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Integration of geophysical methods to characterize a critical zone relevant for water supply of São Paulo state, Brazil: Preliminary results

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Abstract Summary

Studies indicate that pollution and deforestation in Critical Zones are the main factors that contribute to the development of socio-environmental problems, such as prolonged droughts, food supply and hydroelectricity crises. The State of São Paulo is the most populous in Brazil and highly susceptible to water crises.

- In this work, preliminary results are presented from a research that aims to integrate geophysical and hydrogeological data to characterize the underground water resources of a hydrographic microbasin located in a strategic area for São Paulo's water supply.

- The first ERT and GPR profiles show promising results and suggest the occurrence of an unconfined aquifer system consisting of a thin regolith and a fractured crystalline rock.

Introduction

Factors such as global pollution, population growth, uncontrolled urbanization and changing consumption patterns have contributed to increasing the global demand for water and accentuating episodes of water crises (ONU, 2024). Regions with the greatest economic and productive development are usually areas with low water security due to the high demand for water for public supply, industries and irrigation. Brazil's Southeast region is the most populous and accounts for only 6% of the country's water resources. In this region is the state of São Paulo, where around 22% of Brazil's population live, comprising a very vulnerable area to water crises (Stariolo and Nogueira, 2023).

Over the past few decades, São Paulo's population has experienced water supply (Coelho et al., 2016) and hydroelectricity crises (Hunt et al., 2022), both resulting from prolonged periods of water scarcity. In addition to climate change that contributes to accentuating the intensity and frequency of drought and heavy rainfall events (National Geographic Brasil, 2024), the state of São Paulo also faces problems associated with water quality: important sources of surface water, such as the Pinheiros and Tietê rivers, as well as aquifers, are polluted or highly vulnerable to pollution due to irregular waste disposal and the lack of an integrated plan for water resource preservation and management (Sabesp, 2018).

The São Paulo metropolitan region is supplied by the Cantareira System in which the main hydrographic basin, in terms of water production, is the Piracicaba River Basin. Extrema city is in the border of state of Minas Gerais and encompasses the Ribeirão das Posses Basin, which is a direct tributary of the Jaguari River, one of the main reservoirs of the Piracicaba Basin. The Ribeirão das Posses Basin is a strategically important Critical Zone for water production for the state of São Paulo. Extrema was the first city in Brazil to establish a long-term municipal payment program to landowners developing restoration of vegetation around water springs (Richards et al., 2015).

Critical Zone is an environmental concept that can be defined as “heterogeneous spaces in which complex interactions involving soil, rock, water, air and living beings regulate the habitat and determine the availability of resources essential to life” (Giardino and Houser, 2015). The Critical Zone extends from the Earth's surface down to the base of an aquifer unit (Pavankumar et al., 2024). This work presents preliminary results from a study that aims to integrate geological, geophysical and hydrological data to develop a hydrogeological model that helps understanding the processes of water infiltration, storage, and underground flow in critical zones that are important for water and food security in the state of São Paulo. In the initial stage of the research, Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) profiles were acquired at a Ribeirão das Posses River microbasin. The main objectives were to investigate lithological variations, map saturated zones, identify potential aquifer recharge areas and detect structural discontinuities in the subsurface.

Study area

The microbasin studied in this research is called N21 spring. It is located in the southern part of Minas Gerais state, at the border of São Paulo state, in Extrema city, at the Southwest region of the Ribeirão das Posses Basin (Figure 1). The geology of the region comprises banded gneisses of monzodioritic, granitic or migmatic composition, as well as alluvial deposits consisting of medium to coarse sand containing gneiss and granite pebbles (Novo et al., 2015). Additionally, NW-SE lineaments are observed and largely control the drainage patterns in the Ribeirão das Posses Basin (Miranda et al., 2024).

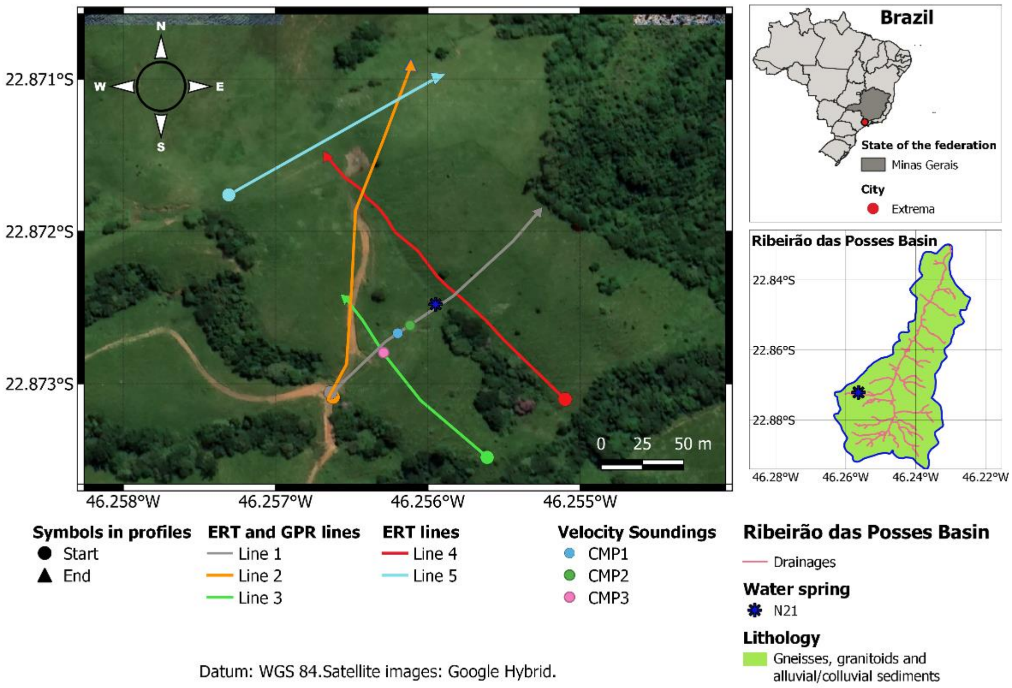

Figure 1: Location of geophysical data acquired around the water spring N21 at Ribeirão das Posses Basin, in Extrema city, Minas Gerais, Brazil.

Acquisition and processing of ERT and GPR data

Figure 1 shows the locations of five lines where ERT profiles were acquired using a Syscal Pro (Iris Instruments). All measurements employed a dipole-dipole array and the spacing between the current electrodes (AB) were 3 m (Line 1) and 5 m (lines 2, 3, 4 and 5). Resistivity data were inverted in the RES2DINV software (Geotomo Software) and the percentage of relative root mean squared (RMS) error change defined as limit was 3% and the maximum number of iterations 6. Three GPR profiles were acquired using a 200 MHz shielded antenna and the SIR 4000 acquisition module, developed by Geophysical Survey Systems Inc. These GPR profiles were acquired over the lines 1, 2 and 3 (Figure 1). Three velocity soundings with the Common Midpoint (CMP) configuration were also carried out in the area. The GPR data were processed using ReflexW software (Sandmeier Geophysical Research) and the main processing steps were: zerotime correction, frequency filters (bandpass), temporal background removal filter, stacking, linear gains and time-to-depth conversion. Analysis of the velocity soundings estimated the electromagnetic wave propagation speed to be approximately 0.05 m/ns, which was used to convert time into depth.

The geophysical data acquired from the five lines have already been processed. However, only the ERT and GPR profiles related to Line 1 are presented and discussed in the results section.

Results

Figure 2 shows the ERT (Figure 2a) and GPR (Figure 2b) profiles referring to Line 1 with topographic data corrected. Line 1 comprises a profile that crosses the water outlet of the N21 spring. The strong contrast around the 72 m position is evident in the resistivity model, suggesting the presence of a fracture zone in the subsurface that coincides with the position of the spring water outlet observed in the field in a NW-SE lineament. It is noted in the model (Figure 2a) that the subsurface geology comprises: 1) a near surface horizon with up to approximately 6 meters thick, which is electrically heterogeneous and 2) a highly resistive horizon extending to the maximum investigation depth of 10 meters. The superficial geoelectric horizon has lower resistivity possibly comprising unconsolidated sedimentary materials, while the higher resistivity observed at greater depths is likely related to the presence of crystalline rock.

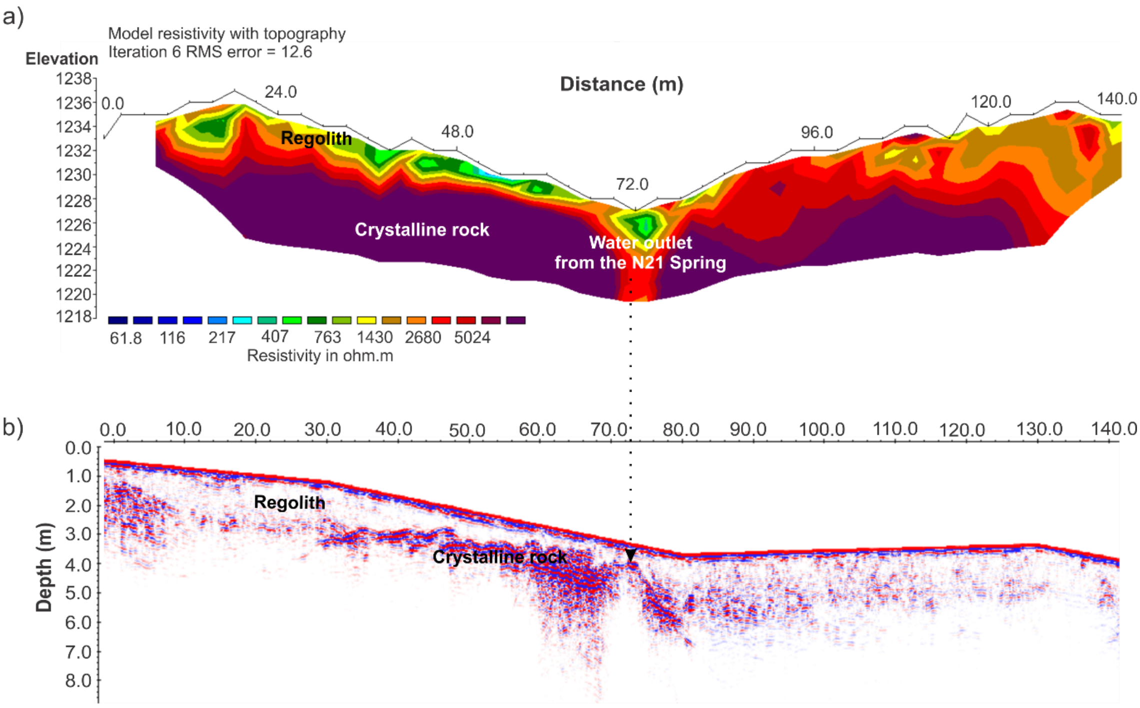

Figure 2: Profiles a) ERT and b) GPR related to Line 1 with topographic data.

In the GPR profile (Figure 2b), a localized pattern of vertical attenuation of the electromagnetic signal is visible at the water outlet from the spring, indicating the presence of water in fracture zones. Additionally, there is a horizontal reflector around 2 m deep between the positions of approximately 30 m and 70 m, as well as an inclined reflector between the positions of 70 m and 80 m. The inclined reflector coincides with the N21 spring's position and is likely related to fractures in the crystalline rock.

Preliminary conclusions

The ERT and GPR profiles allowed inferring lithofacies variations and structural discontinuities in the subsurface around the N21 spring. The first results suggest the occurrence of a free aquifer system composed of a thin weathering mantle and a fractured crystalline rock (gneiss). These preliminary results are promising and show how geophysical methods can effectively help in characterizing groundwater resources in the microbasin. New geophysical data and borehole information will be collected to expand the characterization of the Critical Zone in the study area.

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