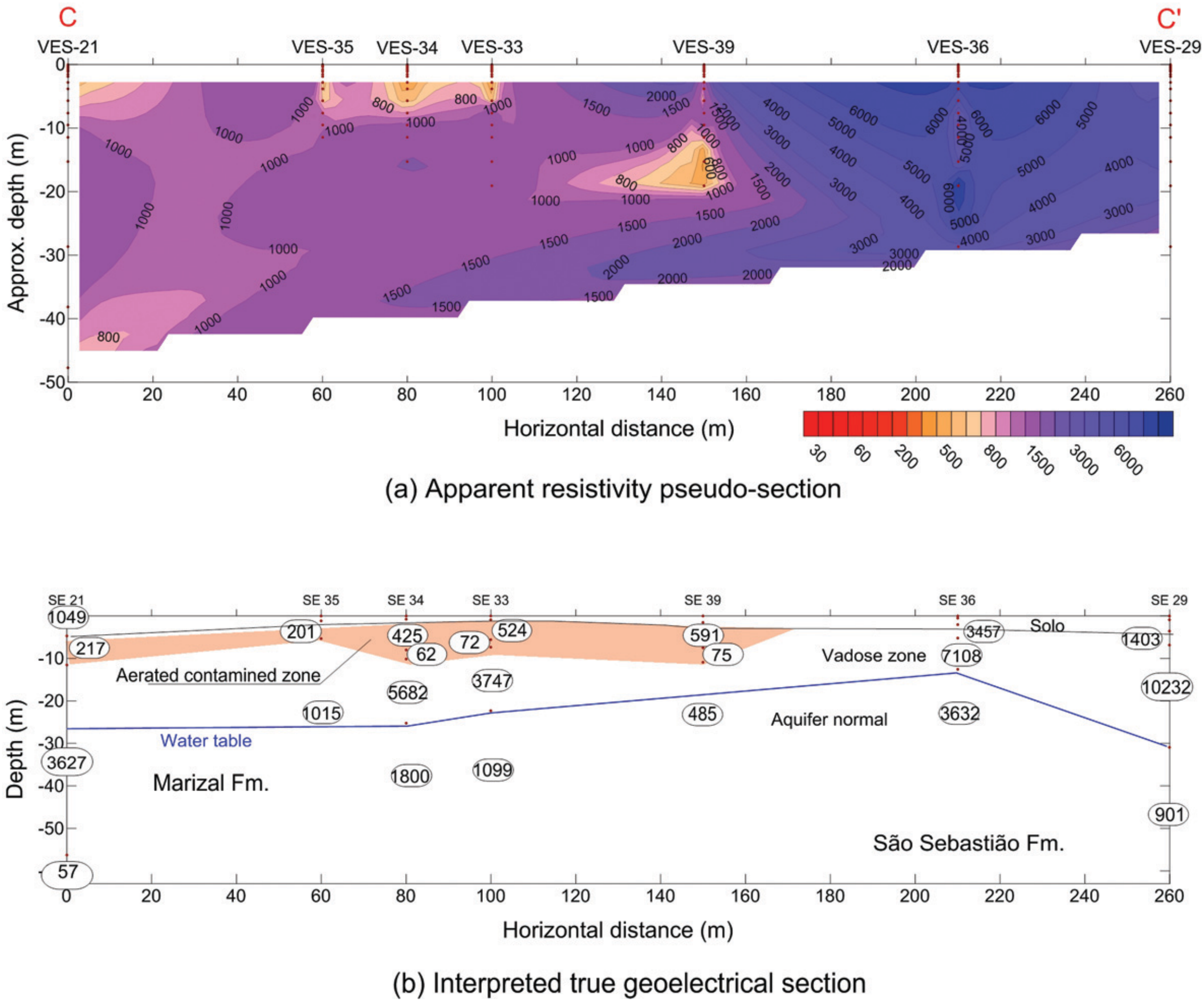

Figure 11 – Apparent resisitivity pseudo-section and interpreted geoelectrical section along transverse C – C'.

radius of influence of the well may eventually reach the plume and the well may begin to produce a mixed water of increase proportion of contaminant.

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REFERENCES

CASTRO DL. 2008. Caracterização geofísica e hidrogeológica do cemitério Bom Jardim, Fortaleza – CE. Brazilian Journal of Geophysics, 26(3): 251–271.

CAVALCANTI SS. 1999. Hidrologia Subterrânea na área do aterro sanitário de Salvador usando métodos geofísicos elétricos. Master Dissertation, Universidade Federal da Bahia, Salvador, Brazil. 71 pp.

CETESB – Companhia Ambiental do Estado de São Paulo. 1999. Manual de Gerenciamento de Áreas Contaminadas. Programa CETESB/GTZ, São Paulo, Brazil.

GALLAS JDF, TAIOLI F, SILVA SMCP, COELHO OGW & PAIM PSG. 2005. Contaminação por chorume e sua detecção por resistividade. Brazilian Journal of Geophysics, 23(1): 51–59.

GHIGNONE JI. 1979. Geologia dos Sedimentos Fanerozóicos do Estado da Bahia. In: Geologia e Recursos Minerais do Estado da Bahia, Textos Básicos, SME/CPM, 1. Brazil.

GOOGLE. 2014. Google Earth. Available on: <https://earth.google.com>. Access on: September 24, 2014.

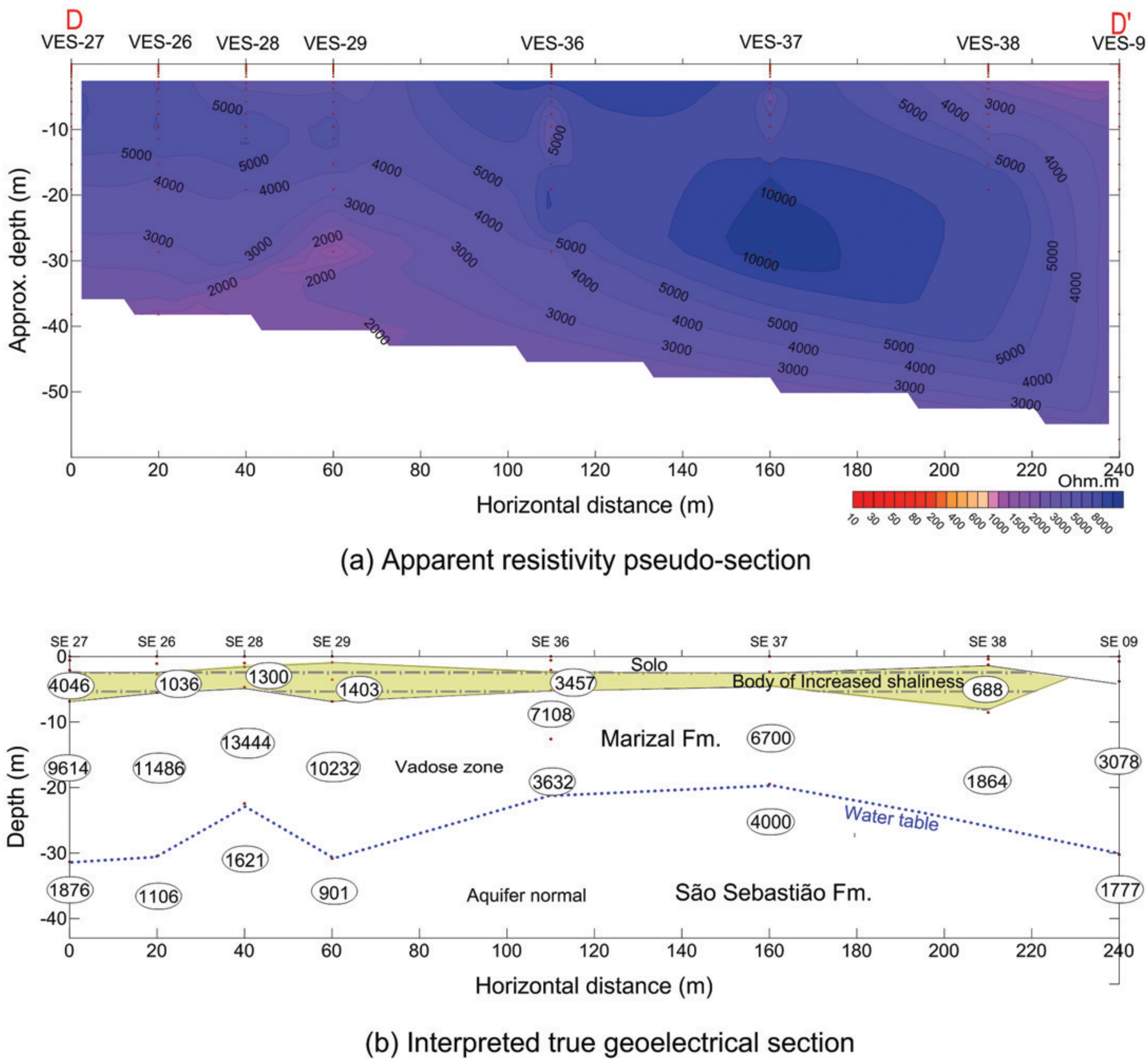

Figure 12 – Apparent resisitivity pseudo-section and interpreted geoelectrical section along transverse D – D'.

IBGE – Instituto Brasileiro de Geografia e Estatística. 2010. Available on: <http://www.ibge.gov.br>. Access on: March 1, 2011.

LIMA AOL. 1999. Caracterização hidráulica e padrões de poluição no aquífero Recôncavo na região de Camaçarí-Dias D'Ávila. Tese de Professor Titular, Universidade Federal da Bahia, Salvador, Brazil.

LOKE MH. 2001. RES1D ver. 1.0 for Windows 95/98/ME/2000/NT – 1-D resistivity, IP & SIP inversion and forward modeling, 1-12.

LOKE MH. 2013. Tutorial: 2-D and 3-D electrical imaging surveys. Geotomo Software.

PEREIRA PA & LIMA OAL. 2007. Estrutura elétrica da contaminação hídrica provocada por fluidos provenientes dos depósitos de lixo urbano e de um curtume no município de Alagoinhas, Bahia. Brazilian Journal of Geophysics, 25(1): 5–19.

PORCIÚNCULA RJP. 2007. Aplicação do método eletrorresistivo na avaliação geoambiental da região de Alagoinhas, Bahia. Undergraduate dissertation, Universidade Federal da Bahia, Salvador, Brazil, 64 pp.

PORCIÚNCULA RJP. 2011. Avaliação Geofísica da contaminação subterrânea em posto de combustíveis e serviços, Alagoinhas-BA. Master Dissertation, Universidade Federal da Bahia, Salvador, Brazil.

SILVA RWC & MALAGUTTI FILHO W. 2009. O emprego de métodos geofísicos na fase de investigação confirmatória em cemitérios contaminados. Revista de Engenharia Sanitária Ambiental, 14: 327–336.

SILVA RWC, MALAGUTTI FILHO W & MOREIRA CA. 2009. Emprego do método da eletrorresistividade no estudo da contaminação subterrânea do cemitério municipal de Vila Rezende, Piracicaba – SP. Brazilian Journal of Geophysics, 27(3): 389–399.

UÇISIK AS & RUSHBROOK P. 1998. The impact of cemeteries on the environment and public health, WHO: Regional Office for Europe, pp. 1–11.

VANDER VELPEN BPA & SPORRY RJ. 1993. RESIST a computer program to process resistivity sounding data on PC compatibles. Computer & Geosciences, 19(5): 691–703.

VIANA CF, GAMA JUNIOR EG, SIMÕES IA, MOURA JA, FONSECA JR & ALVES RJ. 1971. Revisão estatigráfica da bacia Recôncavo-Tucano. Boletim Técnico da Petrobras, 14(3/4): 157–192.

WARD SH. 1990. Geotechnical and Environmental Geophysics, vol. II, Society of Exploration Geophysicists. 352 pp.

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