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Ground penetrating radar non-invasively positions an underground dam and estimates its water reservoir shape and volume

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Abstract

The objectives are to use ground penetrating radar (GPR) to: (a) find a suitable length and location for a future underground dam; and (b) model the shape and estimate the volume of its water reservoir. Radargrams were obtained in a 0.85-ha area in northeastern Brazil along five survey lines parallel to, and eight lines transverse to the slope, starting from the proposed location of the dam. The 13 radargrams were pre-processed and migrated. The terrain surface and the top of the regolith delineated in the radargrams were interpolated, plotted in 3D showing the shape of the water reservoir, and used to estimate its volume. From the radargrams, the future dam should be 45 m longer and centered 22 m south of the proposed location, increasing the water reservoir by 50% to a total of 6 million L. By assessing the terrain surface and regolith, the GPR allows to adjust the length and position future underground dams and assess their water reservoir shape and volume non-invasively.
Keywords: GPR; Geophysics; Brazilian semiarid region; Soil depth; Regolith

Introduction

In the Brazilian semiarid region, underground dams have been used to bar and store rainwater in the subsurface providing water for reuse (SILVA et al., 1998). Despite its importance, the volume of water stored by the underground dam is typically not quantified due to the high cost of the identification and mapping of the impermeable layer that limits the vertical flow of water at the bottom of the reservoir, which requires drilling or opening soil trenches.

The ground penetrating radar (GPR) has been used to map soil restrictive layers (NOVÁKOVÁ et al., 2013; SCHALLER et al., 2020) and to find the ideal location for building an underground dam (LIMA et al., 2018). However, the estimation of the water reservoir volume in the underground dam accumulation area from GPR data remains an open research task.

Thus, the objectives are to use a GPR to: (a) find a suitable length and location for a future underground dam; and (b) model the shape and estimate the volume of its water reservoir.

Methodology

The area is located in Santana do Ipanema, Alagoas state, in the semiarid region of northeastern Brazil, at coordinates 9°23'47.5" S and 37°13'39.4" W. The area has a 3% slope gradient and lies around an intermittent stream, where an underground dam will be built. Soils include *Neossolos Flúvicos* (Fluvisols; Fluvents), *Neossolos Regolíticos* (Regosols; Psamments), and *Planossolos Háplicos* (Planosols; Aqualfs).

A survey was done using a MALÅ GroundExplorer GPR (Guideline Geo AB, Sundbyberg, Sweden), carrying a 450-MHz shielded antenna, consisting of five lines parallel to, and eight lines transverse to the slope (Figure 1a), with line 1 representing the proposed length and location of the future dam (Figure 1a, hatched feature).

Soil trenches were opened at nine sites close to the GPR survey lines (Figure 1a, b) to classify the soil and mark the top of the regolith, which constitutes the bottom of the water reservoir. The GPR radargrams were pre-processed (zero-time correction, dewow, gain, eigenvalue filter, constant offset correction, time-to-depth conversion) and migrated (Kirchhoff), and the top of the regolith was delineated in all radargrams (HUBER; HANS, 2019; R CORE TEAM, 2020). The terrain surface and the top of the regolith elevations were interpolated with 2-m resolution across the area by multilevel B-splines.

The soil pore volume in each pixel was calculated by multiplying the soil depth (terrain surface minus top of regolith) by the pixel area (4 m^2) by a soil porosity of 0.38 m^3 m^{-3} estimated from similar soils of the region (JACOMINE et al., 1975). The water reservoir volume was estimated by summing up the pore volume of all pixels.

For this exercise, it is assumed that: the water reservoir is limited at the top by the terrain surface, at the bottom by the top of the regolith, and laterally by the boundaries of the GPR survey lines; a single soil porosity value represents the whole reservoir both horizontally and vertically; and all pores are available to store water.

Results and discussion

Along the slope, the soil depth increases from the upper (northwest) to the lower part of the area close to the dam (southeast) (Figure 1b, red lines). Across the slope, it increases from both sides towards the intermittent stream thalweg, which is closest to line 10 and trenches P1, P4 and P7 (Figure 1a, b). The soil depth varies between 45 (P8) and 160 cm (P5 and P7) as observed in the soil trenches.

The radargram of survey line 1 corresponds to the proposed length and location of the future underground dam (Figure 1c). The shape of the terrain surface and top of the regolith at line 1 shows that the proposed dam is not centered at the intermittent stream thalweg and its length of 65 m is too short to bar the underground water flow in the southern side of the area. Thus, the underground dam should be extended about 45 m, and centered about 22 m to the left (southwards), assuming that the cross-sectional shape of the slope is symmetrical.

The interpolated terrain surface, and top of the regolith elevations ranged between 213.5 and 215 m, and 210 to 213.5 m, from the dam to the top, respectively (Figure 2). In this exercise, their map extent represents the underground dam accumulation area of about 0.85 ha, and the region between them corresponds to the shape of the water reservoir. The water reservoir is thickest close to the dam along the slope, and to the thalweg across the slope (Figure 2).

The estimated water reservoir volume in this 0.85-ha area is 4013 m^3. Extending the underground dam 45 m southwards to a total of 110 m in length and centering it at the stream thalweg would increase the accumulation area to about 1.44 ha, assuming a proportional increase keeping its rectangular shape. The water reservoir volume would increase to about 6020 m^3, assuming that the area is symmetrical across the stream. Also, this would stop the underground water from flowing outwards laterally at the southern border. Additionally, the top of the dam should be built above the terrain surface to store water aboveground for irrigation, animal watering, and other uses, and capture surface and runoff water during heavy rains.

Conclusions

The results obtained from this exercise show the potential of the GPR to non-invasively identify, visualize and map the terrain surface and the top of the regolith, supporting adjusting the length and location of a future underground dam and estimating its water reservoir shape and volume, with minimal need for soil trenches. The individual radargrams and derived terrain surface and top of the regolith maps can be plotted in 3D to show their variations and the shape of the water reservoir vertically and horizontally, along and across the slope.

The analytical methods, functions, and tools provided by the free and open-source RGPR package in R covered the whole framework of GPR data processing. Thus, using the RGPR package is recommended for its completeness and to reduce the cost of data analysis by replacing proprietary software.

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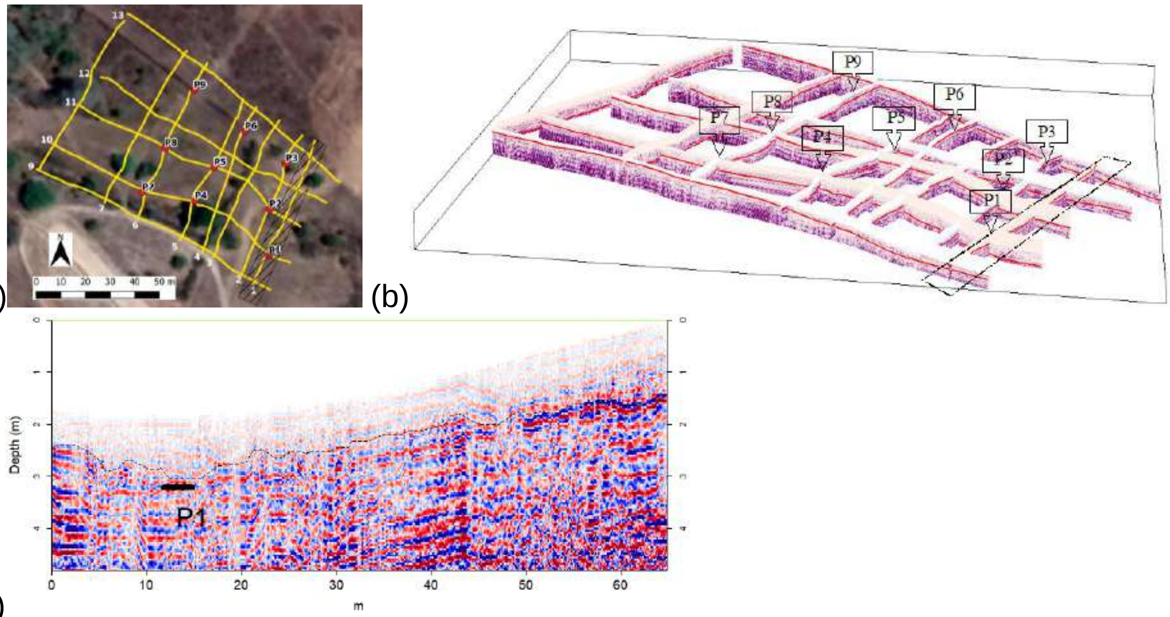

Figure 1. (a) GPR survey lines (1 to 13) and soil trenches (P1 to P9); (b) Migrated radargrams showing the delineated top of the regolith as red lines; and (c) Radargram of line 1 corresponding to the proposed length and location of the future underground dam, showing the delineated top of the regolith (thin dashed line), and the position of the top of the regolith recorded in P1 (thick dash).

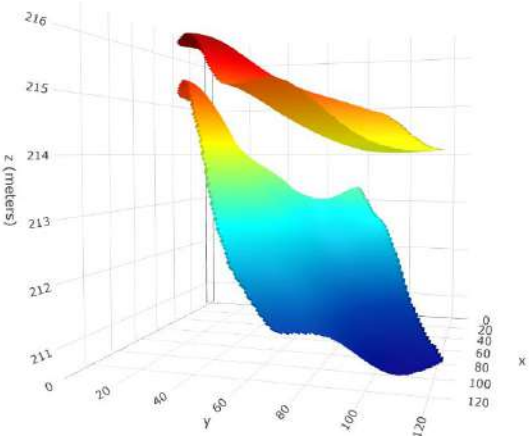

Figure 2. Terrain surface and top of the regolith elevations interpolated from the 13 GPR survey lines. The region between them corresponds to the shape of the water reservoir. Elevations (z) are exaggerated relative to x and y coordinates.