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Electrical resistivity survey combining multiple electrode arrays applied to the studies of underground dams

Jorge Luiz dos Santos Gomes[1], **Fábio Pinto Vieira**[2]

[1] Federal University of the Jequitinhonha and Mucuri Valleys, Teófilo Otoni, Brazil.
[2] National Observatory, Rio de Janeiro, Brazil.

Email address
jorge.gomes@ufvjm.edu.br (Jorge L. S. Gomes) – Corresponding author.
fabiovieira@on.br (Fábio P. Vieira)

Abstract

Groundwater resources are of paramount importance in sustainable economic development in semiarid regions, such as those in municipally of Jenipapo de Minas, southeast Brazil. The focus of the present work is on realization of geophysical studies using merged electrode arrays in the same profile to study the site suitable for the construction of underground dam in the Bolas Stream bed. The measurements were made along a profile cutting across that local intermittent stream bed. A method of combining multiple electrode arrays was applied in the profile survey to increase the input data. The results obtained indicate that the subsurface lithologic sequences of the study area are characterized by low resistivity soil layers (> 800Ωm) overlying basement rocks of higher resistivity (> 1000Ωm). There seems to be no fractures or seepages in the basement rock of the Bolas stream bed. On other hand, in the left bank of the stream was identify a conductivity anomaly that could be caused by a fractured in the crystalline rock. However, there is no connection between with the anomaly with the stream bed. The results of merged multiple electrode arrays in the single profile has been found to be useful in understanding the characteristics of resistivity profiles. Thus, the results indicate the surveyed site as a potential for the construction of underground dam in the study area.

Keywords: Geophysics survey, Geoelectrical, Groundwater.

1. Introduction

The demand for water in semiarid regions and the difficulty of accessing this natural resource has become a reality faced by populations in semiarid regions, such as those in the northeast of the State of Minas Gerais.

Regions where surface water resources are scarce or non-existent, groundwater presents itself as a convenient alternative for domestic and rural needs.

However, well drilling in crystalline rocks has low rate of success in finding underground water without the use of geophysical methods. Furthermore, drilling a well has an expansive cost for the small rural communities. So, it is not a viable economic option. An alternative to living with drought is the use of underground dams that have a low cost of implementation compared to drilling wells.

Nevertheless, selection of suitable sites for such dams require detailed subsurface studies.

In the present work is shown the use of geoelectrical measurements for investigating the subsurface lithology of the stream bed, located in the Municipality of Jenipapo de Minas, in the semiarid region of southeast Brazil (Figure 1).

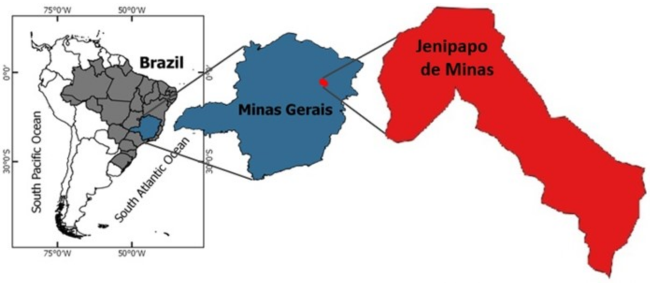

Figure 1 – Location of the Municipality of Jenipapo de Minas in Brazil.

The main objective of this work is to study the site suitable for the construction of underground dam in the Bolas Stream bed using electrical resistivity survey.

2. Methodology

The use of groundwater flow dams is presented as an old concept and refers to constructions that date back to the Roman Empire, in Sardinia, and ancient civilizations in North Africa (Hanson and Nilsson, 1986). According to Ponçano (1981), dams have been used since the beginning of the 18th century, mainly in North and Southeast Africa, India, Israel and Iran.

Usually underground dams are constructed in alluvial valleys. A trench is dug perpendicular to the direction of surface drainage within the alluvial sediment down to the bedrock (Telmer and Best 2004). The downstream wall and the bottom of the trench are covered with suitably selected impermeable materials and then backfilled with the displaced alluvium. The general schematics of the principle of operation of underground dam, have been discussed extensively in the literature (Onder and Yilmaz 2005, Ishida et al. 2011, Gomes et al. 2017). The overview of an underground dam is shown in the Figure (2).

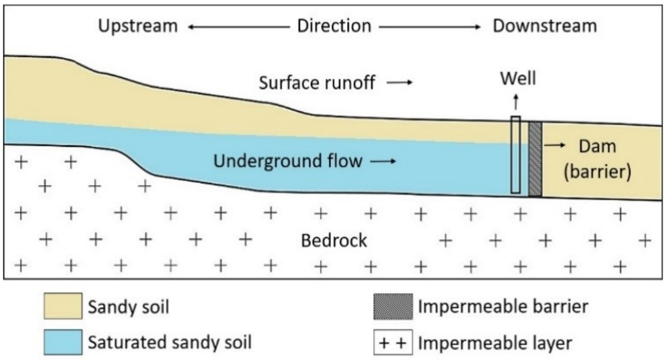

Figure 2 – Scheme of an underground dam (adapted from Gomes, Vieira and Hamza, 2017).

Selection of sites for underground dams require detailed studies of near surface layers. In this matter was used the prospecting geophysical method of electrical resistivity of the soil.

Resistivity variations in subsurface provides clues as to the nature of lateral and vertical changes in the geoelectric structure along the profile.

The methodology used in surveys of electrical resistivity are based on procedures described in practices adopted in the applied geophysics literature (Dobrin and Savit, 1988; Telford et al., 1990; Vogelsang, 1995; Kearey et al., 2002).

The *AGI Super Sting* resistivity equipment was used in data acquisition. In the field was surveyed three electric resistivity profiles with different arrays. The chosen multiple electrode arrays were the dipole-dipolo, Wenner and the Schlumberger. They were combining do rise the quantity of input data in pre-inversion procedure. For data that have the same location, a simple arithmetic mean was used. The pseudo location of de measure data is shown in the Figure (3).

The field data were processing in the *AGI EarthImager 2D Software* and the inversion method employed in whole dataset were the smooth inversion. The main purpose of the inversion is to reduce the misfit between field measurements and calculated values in a physically plausible model.

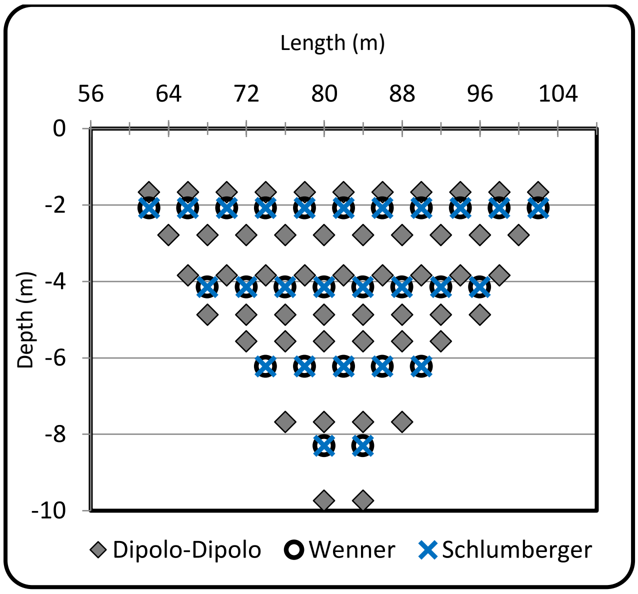

Figure 3 – Pseudo locations of measured data (apparent resistivity data).

3. Geological aspects

The map of Figure (4) outlines the geologic features and drainage systems of the study area. The site selected in the present work is a segment of the local intermittent stream Bolas, the outlines of which are indicated in red color in this figure. It is a tributary of the perennial River Setubal, indicated in green color. The locality Martins in this map, refer to the site where the electrical resistivity studies of near surface layers were carried out. It is situated in a region where availability of water for domestic and agricultural purposes is a major problem, especially during the dry season.

The rock formations in the study area are mostly of the Salinas formation (pEms in Figure 4) of the Macaúbas Group (Almeida 1977; Alkmin et al. 2007). In the east, according to Pedrosa-Soares (1997), there are areas of Quaternary sedimentary rocks (QTd). These are composed of alluvium - colluvium deposits, overlying tertiary plateau surfaces (FEAM, 2010). Geologic mapping carried out by CODEMIG (2012) has also identified occurrences of Tertiary sediments of the São Domingos Formation (Tsd).

Regarding the hydrogeological aspects, the local aquifers can be considered as falling into categories of permeable granular systems and nearly impermeable fractured systems according to the CPRM (2005). The hydrogeological potential of the fissure system is dependent on the intercommunication of geological discontinuities, an aspect that usually translates to random and small-scale reservoirs. The basement rocks occur throughout the municipality and is related to the quartz-mica schists of the Macaúbas Group, represented in the geologic map by Salinas formation (pEms) and the Mangabeiras granite (pEM). The granular aquifer system is represented by poorly consolidated sediments, which constitute the detrital deposits of sand-clay composition (Silva et al., 2018).

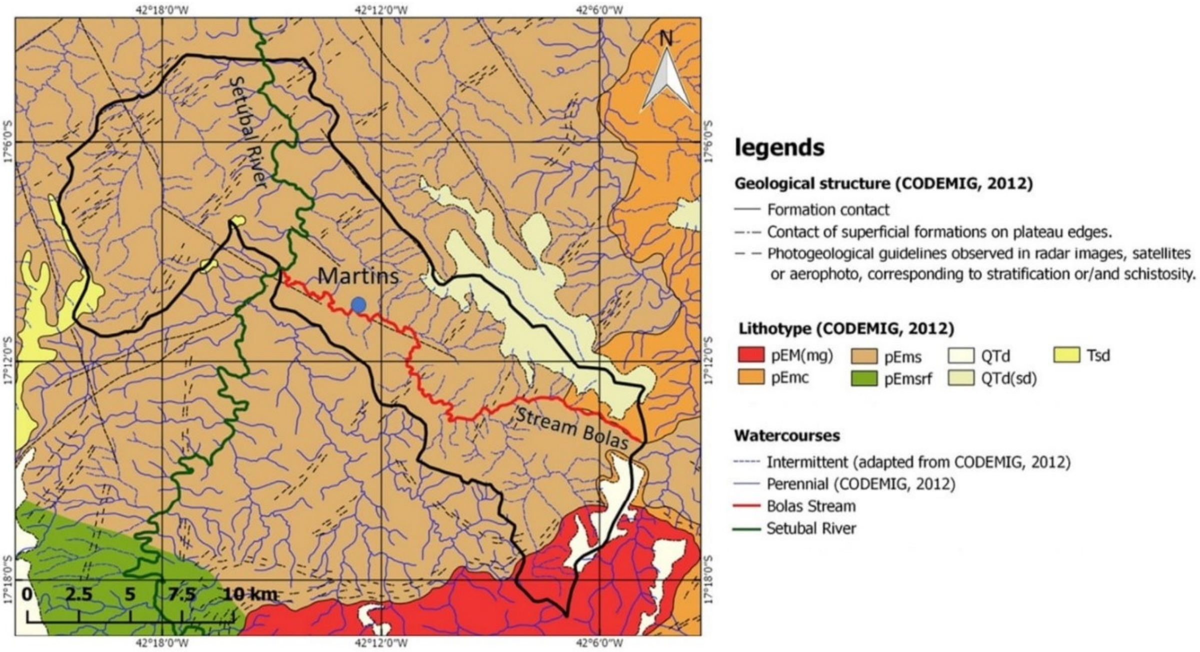

Figure 4 – Map indicating the geological lithotypes and the fluvial drainage systems in the study area (Adapted from Gomes, Vieira and Hamza, 2018).

4. Results and discussion

A total of three electrical resistivity profile were carried out in the same site, the location is indicated in the Figure (5). A spacing of four meters was adopted in setting electrode configuration for field surveys. All of the surveys were carried out in April 2017, during the end of the rainy season of Southeast Brazil. The Wenner, Schlumberger and dipole-dipole arrays were employed for measurements along the profile.

A summary of electrical resistivity data like profile identification, array configuration, number of electrodes used and root mean square (RMS) values is presented in Table (1).

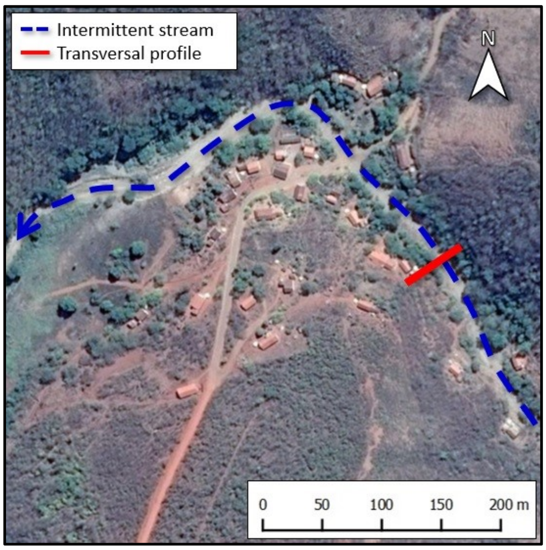

Figure 5 – Martins locality. The blue dashed line indicates the Bolas Stream and the red line the location of the geoelectric profiles.

The smooth inversion method was adopted in the processing of the measured resistivity data. It has leaded to a good fit between the measured and predicted apparent resistivity for the profiles.

For purposes of qualitative evaluation of data analysis, a crossplot of the measured apparent resistivity data per predicted value was generated for all profiles. The results shown in the Figure (6) indicate a great fit of the data in all profiles.

Furthermore, the root means square error (RMS) had values below 5% indicating a good convergence of the inverted model.

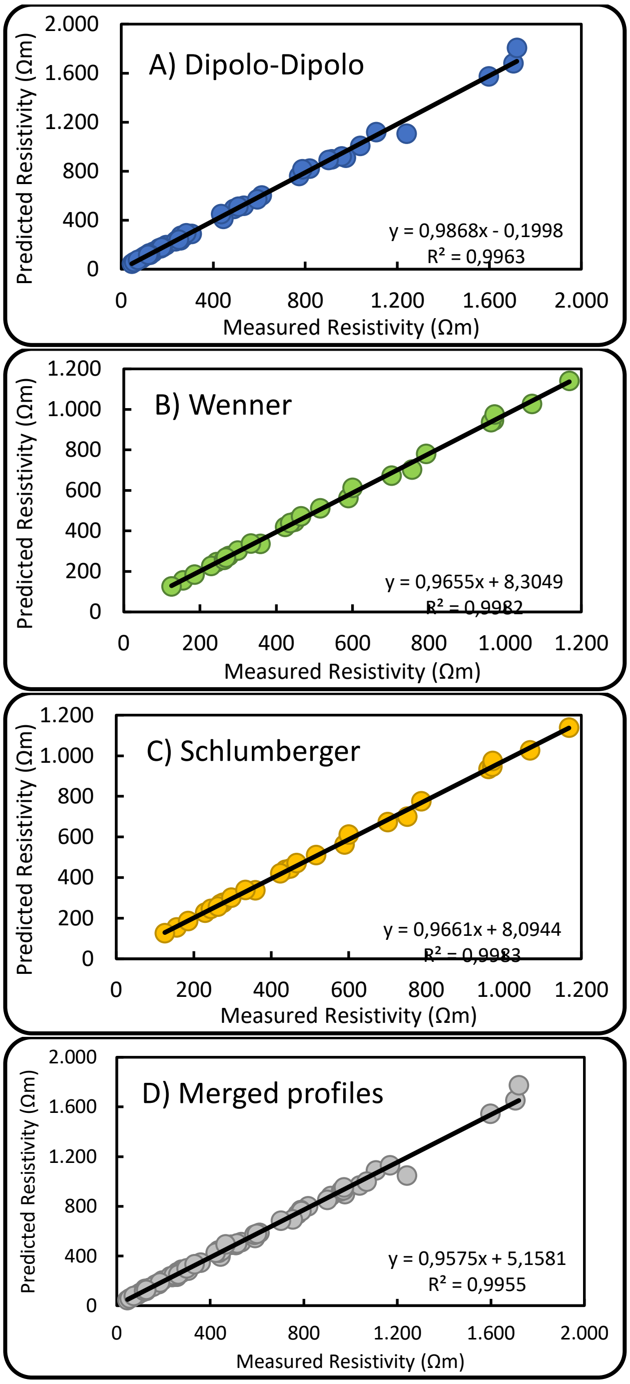

Figure 6 – Crossplot of measured per predicted apparent resistivity data for all profiles.

Table 1 – Summary of electrical resistivity data (QE: quantity of electrodes; QD: quantity of data; Res.Mea: measured apparent resistivity; RMS: root mean square).

Profile	Array	QE	QD	Res. Mea (Ωm)		RMS %
				Min	Max	
1	Dipole-Dipole	14	50	46,03050	1719,6100	3,69
2	Wenner	14	26	125,4440	1168,4100	2,64
3	Schlumberger	14	26	125,4620	1168,0100	2,59
4*	D.W.S.**	14	76	46,0305	1719,6100	4,52

* This is the merged result of the first three profiles.
** D.W.S.: Dipole-Dipole, Wenner and Schlumberger.

Note that the profile indicates a layer of low resistivity (< 800Ωm) near the surface. This is underlain by a layer with resistivity values in excess of 1000 Ωm. The sharp resistivity contrast is indication of substantial changes in lithology occurring at shallow depths, beneath the area traversed by the profiles, as shown in the Figure (7).

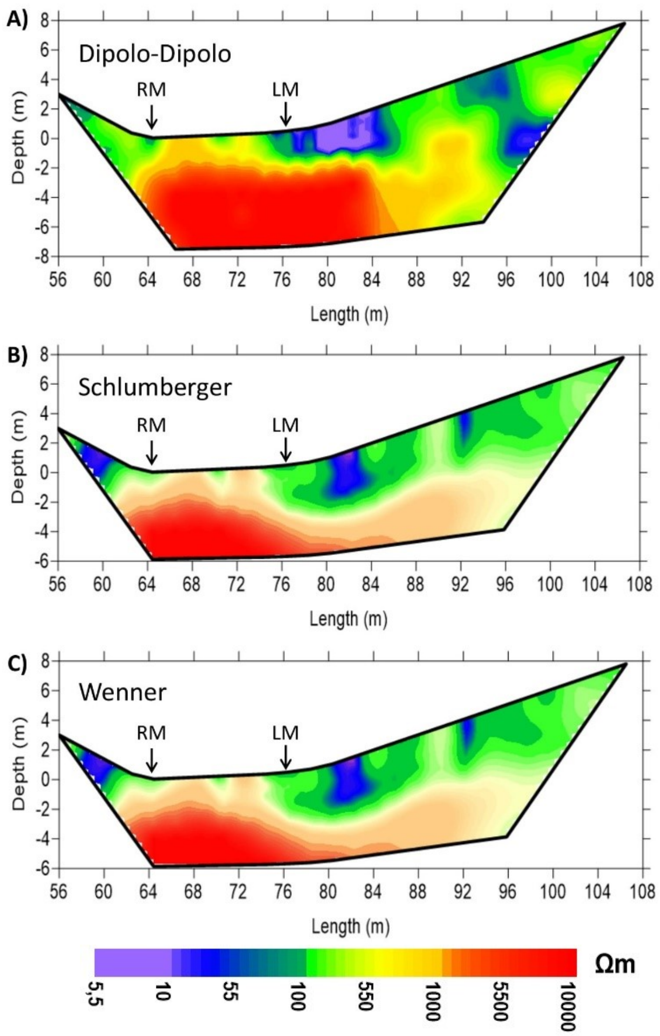

Figure 7 – Electrical resistivity profiles: Dipolo-Dipolo (A), Schlumberger (B) and Wenner (C). The arrows RM (right margin) and LM (left margin) indicate the approximate limits of the stream bed.

The interpretation of the merged profiles shown in the Figure (8) indicate the presence of two layer. The first one a sedimentary and the second one the crystalline rock. The contact between the layers is indicated by the dashed black line in the figure.

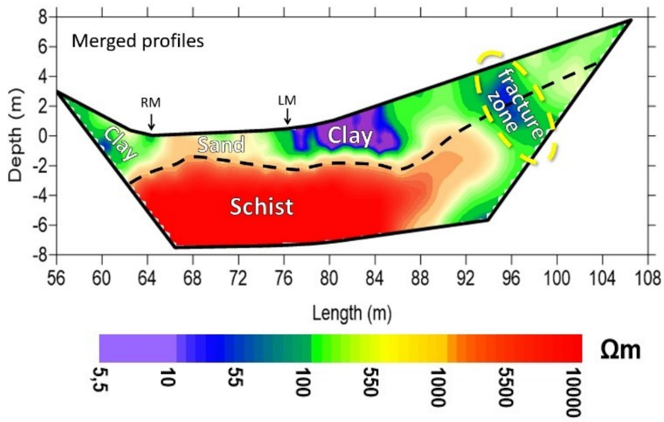

Figure 8 – The inversion model of the merged geoelectric profiles indicates a local crystalline basement rock (high resistivity values) underlying a sedimentary layer (low resistivity values). The dashed black line indicates the interface rock-soil.

There are indications that the sedimentary layer is composed by sand and clay. The clayey soil layer has resistivity lower than 150 Ωm in the stream banks and the sandy soil is restricted to the stream channel.

The crystalline rock layer is a schist that has resistivity values higher than 1000 Ωm.

These values are in agreement with the expected resistivity ranges for schists (20 Ωm to 10^4 Ωm) and for clays (5 Ωm to 150 Ωm), often indicated as illustrative cases in the applied geophysics literature.

Furthermore, was identify an anomaly in the expected electrical resistivity values for the schist rock in the left bank. It could be caused by a fractured zone (or local fault).

Since no resistivity anomaly was identified below of the Bolas Stream bed this site could be considered as suitable sites for construction of an underground dam.

5. Conclusion

The results of the combining multiple electrode arrays improve the quantity of the input data for the inversion processing. It might to minimizer possible local spikes or even some artifact caused by the spike or noise data. But, even with the increase in the input data there was no improvement in the RMS value in the combined profile compared to the others.

The geoelectric profile survey indicates the existence of two layers beneath the dry bed of the Bolas stream, near the locality of Martins. The sedimentary layer (5,5 to ~1200Ωm) composed by clay in the stream banks and sand in the stream bed. The other layer was identified being the regional schist rock (>1000Ωm).

In addition, there is a water well located nearby with a litho-log that describes two layers. The first one of unconsolidated soil with a depth of 5.4 m and the second of schist rock up to 104 m.

Also, a fractured zone in the left bank was identified, but with no connection with the stream bed. So, it will not interfere with the impounding of groundwater contained in the alluvial soil of the underground dam.

The results obtained are also found to be of considerable importance in selection of sites for underground dams in the study area, as well, to a similar geology's conditions in semiarid regions.

6. Acknowledgments

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