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Geoelectrical characterization with 1D VES/TDEM joint inversion in Urupês-SP region, Paraná Basin: Applications to hydrogeology

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ABSTRACT

Although Brazil is well known by the large rivers and the Amazon Rain Forest most cities do not have access to sufficient quantities of surface water to supply the population. Because of this 61% of Brazilian population (IBGE, 2003) depends on groundwater resources. In order to help the conscious exploration of this resource in Urupês city (São Paulo State) which is characterized by problems of lack of water, this research applied the transient electromagnetic method (TDEM) and Vertical Electrical Sounding (VES) for the geoelectrical characterization of the interest region. So, the objective of this work was increase the hydrogeological basis for groundwater exploitation of Bauru sedimentary aquifer and Serra Geral fractured aquifer (Paraná Basin). A total of 23 TDEM and 15 VES soundings were conducted during the years of 2009, 2011 and 2012. In addition, 10 pairs of VES/TDEM soundings were acquired with coincident centers to be able to perform the joint inversion. The joint inversion technique is a promising tool, which enables to get the best of both methods, where the VES add the shallow information and TDEM the deeper one. In this work, the individual and joint inversions were performed using the "Curupira" software. After data process and inversion, the results were interpreted based on geological well information provided by the Department of Water and Electrical Power (DAEE) and the Brazilian Geological Survey (CPRM) which enabled to estimate favorable places to exploitation of water in Bauru and Serra Geral aquifers. For the Bauru aquifer, the results suggest areas where thickness exceeds 100 m. In these areas, the resistivity calculated was about 20 Ω·m. Therefore, the sediments have been interpreted as saturated sandy clay. In the basalt layer of Serra Geral Formation, the suggested locations present resistivity values <100 Ω·m at ~200 m depth. The indicated places in sedimentary aquifer and the locations in the fractured aquifer will may show alternative sources for groundwater exploitation and water supply for Urupês city.

1. Introduction

In recent years, the interest in water resources in Brazil has increased, mainly by the expansion of agriculture and the growth of some cities that demand a greater amount of fresh water. In São Paulo State much of the consumed water is supplied from sedimentary aquifers (Bauru Aquifer, Guarani, São Paulo, Taubaté and others). The most important and also the more difficult to access is the Guarani aquifer, which can reach 1300 m (top) in Presidente Prudente region. Due to the higher depths in most of its extension (Guarani aquifer), many cities choose to explore the Bauru aquifer of the Adamantina Formation (shallower). In this aquifer, the sustainable flows are around 10 m^3/h, with the exception of some cities near São José do Rio Preto, with sustainable flows near to 40 m^3/h (Iritani and Ezaki, 2009).

In this context, Urupês city is in the Northwest of São Paulo State in the Paraná Basin. To construct wells, it is recommended geological and geophysical studies to reduce the uncertainties involved in the drilling process. Electrical and electromagnetic methods can contribute to find new points for water exploration. With these methods, it is possible to obtain an electrical resistivity model as a function of the depth which can be associated with a given geological model. This association is related to the concept that different minerals have different associated resistivity and therefore, it is possible to infer a geoelectric model in subsurface.

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In this work, the Vertical Electrical Sounding (VES) and the Time Domain Electromagnetic (TDEM) sounding were the geophysical methods used to estimate the electrical resistivity distribution in the underground. In the studied area, the VES investigates shallow depths (the first) effectively and has good sensitivity to estimate the top of shallower and resistive layers. The TDEM sounding can define well the interface between resistive and conductive layers, and has a great capacity to define deeper structures. In terms of sensitivity, the two methods are complementary. The VES defines better the shallow and resistive structures and TDEM defines well the deeper and conductive structures (Schmutz et al., 2000). Therefore, the integration of the two methods is a good option to reduce the ambiguities inherent to the results interpretation. Therefore, the integration of the two methods is a good option to reduce the ambiguities inherent to the results interpretation.

Jointly invert data sets is not a simple task, but the benefits from this technique are very promising. The results are better defined because the database is greater (Raiche et al., 1985; Bortolozo, 2011, Bortolozo et al., 2014a, 2014b, Bortolozo et al., 2015a, 2015b). Some researchers such as Albouy et al. (2001) and Schmutz et al. (2000), showed how the joint inversion reduced the uncertainty of parameter determination, becoming a great tool to infer the resistivity and thickness of a geological model.

In short, this study aims to define a local insight of the geology of Urupês region through borehole information, VES and TDEM methods. With the results, it is expected to define the most promising areas for groundwater exploitation in the sedimentary aquifer (Bauru) and in the fractured aquifer (Serra Geral).

2. Geological settings

The study region is in the Paraná sedimentary basin and it is constituted mainly by three formations: Adamantina, Serra Geral and Botucatu Formations. The Adamantina formation is characterized by sand sediments with almost 90 m thickness, intercalated by clays and sand lens. Usually, this formation is associated to Bauru aquifer, which is an important water reservoir in São Paulo State. Below Adamatina formation, there is the Serra Geral formation characterized by basalt rocks. In some areas, the basalt can be fractured and filled with water (Serra Geral aquifer). According to deep wells information in the studied region, the thickness of this layer is between 400 m to 600 m (Porsani et al., 2012). The last formation is Botucatu which is formed by sandstones rocks and host the Guarani Aquifer, the most important groundwater reservoir in South America. In the Table 1 below the geological profiles of eleven wells are shown.

Table 1
Location and stratigraphy of wells in Urupês city (http://siagasweb.cprm.gov.br/layout/index.php).

Wells (location)	Geological description (m)
P1 – Rural road	0 to 40 – Adamantina Fm. 40 to 75 – Serra Geral Fm.
P2 – Rubens Celso Tortola Av.	0 to 60 – Adamantina Fm.
P3 – Gustavo Martins Siqueira St.	0 to 80 – Adamantina Fm.
P4 – Rural road	0 to 60 – Adamantina Fm.
P5 – Barão do Rio Branco St.	0 to 100 – Adamantina Fm. 100 to 130 – Serra Geral Fm.
P6 – Domingos Logulo St.	0 to 90 – Adamantina Fm. 90 to 152 – Serra Geral Fm.
P7 – Near to Slaughterhouse	0 to 45 – Adamantina Fm. 45 to 78 – Serra Geral Fm.
P8 – Near to Guaripú Stream	0 to 47 – Adamantina Fm. 47 to 80 – Serra Geral Fm.
P9 – Antônio Carlos Logulo St.	0 to 73 – Adamantina Fm. 73 to 151 – (crystalline rock)
P10 – City hall	0 to 104 – Adamantina Fm. 104 to 158 – Serra Geral Fm.
P11 – Madeira Stream	0 to 47 – Adamantina Fm. 47 to 74 – Serra Geral Fm.

3. VES and TDEM data acquisition and processing

Fifteen TDEM soundings and twelve VES soundings were acquired in three field campaigns conducted in 2009, 2011 and 2012. TDEM soundings were carried out with PROTEM-57-MK2 (Geonics) that allow working in three different frequencies (30 Hz, 7.5 Hz and 3.0 Hz). Data were acquired using a square central loop of 100 m side, current of 28 A. The total time for each frequency was 360 s, in this way it was possible to obtain a good signal/noise ratio.

The VES data was acquired with SYSCAL-R2 (Iris Instruments) in Schlumberger array and AB/2 length up to 200 m. All VES soundings were acquired in center of the TDEM receiver coil, to guarantee the same 1D model investigated by each VES/TDEM pair and to proceed the joint inversion. The data were statistically reduced and processed to avoid misleads in the geophysical response of each method.

The static-shift present in the VES data was corrected using the Static_Shift_Correction, a program developed in the Geophysics Department. Details about the static-shift formulations can be found in Meju (2005). Then, the data were inverted in Curupira program (Bortolozo and Porsani, 2012), which totalizes ten joint inversions.

4. VES/TDEM joint inversion

Typically, VES and TDEM data are inverted separately, based in 1D geoelectrical models. This process, although classical, carries ambiguity when results are interpreted, because they investigate the subsurface in different ways. The ambiguity present in geophysical interpretations can normally be caused by the fact that most of the geophysical problems are poorly determined. Therefore, the parameter determination is non-unique, which means there are more than one solution for the same parameter. One way to minimize this ambiguity is to bring in additional information (or data) to the problem, which in this case can be provided by joint inversion.

The joint inversion process applied here was the same applied in Bortolozo et al. (2014a, 2014b) and Bortolozo et al. (2015a, 2015b). In those works are described in details how the joint inversion process works and even how the physics of the problem can weigh the contributions of both methods in the final model. Also, those articles explain the majors advantages of the joint inversion scheme used in this paper. In Bortolozo et al. (2015a,b) the author uses the Residual Function Dispersion Maps technique (Bokhonok, 2011; Bokhonok et al., 2013; Bortolozo and Bokhonok, 2015; Bokhonok et al., 2015) to understand the topological aspects of the objective functions of the VES, TEM and joint inversion cases. The result with this study shows how the combine objective function behaves. In a simpler and schematic form, the idea of the joint inversion can be explained by Fig. 1.

If only one method was used, the solution space could admit a large number of mathematical solutions, i.e., any of the points present in space A or B could satisfy the data set. As both methods work with the electrical resistivity property, it is natural that there is a solution space that satisfies both data sets. This space can be defined by the intersection of the spaces A and B, represented by C in Fig. 1. Note that this space restricts the number of possible solutions. The advantage of joint inversion is in reducing the space solutions allowing the parameter estimation to be more reliable. In this work, the process of VES/TDEM inversion was carried out with the "Curupira" software (Bortolozo and Porsani, 2012) that allows the inversion of VES and TDEM data jointly and separately. Is possible to define some weight values for the soundings, but this option was not used in this research.

5. Discussion of the joint inversions results

The results presented in this section correspond to five different areas (A, B, C, D and E) as shown in Fig. 2. For each area, the most representative results of the 1D joint inversion are presented.