Use of geophysical surveys in selection of sites for underground dams in the municipality of Jenipapo de Minas.

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Abstract

A number of geophysical studies have been made over the least two years as part of a study for identifying suitable sites for underground dams in the municipality of Jenipapo de Minas (MG). The results obtained have allowed identification of an elevated basement structure beneath the soil cover of the intermittent stream Bolas, near the locality of Martins. Results of recent geo-electric studies indicate that this structure is characterized by a high resistivity layer (R > 1200Ωm) beneath a low resistivity permeable surface layer (R < 800Ωm). The high resistivity layer has been identified as impermeable metamorphic rocks of the Macaubas Group. The overlying low resistivity layer is mostly sandy soil present in the dry bed of Bolas stream. The depth to the top of basement rocks varies from 1.5 to 8.6 meters. It is proposed that this structure can potentially serve as a suitable candidate for grouting the foundation of the underground dam proposed for this site.

Introduction

Underground dams are widely recognized as convenient solution for subsurface storage of water in semi-arid regions (HANSON & NILSSON, 1986; BRITO ET AL, 1999; TELMER & BEST, 2004; GOMES ET AL, 2016). Such dams, built as barriers transverse to the direction of stream can impound horizontal flow of water in subsurface soil. A major attractive feature of such dams is that it minimizes damages resulting from flash flood resulting from fluvial discharges and has the additional advantage of minimizing evaporative loss of impounded waters. It also does not interfere with environmental conditions at the dam site. The principle of operation of an underground dam is illustrated in Figure (1).

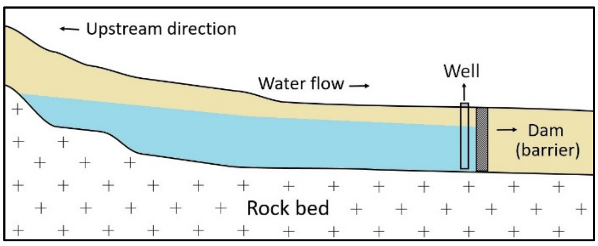

Figure 1 - Model of an underground dam.

However, selection of suitable sites for such dams require detailed subsurface studies. The objective of the present work is to investigate the viability of using geophysical surveys for selection of sites suitable for construction of underground dams in semi-arid regions of northeast Brazil. The region selected for the present study are the valley regions of Jequitinhonha and Mucuri in the state of Minas Gerais. These are regions known to host several localities with high regional evaporation and scarce rainfall rates in the dry season.

Hydrogeological aspects

According to results of local geological studies, the municipality of Jenipapo de Minas is composed almost predominantly by the Salinas formation (pEms) of the group Macaúbas. In the east, according to CODEMIG (2012), there are Cenozoic cover (QTd) composed of eluvio-colluvionar cover and restricted alluvial deposits, on tertiary plateau surfaces; QTd (sd) indicates the existence of sediments of São Domingos Formation (Tsd).

The groundwater systems in the municipality of Jenipapo de Minas are characterized by two hydrogeological domains: 1) Neoproterozoic metamorphic rocks and Paleozoic granites, which constitute highly fractured rock formations, but which are relatively impermeable; 2) Cenozoic detrital covers, which are highly permeable for groundwater flows. As a result, the aquifers in these domains can be considered as falling into the categories of near impermeable fractured systems and highly permeable granular systems. The hydrogeological potential of the fissure system is dependent on the intercommunication of the discontinuities, an aspect that usually translates to random and small-scale reservoirs (CPRM, 2005). It occurs throughout the municipality and is related to the shale rocks of the Macaúbas Group (Ribeirão da Folha Formation) and the Mangabeiras granite. In general, it presents low hydrogeological potential, with structural features responsible for local variations in productivity. The granular aquifer system is represented by poorly consolidated sediments, which constitute the detrital deposits of sand-clay composition. In hydrogeological terms, it may be considered as lateralized. These have primary porosity and good permeability (CPRM, 2005; GOMES ET AL, 2016).

The map in figure (2) outlines the hydrogeological units and drainage system of the area selected in the present work. In this figure, the green colored curve indicates the main local river (Setubal River), which is perennial. The red colored curve indicates the local intermittent steam Bolas, which have no water flow during the dry season. The locality Martins, indicated in this map, refer to the site where geophysical studies were carried out.

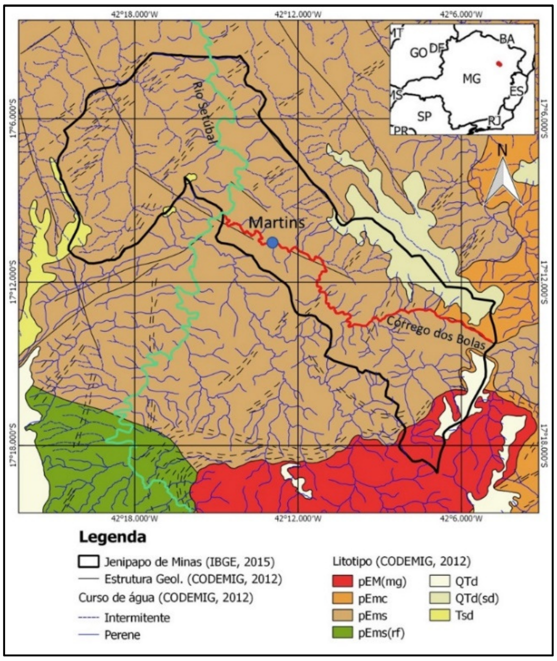

Figure 2 – Map indicating the fluvial drainage systems and geological in the Municipality of Jenipapo de Minas (MG). The red colored curve indicates the intermittent stream Bolas, which has no water flow during the dry season. Martins refer to the locality where geophysical surveys were carried out.

Geophysical Studies

A number of geophysical studies were carried out in the municipality of Janipapo de Minas with the objective of identifying sites suitable for construction of underground dams. It included compilations of data on local topography, drainage systems, water wells and geothermal investigations. The focus of earlier efforts has been in mapping intermittent streams and identifying suitable sites for detailed geophysical surveys. In the present work, we report progress obtained in electrical resistivity surveys in near the locality of Martins. The location of the profile is shown in Figure (3).

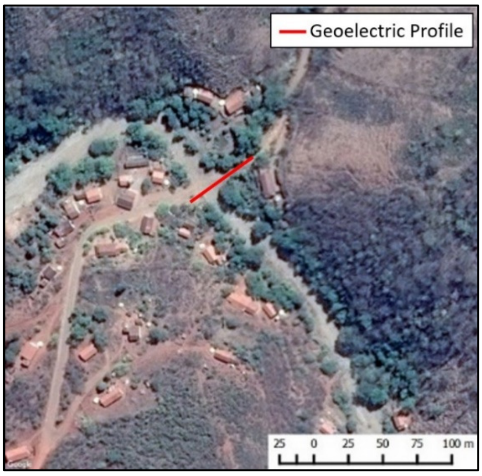

Figure 3 – Location of geophysical profiles in Martins.

Field Procedures

AGI Super Sting resistivity equipment (Figure 4) was used in data acquisition. Measurements were carried out along profiles over selected targets, using the Wenner arrangement. In most cases, electrode spacing of 4 m was adopted. The field-acquired resistivity data was processed using the Earth Imager 2D software.

Figure 4 – Equipment used in the field survey.

This equipment has a receiver with accuracy resistivity of 1% in most cases and resolution of 30nV (LAMBOT ET AL, 2009). The built-in software allows automatic acquisition and display of field data.

Data Analysis

An inversion procedure was employed in processing field data obtained in electrical resistivity surveys. The objective of inversion is to reduce misfit between field measurements and calculated values of a physically plausible model. One of the objectives of the resistivity inversion is to find a resistivity model whose response (predicted values) best fits the measured data. The goodness of fit was characterized by calculating root mean square (RMS) error in percent (Advanced Geosciences, 2008):

$$RMS = \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{D_i^{Pred} - D_i^{Meas}}{D_i^{Meas}}\right)^2}{N}}\ X\ 100\%$$

where N is the total number of measurements, d_i^{Pred} the set of predicted values and d_i^{Meas} the measured data. It is clear that the RMS error depends on the number of misfit points and how bad each misfit is (Advanced Geosciences, 2008).

L2-norm was also employed as another measure of misfit. It is defined as the sum of the squared weighted values of deviations as per the relation:

$$L2 - Norm = \sum_{i=1}^{N}\left(\frac{D_i^{Calc} - D_i^{Meas}}{W_i}\right)^2$$

In the above equation, N is the number of measurements. W_i the weight assigned, D_i^{calc} is the calculated value, and D_i^{meas} is the measured data (Advanced Geosciences, 2008). The number of measurements (data points) varies from one set to another. We define a normalized L2-Norm measure as

$$Normalized\ L2 - Norm = \ L2 - Norm/(Number\ of\ Data)$$

The inversion is considered as converged when the normalized L2-norm reduces to values near unity, (Advanced Geosciences, 2008).

The number of steps in the inversion process is defined by repetitions that the nonlinear iterative process needs to be performed. In the present study, the iteration cycle was interrupted when the value of RMS becomes less than 3% or when a prescribed maximum number of iterations (in the present case 10) is reached. An example of the convergence curve of the resistivity inversion is illustrated in Figure (5).

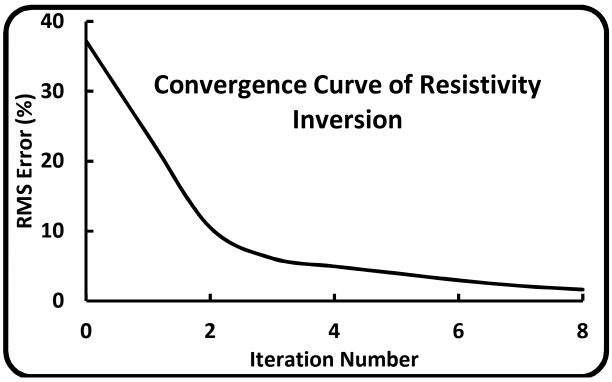

Figure 5 - Numbers of iterations per RMS error values.

For purposes of qualitative evaluation of data analysis, a cross plot of the measured apparent resistivity data per predicted value was generated. As illustrated in Figure (6) it is possible to verify a fit coherence between them.

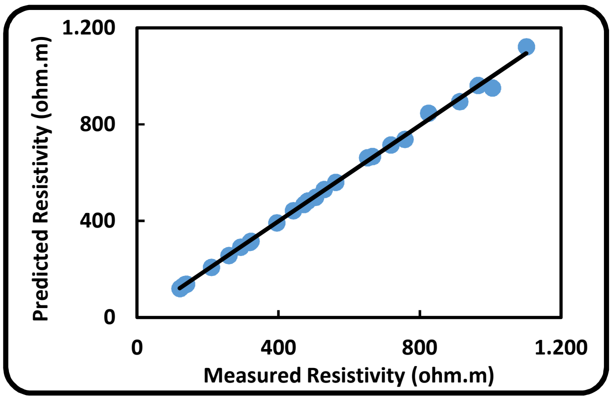

Figure 6 – Cross plot of the apparent resistivity data measured and the predicted values.

Results of Geo-electric Surveys

As a specific example, we discuss data obtained in surveys carried out along the profile near the locality of Martins. The results of this geo-electric profile is illustrated in Figure (7). The top panel of this figure refers to a representation of the observational data acquired in the field, illustrating vertical distribution of electrical resistivity. The middle panel provides a similar representation of the predicted (calculated) values obtained in data analysis. The triangular shapes of the profile in these two upper panels arise from practical limits in determining the vertical distribution of resistivity values. The bottom panel illustrates the distribution of resistivity as a function of surface elevation of the profile. It is referred to as the resistivity section model, obtained in the inversion process.

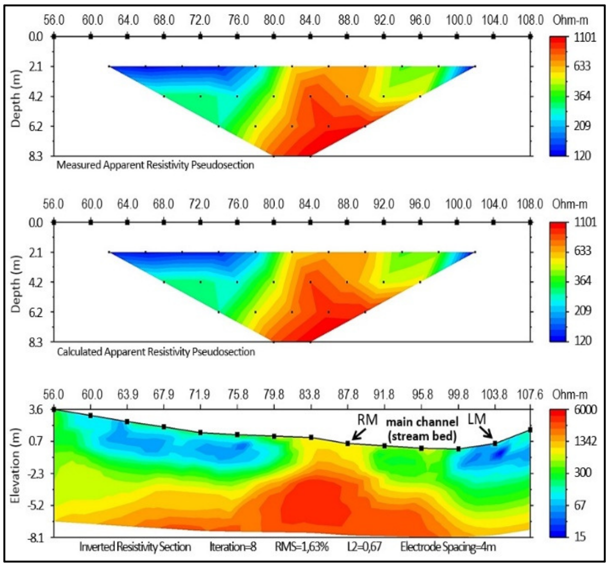

Figure 7 – Results obtained for Profile 1. The top panel refers to data measured in the field and the middle panel the predicted data. The lower panel illustrates dependence of resistivity on surface elevation.

Note that the profile indicates a layer of low resistivity (< 300Ωm) near the surface, at depths ranging from 1.5 to 8.6m. This is underlain by a layer with resistivity values in excess of 400Ωm. The sharp resistivity contrast is indication of substantial changes in lithology occurring at shallow depths, beneath the area traversed by the profile.

A preliminary identification of lithotypes responsible for the observed electrical resistivity contrast has been obtained by examining the descriptive log of a water well drilled by CPRM at a nearby site. According to log data of this well, the top layer is sandy soil, extending to a depth of 5.4m. The deeper parts of this well penetrates shale sequences, which extend to depths of at least 104m.

Based on lithologic sequences identified in log data of this well it has been possible to establish an association of the upper zone, with electrical resistivity in the range of 15Ωm to about 300Ωm, with the water saturated soil sediment cover. There are indications that this layer (composed of sand and pebbles) is present not only in the streambed but also along its margins. Beneath the surficial sediment layer there is a thin layer where resistivity increases rapidly from 300Ωm to values in excess of 1000Ωm. The layer beneath the middle transition layer, with resistivity higher than 1200Ωm, has been considered indicative of relatively impermeable shale sequences.

The effect of imposing limits of practical resolution in resistivity determination and projecting the results onto a map with topographic information is illustrated in Figure (8). The trapezoidal shape of the profile results from this truncation process. It leads to removal of a portion of the profile edges, based on values of the aspect ratio of horizontal/depth offset. This procedure reduces uncertainties arising from edge effects in the interpretation.

It also minimizes undesirable effects of possible artifacts created by the interpolation in those regions that do not have measured data. In this figure, the black arrows indicates approximate limits of the main channel of the Bolas stream. The right margin is indicated by the abbreviation RM and the left margin by the abbreviation LM. The dashed line indicates the upper limit of bedrock with resistivity greater than 1200Ωm.

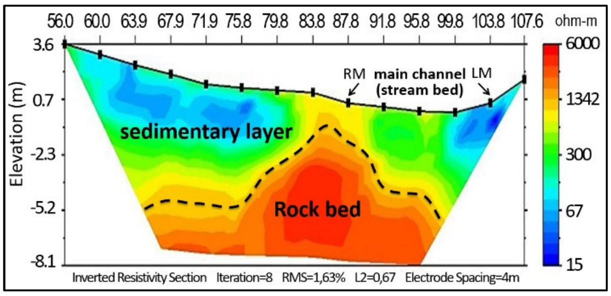

Figure 8 – Projection of interpreted values onto topographic profile.

Bedrock configuration

For purposes of determining the bedrock, configuration three interpretive profiles were created with apparent resistivity values greater than 1200Ωm for the bottom layer. In this procedure, interpretative profiles which indicated no sedimentary layer at the right border of the Bolas stream, were eliminated. These are considered unrealistic as no bedrock outcrops were identified during the field survey works.

In the interpretive profile (Figure 9), with resistivity greater than 1200Ωm for the bedrock, the upper sedimentary layer has a mean thickness of 4.8m, the low and high depth values being 1.5 and 7.4m. Considering only the dry bed area of the stream, the mean thickness is 4.2m and the low and high depth values are respectively 2.2 and 5.9m.

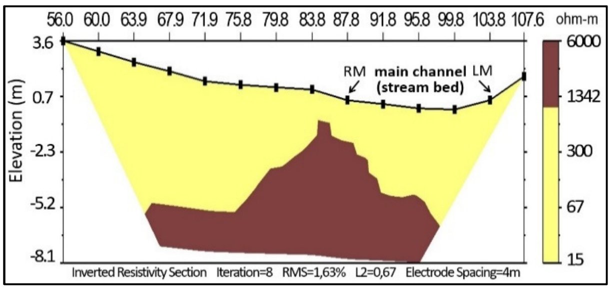

Figure 9 - Area with resistivity greater than 1200Ωm.

In the interpretive profile (Figure 10) with resistivity greater than 1400Ωm for the bedrock, the upper sedimentary layer has a mean thickness of 5.2m, the low and high depth values being 2.2 and 8.2m. Considering only the dry bed area of the stream, the mean thickness is 4.5m and the low and high depth values respectively are 2.6 and 6.1m.

In the interpretive profile (Figure 11) with resistivity greater than 1600Ωm for the bedrock, the upper sedimentary layer has a mean thickness of 5.4m, the low and high depth values being 2.7 and 8.6m. Considering only the dry bed area of the stream, the mean thickness is 4.7m and the low and high depth are 2.9 and 6.3m.

The depth values associated with these interpretive profiles are considered as indicative of possible bedrock configurations in the study area.

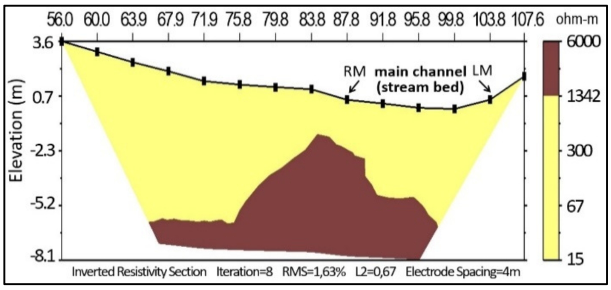

Figure 10 - Area with resistivity greater than 1400Ωm.

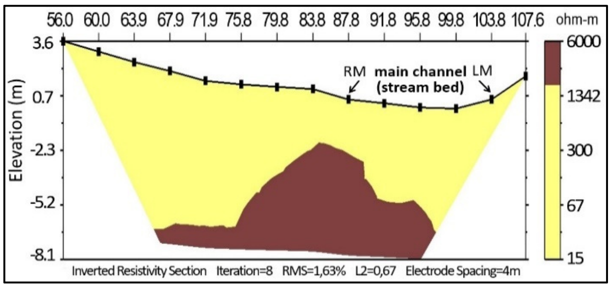

Figure 11 - Area with resistivity greater than 1600Ωm.

Conclusions

The results of geo-electric survey indicate the existence of two layers beneath the dry bed of the Bolas stream, near the locality of Martins. The top layer has low electrical resistivity (less than 400Ωm), which has been considered as indicating the presence of a water saturated sandy layer in the subsoil. The thickness of this sandy layer varies from 1.49 to 8.56 meters at the study site. It has relatively high porosity and permeability and hence can store significant quantities of subsurface water.

Below this top layer is a thin transition zone where resistivity increases are substantial. It has been considered as indicative of the weathered and fractured part of the basement rocks.

Beneath the transition zone is the high resistivity layer (with resistivity more than 1200Ωm). It has been identified as the relatively impermeable bedrock, with shales and schists of Macaúbas group constituting the main lithotypes.

In view of these results, the bottommost layer beneath the bed of the Bolas stream, may be considered as a suitable candidate for grouting the foundation of the proposed underground dam, near the locality of Martins,

The bedrock configuration is such that grouting the underground dam would require foundation extending to depths of 4 to 6 meters.

The volume of sediments in the catchment area above the dam is estimated to be of the order of 400000 cubic meters. For average porosity of 20% the It imply a volume of impounded water is likely to be 80000 cubic meters.

Acknowledgments

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