STRUCTURAL AND GEOPHYSICAL SURVEY IN THE IDENTIFICATION OF FAVORABLE AREAS FOR GROUNDWATER EXPLORATION IN FRACTURED AQUIFER

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Abstract

The inherent structural complexity of fractured aquifers, which controls the groundwater accumulation and flow in restricted zones, can lead to a high number of non-productive wells This paper deals with regional and local structural surveys coupled with electrical resistivity tomography data in order to identify favorable targets for groundwater exploitation for urban consumption in a fractured granite.The results show a triple fracture intersection pattern also recognized in satellite images, which are highly favorable for groundwater accumulation and exploitation.

Introduction

The universalization of the public water supply system in Brazil is a reality based on massive public investments and public-private partnerships. However, an issue of great relevance is the average loss of 38% of water throughout the distribution system, due to its extension and complexity, lack of maintenance, system degradation, clandestine connections, among other aspects (SNIS, 2018). An alternative to extensive and inefficient public supply networks is the use of independent water collection systems. In regions lacking surface water sources or peripheral to the usual public supply systems, underground water sources can be a highly viable technical and economic alternative (Balek, 1989). However, fractured aquifer systems are considered particularly complex, due to the condition of water storage and transmission along the fractured planes. The intrinsic structural complexity of fractured aquifer systems often results in the predominance of dry wells or wells with insufficient flows to meet human demands. In this sense, the identification of favorable sites to groundwater accumulation of is the geomorphological interpretation of aerial photographs and satellite images, combined with geological fieldwork and geophysical surveys (Brassington, 2007). The use of Electrical Resistivity Tomography (ERT) allows two-dimensional underground investigations, which may reveal potential fractured rock aquifers. A particularly challenging paradigm is the adaptation of a geophysical survey method with mathematical formulation based on isotropic and homogeneous media for use in highly anisotropic and heterogeneous media (Rubin and Hubbard, 2005). This work presents and discusses the results obtained through geological and structural analyses, combined with ERT surveys for the identification of areas favorable to the extraction of groundwater in a small village located in southern Brazil, which has restricted surface water resources. The acquisition of geoelectrical data and the generation of pseudo 3D models from 2D inversion used in this study aims to recognize structural alignments at different depths, which represent potential targets for groundwater exploration..

Metodology

The study area is located on a rural property six kilometers north of the center of Caçapava do Sul (RS) (Figure 1). Geologically, the study area is part of the Caçapava do Sul syntectonic granitic suite, contained in the Western Domain of the Sul-Rio-Grandense Shield (CPRM, 2000). Syntectonic granitoids invaded the metamorphic units of the Western Domain and present mylonitic foliation with NNE orientation. In the eastern center of the study area there is a lagoon that was excavated until it came into contact with the granitic rock. It is believed that the fractured aquifer system and the lagoon can be recharged by the free aquifer, since during the dry season it remains with water. Generally, the flows produced by the wells are small, and the water, due to the lack of circulation and the type of rock, is, in most cases, salinized (PMSB, 2013). Wells usually have specific capacities below 0.5 m³/h/m, and dry wells also occur (Machado & Freitas, 2005).

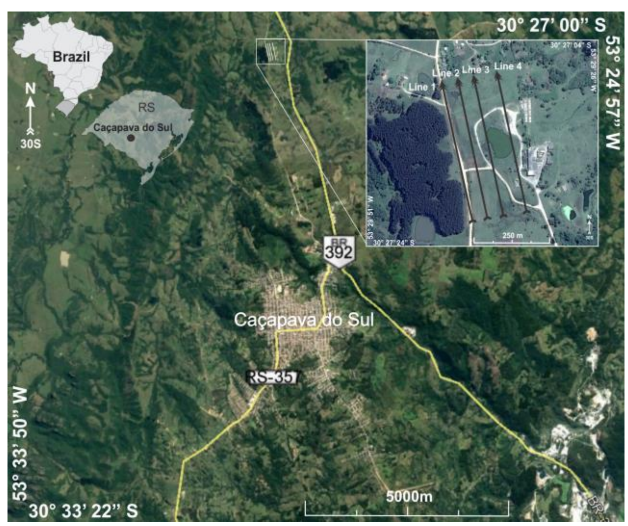

Figure 1 - Location of the study area and layout of the geophysical lines.

The acquisition of geophysical data consisted of electrical resistivity readings using the electrical resistivity tomography (ERT) technique in a Wenner-Schlumberger arrangement. This configuration tends to have more sensibility and favor the representation of lateral variations, being more suitable for the identification of conductive (low resistivity) vertical structures or zone. Four parallel lines oriented in the N282 direction with individual length of 420 m and spacing of 10 m between the electrodes were used (Figure 1). The geophysical equipment used was the Terrameter LS, manufactured by ABEM Instrument (Sweden). The measurements acquired in the field were processed in the computer program Res2Dinv. The numerical data of two-dimensional inversion of each section were gathered in a single worksheet, which gathers the position of the readings along the survey lines (variable "x"), spacing of the lines (variable "y"), depth modeled by inversion (variable "z") and the electrical resistivity value (variable "R"). This worksheet was used to generate 3D visualization models, which allowed better interpretations.

Results

Initially, the results are based on regional geomorphological lineaments interpreted from satellite images that reveal a similar pattern in both the granitoid rocks and the surrounding metamorphic complex. Fracture orientations were extracted from satellite images and integrated with rock exposure measurements and assembled into a diagram (Figure 4), which indicates predominant orientation towards N315°, with fracture groups in the N350° and N50° directions less frequently

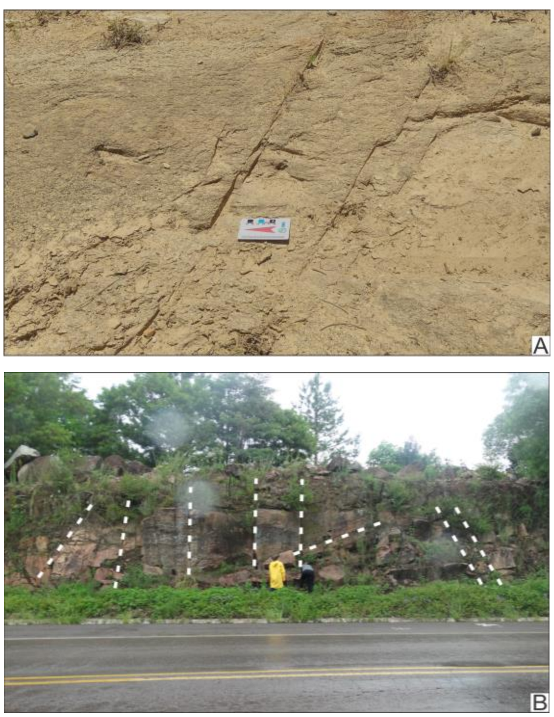

Figure 2 - Geological features identified in the structural survey: 2A) fractures in sandy saprolite 2B) fractures in granite massif

The resistivity models generated from the ERT data are presented on a logarithmic scale to allow a comparative analysis between the sections and the range of resistivity values varied from 11 Ωm to 51.851 Ω.m. The inversion models are characterized by a surface layer with resistivity values lower than 100 Ω.m with significant thickness variation, but limited between the range of 0m and 40m, which possibly reflects the regolith profile. This large variation in the thickness of this surface layer reflects a selective action of weathering processes and alteration of the granitic rock. The deeper portions of the profile are related to the ease of infiltration of rainwater in the fractured zones and consequent hydration of minerals such as feldspars and micas. The shallower portions, more resistant to chemical weathering, are made up of non-articulated or moderately articulated rock masses, with a predominance of quartz in the rock matrix. Portions of the rock mass with resistivity values lower than 40 Ωm may indicate greater permeability, with accumulation of groundwater and/or rocks enriched in weathered minerals such as biotite and feldspar, which locally result in concentrations of clay minerals in the fractures. Resistivity values greater than 1,000 Ωm indicate the presence of loose and moderately weathered rock masses (Figure 3).

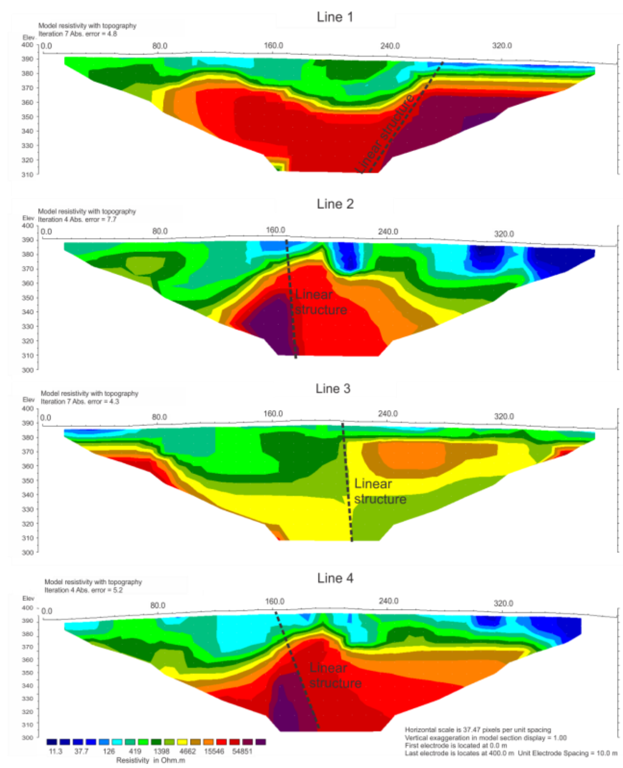

Figure 3 - Electrical resistivity inversion models with interpretation of linear features (fractures) related to geological structures

The orientation and slope of the fractures interpreted in the profiles of Figure 3 are consistent with the structural pattern described during the preliminary geological reconnaissance phase. Although contained largely within highly resistive zones, with the exception of Line 3, this set of geological fractures possibly presents a connection with the weathering mantle and, consequently, with the free aquifer. To evaluate the lateral continuity and possible connectivity of the fractures recognized in the 2D sections, 3D visualization models were created and resistivity maps were generated for different depths (Figure 4). The elevation maps from 385m to 365m show a reduction in areas of low resistivity and an increase in areas where saprolitic rock and granitic rock with different degrees of chemical weathering may predominate. From the elevation of 355m, there are indications of possible linear features that form a triple junction pattern of lineaments oriented in the directions N104, N205 and N325. This characteristic is more evident in the maps of the 345m and 305m elevations. The resistivity pattern found in Line 3, where values below 4,500 Ωm predominate, is essentially related to the orientation of this line along a possible saturated geological fracture. This resulted in a relatively homogeneous pattern, different from the average values for the granitic rocky horizon of the other sections, which is above 15,000 Ω and below the 355m elevation. Figure 5 compares the pattern of the drainage network in the study region, with anomalous zones of resistivity in the study area for 60m depth in this study. As can be seen from the satellite image, there is a high correlation of these drainage patterns at different scales. The intersection area between the structural alignments represents the most favorable locations for the exploitation of groundwater.

Discussion and Conclusions

Geological fractures are essential features for the storage and movement of groundwater along rock massifs. The expression of these landforms on the topographic surface is not always evident. The joint analysis of geomorphological and structural aspects, both locally and regionally, are essential for the programming of geophysical surveys aimed at hydrogeological studies. The electrical resistivity tomography technique is particularly relevant in the identification of geological discontinuities that can serve as pathways for the accumulation and movement of groundwater. However, this work revealed a particular case, in which the geological structures identified in the 2D inversion models, similar to those described in rock exposures, would, in principle, be unfavorable for hydrogeological purposes due to the apparent lack of connectivity of the structures. Fracture system connectivity was clearly highlighted in the pseudo 3D models. Below 40m depth, low resistivity values (about 500Ωm), aligned in three well-defined directions, were detected adjacent to high resistivity values (> 15,000Ωm), which indicate the presence of saturated fractures. Similar structural features are recognized in the drainage network around the study area to which the water sources are associated. The low number of producing wells for groundwater exploration in fractured rocky aquifers can be substantially increased by the integration of traditional geological analyzes at different scales and geophysical research tools.

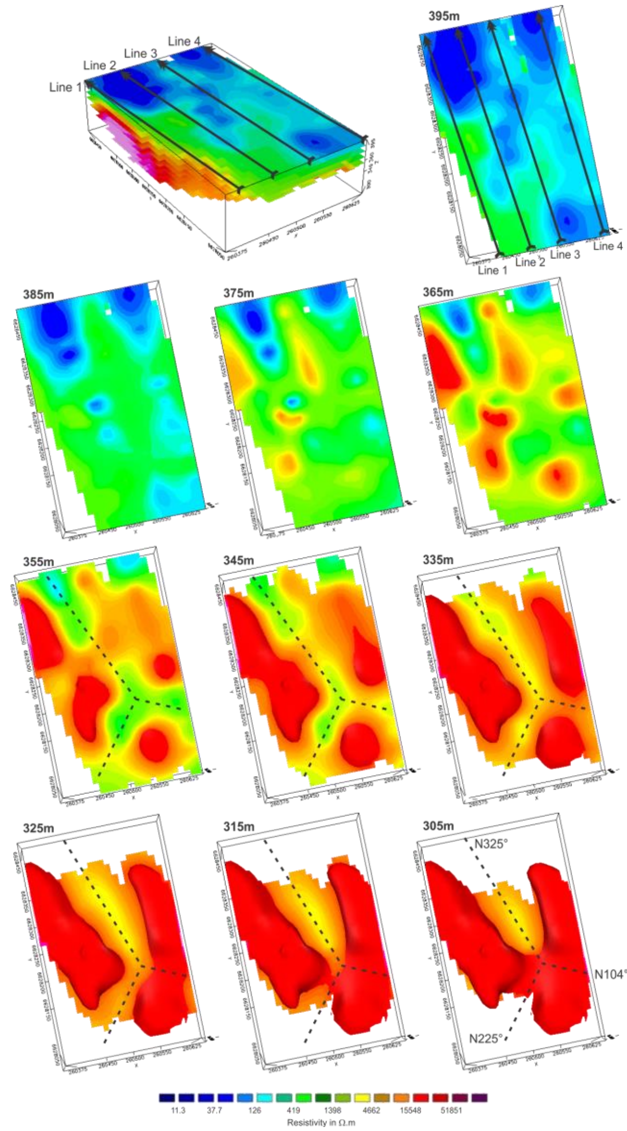

Figure 4 – Electrical resistivity inversion models with interpretation of linear features (fractures) related to geological structures.

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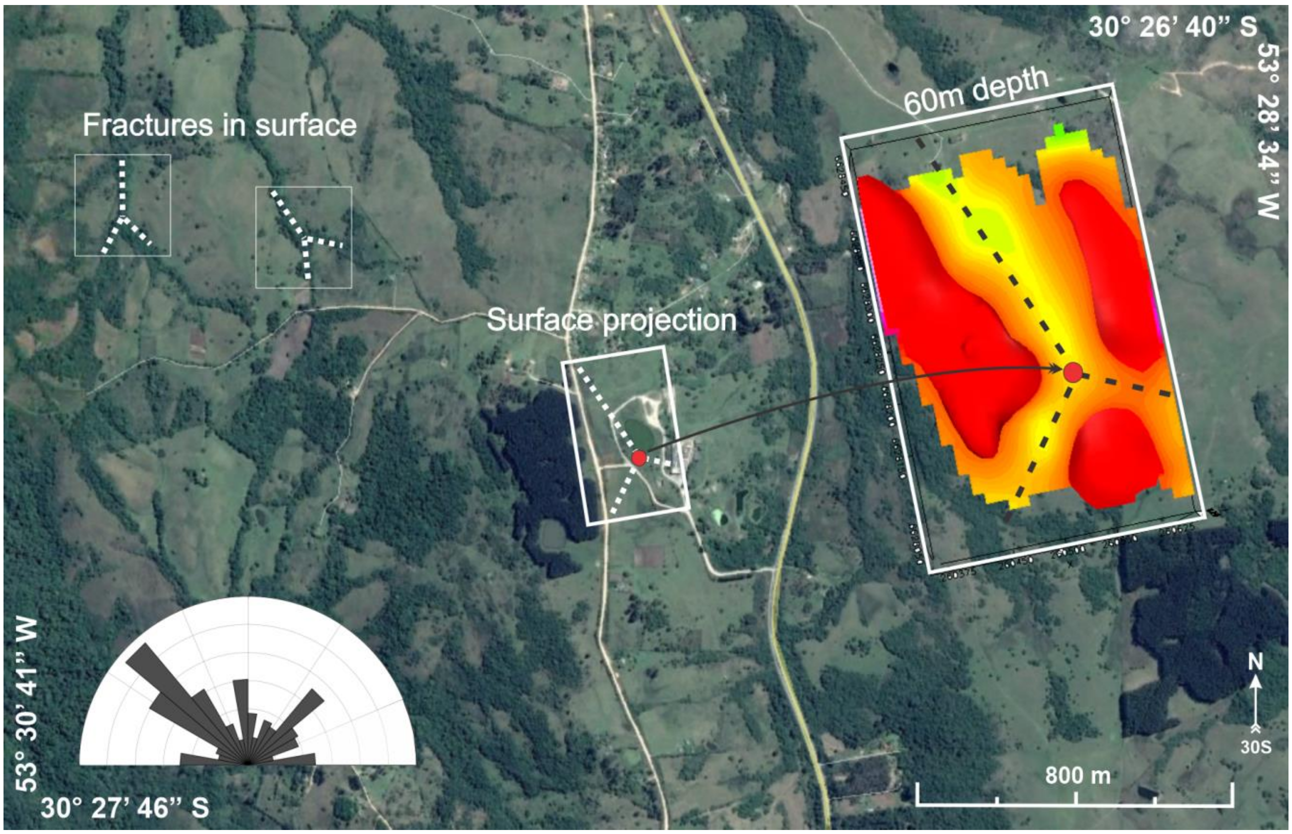

Figure 5 - Drainage pattern similar to the triple junction geophysical anomaly recognized in this study, with most favorable area for groundwater exploitation (red dot).