Identification and evaluation of groundwater resources for small rural and aboriginal communities in Chaco, Argentina

Luis Guarracino, CONICET & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina*
Macarena Amaya, Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Santiago Perdomo, CONICET & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Amilcar Juarez, Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Gabriel Gelpi, CONICET & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Jonatan Pendiuk, CONICET & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Soledad Lagos, CONICET & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
José Gómez, Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Claudia Tocho, CICBA & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina
Jerónimo Ainchil, UNSADA & Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina

Summary

In this work the main results of the first humanitarian geophysical project founded by GWB in Argentina are presented. The objective of the project is the search of groundwater resources for small rural and aboriginal communities in Miraflores (Chaco) using electrical prospecting methods. The study site faces serious water scarcity and quality problems. It is located on one of the poorest regions of the country with high child malnutrition and infant mortality rates. From a hydrogeological point of view, the only sources of freshwater are small shallow-buried paleochannels which have sandy textures and therefore capacity for storing water. In order to identify these paleochannels, Vertical Electrical Soundings and Electrical Resistivity Tomographies were performed in priority areas. Based on the analysis of geoelectrical data, 10 new wells were drilled and hand-operated pumps were installed to protect and facilitate water extraction. The results of the project have a direct impact on the quality of life of local communities and also provides solid basis for replicating this type of study in other critical areas of Chaco.

Introduction

The study site is located in a native tropical forest called "El Impenetrable" in Chaco province, Argentina. The name of the forest refers to the dense and wild vegetation that makes the access to the forest very difficult. The climate is subtropical continental. Springs and summers are hot, with maximum temperature values that can reach 45 degrees Celsius. The rainy season is from November to April with an annual rainfall ranging from 500 to 750 millimeters. The rest of the year (from May to October) is the dry season with long periods without rainfall and droughts that seriously affect water availability. This season is the most critical one for the inhabitants of the Impenetrable. The zone is inhabited by Qom, Toba and Wichi pre-Columbian communities and rural family groups. The economy of these communities is based on agriculture, cattle raising and brickworks. Although there are not official statistics, it is estimated that this region has the highest child malnutrition and infant mortality rates of the country.

The town of Miraflores has about 15,000 inhabitants and a huge rural zone with about 9,500 people. It does not have a water supply system. The nearest aqueduct is 50 km away and 100,000 liters of freshwater are transported to Miraflores by truck every week. In order to face this situation, people make wells (5 to 15 meters deep) using picks and shovels (see Fig. 1). During droughts, wells dry up and the situation gets worse. In 2013 the situation was so critical that water supply was restricted only to human consumption. Moreover, groundwater usually contains salts and arsenic concentrations that exceed the limit for human consumption established by the World Health Organization (Nicolini et al., 2012).

Figure 1: Typical dug well in Miraflores (Chaco)

At the beginning of the project, the hydrological knowledge of the area was virtually non-existent. The analysis of available geological data, the information collected during the eight campaigns and the geoelectrical surveys have resulted in significant advances in the understanding of groundwater dynamics and in the search of realistic solutions for water supply. From a hydrogeological point of view, the only sources of freshwater are small shallow-buried paleochannels (remnant of an inactive river or stream channel) located at depths from 5 to 15 m. Paleochannels have sandy textures with high porosity and high capacity for storing water. Some paleochannels emerge on soil surface and can be detected in satellite images, but most of them are buried by volcanoclastic loess (fine clayey sediments) with high concentrations of natural arsenic. There is no geophysical evidence that supports the existence of a deeper aquifer with fresh water.

One of the major problems of the Impenetrable is the scattering of population in small groups of families over vast areas of the forest. In rural areas of Miraflores there are 99 groups of families, some of them are completely insolated. For aid to be effective, the sources of fresh water should be near these groups of families. For years now, the proposal of local authorities has been the construction of a 50-km aqueduct from Castelli to Miraflores. However this solution would have little impact on the rural and aboriginal communities which are far away from the town and have serious transportation problems. Consequently, local near-surface aquifers (paleochannels) are the best and more realistic option for water supply in rural areas. In this general context, project activities were focused on the identification of groundwater resources using Vertical Electrical Soundings (VES) and Electrical Resistivity Tomographies (ERT). These methods are sensitive to saline concentration changes and can be used to detect fresh water bodies.

The access to water and sanitation was recognized as a human right by the United Nations (UN) General Assembly on 28 July 2010. This right is also recognized in Argentina through several decisions of the Supreme Court of Justice, but it is not universally guaranteed. In this regard, the GWB Project is also an attempt to make this human right a reality for the community of Miraflores.

Geophysical surveys

The electrical resistivity method, which is a noninvasive technique, was selected for delineating lateral and vertical variations in subsurface geoelectrical structures. The resistivity contrast between fresh and saline water is usually large enough to be detected by VES and ERT (e.g. Wilson et al., 2006).

A four electrode collinear Schlumberger array was used for VES measurements. The data was acquired with a direct current resistivity meter and maximum current electrode separation of 200 and 400 m. In order to validate the hypothesis that this geophysical technique can detect buried paleochannels, VES were measured across a paleochannel that can be clearly distinguished in a satellite image. Figure 2 shows sounding curves obtained in three stations across a paleochannel. High apparent resistivity values were obtained on the paleochannel (station B) while very low apparent resistivity values were measured on clayey sediments outside this feature (stations A and C).

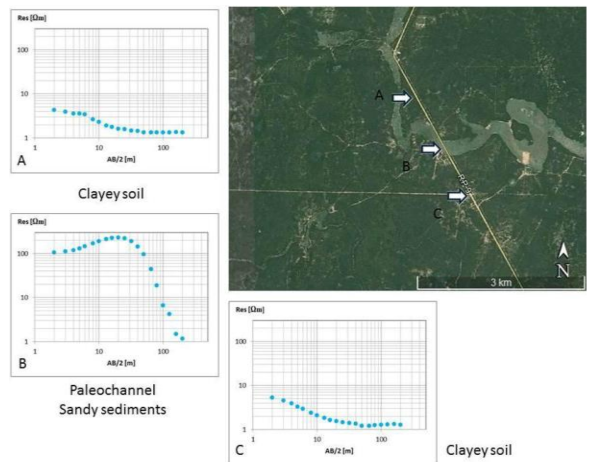

Figure 2: VES measured across a paleochannel

For the quantitative analysis of VES data, 1D modeling has been performed using an automatic and interactive inversion code developed in the University of La Plata (UNLP). The inversion code is based on the Zohdy (1989) algorithm to provide a multilayer model and then, the number of layers is reduced using the equivalence criteria of Dar Zarrouk parameters. The final proposed model has a minimal number of layers to obtain the best fit, with an error of less than 5% between observed and calculated data. An automatic resistivity system ARES was used for ERT measurements. This equipment consists of a single unit with a transmitter and receiver. The transmitter could provide 2000V and a maximum current of 5A. The high impedance receiver (20MΩ) is able to measure an input voltage range of ±20 V. This instrument injects direct current in cycles with reverse polarity. During each cycle the apparent resistivity is calculated in order to provide a mean value with a standard deviation (less than 2%). Stainless electrodes are used to inject current and bronze electrodes to measure potential differences.

The ERT is a more precise and detailed technique which provides a 2D resistivity profile of the subsurface. This technique is used to delineate the geometry and to detect the edges or boundaries of paleochannels. ERT data is obtained using a multi-electrode system with 32 electrodes and a 2.5 m separation. This system is connected to the resistivity meter via a multi-core cable and is controlled through a switching circuitry that automatically selects the appropriate 4 electrodes for each measurement.

ERT data is inverted using the Res2DInv software of Geotomo. This software uses the smoothness-constrained least-square method inversion technique (Sasaki, 1992) to produce a 2D subsurface model with a large number of rectangular cells from the apparent resistivity data. The resistivity of each cell is allowed to vary in the vertical and horizontal direction, but the size and position are fixed. Data processing involves the calculation of potential values for the 2D forward model. The inverse method starts from a simple initial model and then the resistivity of each cell is changed through an optimization technique.

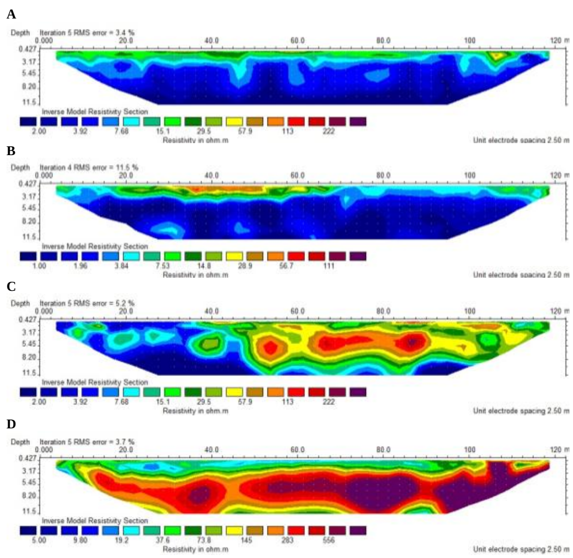

Figure 3: Resistivity patterns of ERT

During the project, a number of short VES (200-400m) were conducted in order to identify groundwater potential zones. Also some long SEV of 500m were performed to detect the possible existence of a deep aquifer system. ERT were used to define the boundaries and depth of paleochannels in local studies. In general terms, the analysis of ERT allows to distinguish two types of patterns in resistivity sections. Figure 3 shows some examples of these sections at different sites. Resistivity sections A and B show typical patterns of saline aquifers (low resistivity values) while sections C and D might indicate the presence of near-surface fresh water aquifers (bodies with high resistivity values).

Based on the collected hydrogeological information and geophysical surveys, we select the sites more likely to have freshwater. In these sites 10 wells were drilled to 5-12 m depth (see well locations in Figure 4). All water wells were cased with PVC pipes and surfer water pumps were installed. Water pumps are robust and adapted for manual use because there is no electricity supply in rural areas. From each well, information about water table depth and lithological samples were obtained. Unfortunately, 4 wells provide water with water electric conductivity equal or greater than 20 mS/m, which is an indicator of high concentrations of dissolved salts. The next step will be the physico-chemical analyses of water samples to identify and quantify water properties and chemical components like arsenic concentration. These analyses are critical to determine which of these wells can be used for human consumption (with or without treatment) or for sanitation purposes.

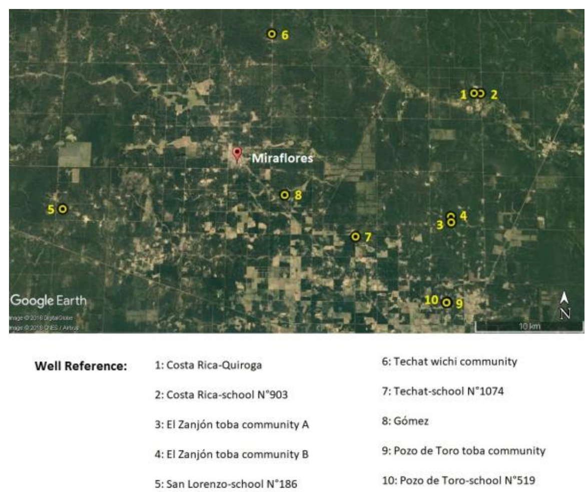

Figure 4: Location of drilled water wells

Conclusions

The GWB Project has provided 10 new water wells to Miraflores and has also contributed to increased knowledge of local hydrogeology and groundwater quality that can be used as a starting point for future works in the area. Based on our results and the information provided by inhabitants we conclude that the only groundwater resources for human consumption are shallow paleochannels. These geologic structures have high resistivity contrasts but are small in size and therefore difficult to detect and map. Near-surface aquifers are recharged by precipitation through the soil and are strongly affected by climatic variability. Preliminary estimates indicate that aquifer recharge is close to 18% of the total precipitation. For the use of the groundwater resource to be sustainable, the rate of extraction should be equal to or less than the rate of recharge. Then the water supply of the new wells must be restricted to human consumption. Another important aspect related to both sustainability and water quality is the type of well construction. In the study site most wells are excavated by hand using picks and shovels (dug wells). These wells have diameters greater than 1 m (Fig. 1) and are exposed to contamination, which may occur directly by leaves, insects and small animals falling into them. In this regard, drilled wells with plastic casing and pumps play a significant and effective role in water quality preservation. Additionally, several talks were organized in rural schools in order to inform people about topics related to the origin, quality, preservation and sustainable exploitation of water resources. As a future work, we plan to install a plant for arsenic abatement using geomaterials. A prototype of a hand-operated plant is being designed by researchers of the UNLP. It is important to remark that this GBW Project has also marked a milestone in our institution. This is the first time that our Faculty is involved in a humanitarian project and it has opened an interesting debate about the gap between social problems and the scientific community. Undergraduate and graduate students were deeply involved in field and desk activities. The project gave them the opportunity to help people using geophysical methods and a wider view of both the discipline and social reality. Moreover, three graduate thesis based on data collected in Chaco are currently in progress. All these achievements would not have been possible without the financial support of GWB.