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Geophysical Methods in Groundwater Prospecting, Quinta El Pedregal, km 21 Highways to Masaya in the Period from September to December 2022, Nicaragua

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The present study was carried out in Quinta el Pedregal, located at km 21 of the highway to Masaya, Nicaragua in the period from September to December of the year 2022; the purpose of the investigation was the identification of underground water and later to determine the optimal place for drilling; The methods of geoelectrical tomography and vertical electrical soundings were used. In both methods, the Wenner-Schumberger techniques were used, in the case of the geoelectric tomography technique, a longitudinal profile of 200m was made, reaching a depth of 49m, determining resistivity at 28m between 70 and 150 Ohm and after 28m resulting resistivity in the order of 400 Ohm. Using the vertical electrical sounding (SEV) technique, 7 profiles with lengths of 888 m were made, reaching a depth of 160 m. At 24 m, resistivities were found between 59 and 140 Ohm x m, from 24 to 98 m depth the resistivities varied between 200 to 1100 Ohm x m, from 98 to 160 m from 60 to 140 Ohm x m, as a result it was concluded that No anomalies related to the presence of water were found on the site.

Keywords: *geoelectric, vertical electrical sounding, aquifer, wenner-schumberger, resistivity*

Introduction

Geophysics is just a segment of physics that contributes to the works of:1. Groundwater prospecting 2. Geotechnology, 3. Determination of underground and agricultural environmental contamination, 4. Archeology 5. Location of structures and complex anomalies, generally subsurface; geophysical methods are considered ideal in groundwater prospecting due to their robustness in the results shown.

In the first stage of the study, the existing data and information on the area were collected and analyzed, including topography, geology; Subsequently, two field data collection campaigns were carried out using the ARES I geoelectric unit.

The arrangement in obtaining 2-D Electrical Tomography Images are: a) Wenner-Schlumberger, b) Wenner, c) Dipole-Dipole, d) Pole-Pole, d) Pole-Dipole and e) Gradient. Among the characteristics of a certain array, the following should be considered: i) the depth of investigation, ii) the sensitivity of the array to vertical and horizontal changes in underground resistivity, iii) the horizontal data coverage and the signal-to-noise ratio.

One of the fundamental reasons for carrying out the study is to contribute significantly to the identification of areas where there is water potential and that can be exploited in a sustained manner in Nicaragua. Finally, for the realization and support of said research, previous studies have been considered such as "Study on the water supply project in Managua, September 1993", "Study on the hydrogeological and isotopic characterization of Lake Nicaragua, October 2009", and "Study preparation of the project to improve the water supply in the city of Managua, February 2022". The results of the different studies have allowed to analyze and correlate the data acquired with the geophysical methods implemented in this research.

Objectives

General Objective

Apply geophysical methods in the prospecting of groundwater, Quinta el Pedregal, Km 21 highway to Masaya in the period from September to December 2022, Nicaragua.

Specific Objective

Determine the resistive characteristics of the different selected strata. Analyze the methods used and their results in the prospecting of groundwater.

Methodology, Materials and Methods

Kind of Investigation

The research is quantitative, since an interpretation of the data was carried out using the RES2DINV program.

The quantitative approach used data collection and analysis to answer research questions and test previously established hypotheses, and translates into

> “the sequential and probative. Each stage precedes the next and we cannot "jump" or avoid steps. The order is rigorous, although of course, we can redefine some phase. It starts from an idea that is being delimited and, once defined, objectives and research questions are derived, the literature is reviewed and a theoretical framework or perspective is built. From the questions hypotheses are established and variables are determined; a plan is drawn up to test them (design); variables are measured in a certain context; The measurements obtained using statistical methods are analyzed, and a series of conclusions are drawn regarding the hypothesis or hypotheses. (Sampieri, Fernández Collado, & Baptista, 2014)

The technique of basing the measurement was taken from the quantitative approach. It was carried out through the use of standardized procedures and accepted by the scientific community in the comparison of the resistivity of geological materials to analyze the existence of water, using geophysical methods such as: electrical tomography and vertical electrical sounding.

Execution Time

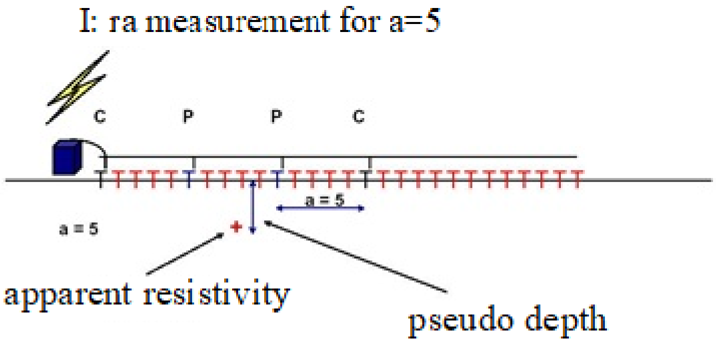
For the development of the research, there were four weeks to carry out the surveys, five weeks to analyze the data, and 8 weeks to interpret the results and write the final report.

Technique and Methods of Data Collection

In geoelectric tomography the method used is Schlumberger, in the order they follow Wenner, Wenner-Schlumberger Combined, gradient. Each method has a characteristic sensitivity which depends on the separation between electrodes. For this study, 1 profile was executed in the entire extension of the area of interest. A multi-electrode arrangement (40 electrodes spaced 5 meters apart for a total length per profile of between 200 meters) was used.

The measurement principle with Multielectrode arrangement is shown in figure 1:

Figure 1. *Measurement Principle with Multi-Electrode Arrays*



Note: As can be seen in the figure, the separation between electrodes can be arbitrary. In this case, the separation between electrodes is considered a=5, for a Wenner arrangement.

According to (Zunino & Ainchil, 2000) a methodology is proposed for the Vertical Electrical Survey (SEV) that persists to this day. The methodology for the SEV is materialized in the field with a tetraelectrodic device, linear and symmetrical with respect to an origin. Of the available electrodes, two are for potential or reception MN and two for current or emission AB. The electrodes A and B are interconnected through a source and a milliammeter and make up the emission circuit, while the potential ones, connected to a millivoltmeter, make up the reception circuit.

It goes on to describe (Zunino & Ainchil, 2000) that a SEV consists of a series of apparent resistivity determinations from circulating a current I through the emission circuit and measuring the potential difference ΔV that is generated between the reception electrodes. For [2] the apparent resistivity in the soil is heterogeneous and the measured resistivity will be in fusion of the existing real resistivities under each electrode. (Zunino & Ainchil, 2000) states that the apparent resistivity cannot be considered as an average of the present resistivities, since it can be lower or higher than all of them.

(Zunino & Ainchil, 2000) in his research he implements the Schlumberger method, in which the separation MN is considered zero compared to AB, and in this way only flows one distance. In practice MN≤AB/5 is used. See figure 2

The apparent resistivity is calculated by the expression:

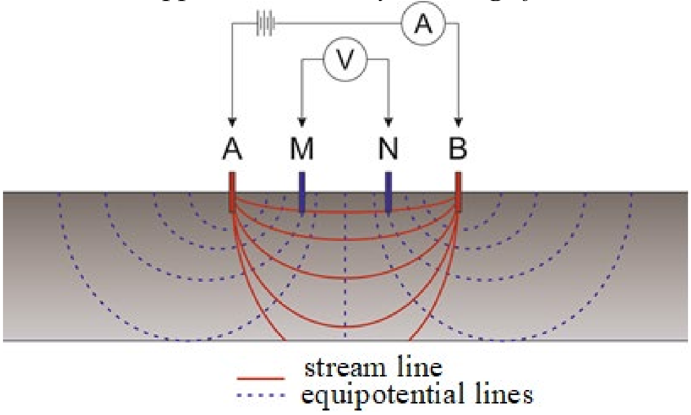
$\rho_a = k\frac{\Delta V}{I}$ ecuation (1)

Where:

K: constant that depends on the geometric configuration of the device, and for this case it takes the following form: $k = \frac{\pi(AB^2 - MN^2)}{4MN}$ ecuation (2)

ΔV: is the potential difference measured between the MN electrodes with a current I in Ohmohmmeter

Figure 2. *Graphical Representation of the Lines of Currents and Equipotential Lines in an Apparent Resistivity Reading of a Vertical Electrical Sounding*



Note: The graph shows the representation of how the measurement is carried out with the SEV methodology, retrieved from (EVEREST, Geophysics, 2023).

An ARES I geoelectric unit was used for data acquisition; This unit includes a resistivity meter, and a current amplifier all included in one unit. An intelligent cable is used, composed of a sequence of small cables of 40 meters in length with 8 electrode sockets each, the spacing between sockets is 5 meters in its entirety (in our study 5 cables were used in each measurement). To perform the measurement, all 5 cables can be placed in line at the same time.

The sequence of measurements to be taken (protocol) are edited by changing appropriate parameters with the line to be made, which automatically selects the appropriate electrodes for the cycle of measurements. The sequence of measurements for the electrode arrangement can be described as follows: using the Wenner-Schlumberger composite arrangement, for example, all possible combinations are made using a spacing between electrodes "a" equivalent to 5 meters; in the first measurement, the first 4 electrodes are used, electrodes 1 and 4 being used to send the current, and electrodes 2 and 3 the electrodes for the potential reading, in the next measurement electrodes 2, 3, 4 and 5 are used being electrodes 2 and 5 the current electrodes and electrodes 3 and 4 the potential ones, this process is used until electrodes 13, 14, 15 and 16 are used for the last measurement with spacing “a”. The following sequence of measurements is used with a spacing of "2a" equivalent to 10 meters, the first measurement is now made with electrodes 1, 3, 5 and 7, this time being injector electrodes 1 and 7, and potential electrodes 3 and 5. The second measurement is made with electrodes 2, 4, 6 and 8, this process is repeated until the end of the cable length.

Inversion of the Tomographic Image of Electrical Resistivity (ITRES)

The investment program used is RES2DINV, which divides the subsoil into a mesh of rectangular blocks, then the program determines the resistivities of the blocks, creating a finite element model of the resistive distribution of the subsoil, said model is adjusted then to iteratively match the actual measurements. The program has a data optimization process which attempts to reduce the difference between the measured and calculated apparent resistivities by adjusting the resistivity in the block model. The way to measure this discrepancy is given by the Root-Mean-Squared error (RMS). Enough with three interactions.

The inversion routine used by the program is the least squares, which is based on a quasi-newton optimization, which allows reducing processing time (Loke and Barker, 1996).

Primary Sources

Instituto Nicaraguense de Acudeductos y Alcantarillados (INAA), (1993). Estudio sobre el proyecto de abastecimiento de agua en Managua. Kokusai Kogyo Co., Ltd., Tokio.

Zunino, E. & Ainchil, J. (2000). Evaluación geofísica del Acuífero Guraní en la Argentina. *Aguas Subterraneas*.

Krásný, J. (2003). Distribución espacial de los parámetros hidráulicos en diversos medios hidrogeológicos. *Boletín Geológico y Minero*, 114, 171-182.

Instituto Nicaraguense de Estudios Territoriales (INETER), (2009). Estudio caracterización hidrogeologica e isotopica del lago de Nicaragua. Dirección General de Recursos Hídricos.

Gómez Rave, J.C. (2009). Geologia, geofisica, hidroquimica e isotopos, como herramientas para definir un modelo conceptual hidrogeologico, caso de aplicación: acuifero costero municipio de Turbo. *Escuela de Geociencias y Medio Ambiente.*

Picado, M. A. (2012). MODELAMIENTO NUMÉRICO DE LA DINÁMICA DE FLUJO SUBTERRÁNEO DEL ACUÍFERO DE TISMA, PARA EVALUAR LA CONECTIVIDAD ENTRE LOS LAGOS XOLOTLÁN Y COCIBOLCA (Doctoral Dissertation, UNIVERSIDAD NACIONAL).

Supandi, S.(2021). Geotechnical profiling of a surface mine waste dump using 2D Wenner-Schlumberger configuration. *Open Geosciences*, 13 (1), 335-344.

Empresa Nicaraguense de Acueductos y Alcantarillados Sanitarios (ENACAL), (2022).

Estudio preparatorio del proyecto para mejoramiento del suministro de agua en la ciudad de Managua. Agencia de Cooperación Internacional de Japon (JICA).

Secondary Sources

Nicaraguan Institute of Territorial Studies (INETER). General Directorate of Geology and Geophysics.

Nicaraguan Institute of Territorial Studies (INETER). General Directorate of Water Resources.

National Water Authority (ANA). General Directorate of Water Resources.

Universe

The universe of study is the Buena Vista region with an extension of 12 km2. Population Quinta el pedregal with an area of 2 km2

Sample

For the geoelectric Tomography, a profile of 200 meters east-west orientation was used to reach a depth of 50m.

For the Vertical Electric Sounding: Seven SEVs with a profile of 800 meters each to reach a depth of 150 m, SEV 1-2-3 east-west orientation; SEV 4-5 northwest-southeast orientation; SEV 6-7 northwest-east orientation

Inclusion Criteria

The site will be measured within a radius of action of 1 km, taking Quinta el Pedregal as a reference point.

Exclusion Criteria

All those measurements that are not within a 1km radius of action from the Quinta el Pedregal reference point.

Theoretical Aspects

For (Gómez Rave, 2009), the geophysical technique is a non-invasive methodology dedicated to superficial investigation, this technique is characterized by two-dimensional electrical tomographies, which have been used in investigations such as: 1. Search for aquifers, 2. Geotechnology, 3. determination of underground and agricultural environmental contamination, 4. archeology and, in general, the location of structures and complex anomalies, generally sub-surface (Ackworth, 2001; Bernstone and Dahlin; 1999, Dahlin,1996; etc.). The availability of modern investment programs (Daily and Owen, 1991; Li and Oldenburg, 1992; Loke and Barker, 1996, etc.), as well as measuring equipment (Dahlin, 1993) have greatly contributed to this development. In order to model the subsoil with an arbitrary distribution of resistivities and also take into account the variation of other parameters that influence it, such as topography, the finite element and finite difference methods are used for its calculation, the which allow to consider these variations point to point and in all directions in a considered volume of land. (NICASOLUM, 2022)

In order to model the subsoil with an arbitrary distribution of resistivities and also take into account the variation of other parameters that influence it, such as topography, the finite element and finite difference methods are used for its calculation, the which allow to consider these variations point to point and in all directions in a considered volume of land. (NICASOLUM, 2022)

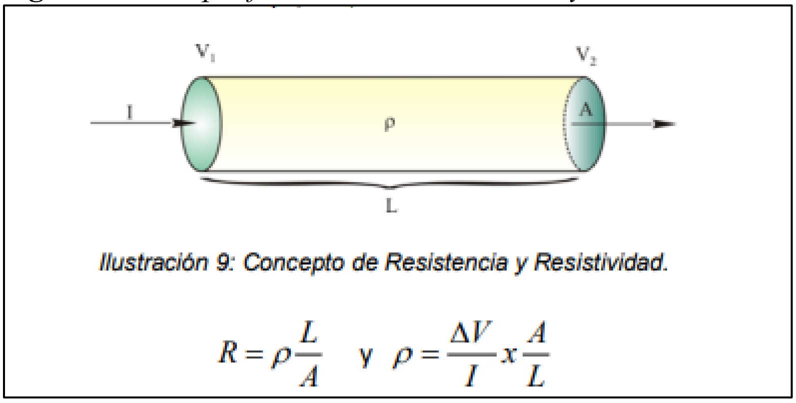
The electrical prospecting method is based on the study of electrical potential fields, both in relation to what naturally exists in the earth's crust, and those artificially caused in it. By means of these measurements, the situation in the subsoil can be determined, structures or geological accidents can be recognized (cantos, 1974). One of the advantages of these methods is being able to control the depth of penetration and in some of the modalities it is done in a quite specific way, such as the resistivity method using the technique of Vertical Electrical Soundings (lakubosvkii and Liajov, 1980). (Figuera Martínez, 2010)

Ohm's Law Ohm's law expresses that the Resistance (R) offered by a conductor to the flow of a current is directly proportional to the potential difference (ΔV) between the ends of the material and inversely proportional to the intensity (I) of the current flow. (García & Castro, 2018)

$$R = \frac{\Delta V}{I} \text{ ecuation (3)}$$

The unit of measurement of resistance is the Ohm, which arises from the following definition: When a current of intensity I = 1 Ampere is circulated through a conductor, and the potential difference between its ends is 1 Volt, the Resistance is of R = 1 Ohm (Ω). In turn, the Resistance (R) of the conductor is directly proportional to the length (L) of the material considered, and inversely proportional to its section (A), multiplied by a constant of proportionality, known as resistivity ρ (Rho). See figure 3.

Figure 3. *Concept of Resistance and Resistivity*



Note: is an illustration of the concept of resistance and resistivity.

Resistivity (also called specific resistance) is a constant inherent to each material, regardless of its shape. The unit of measurement is the Ohm x meter (Ω.m). A conductor with a section of 1 m2 and a length of 1 meter has a resistivity of 1 Ohm x meter when it allows a current of intensity I = 1 Ampere to pass while the potential difference between its ends is equal to (ΔV) = 1 Volt. (García & Castro, 2018)

Electrical Resistivity of Rocks

The materials that make up the earth's crust are generally insulators or poor conductors, since only metals and some of their salts behave as conductors.

This means that rocks generally have very high resistivities. Pure water also has very high resistivity, but the presence of dissolved salts makes it an electrolytic conductor. But most of the rocks that make up the most superficial portion of the crust are weathered to a greater or lesser extent and have fissures or pores, in which a certain moisture content is generally found. The water contained in the pores generally has dissolved salts, which contribute to increase the capacity to conduct electrical current. (García & Castro, 2018).

Por esta razón la resistividad de las rocas consolidadas y no consolidadas depende de su constitución mineralógica, de su porosidad, del grado de saturación y del tipo de líquido que rellena los poros. El agua destilada posee una resistividad que alcanza los 3.000 Ω*m, mientras que el agua marina puede tener 0,03 Ω.m. Como la resistividad depende también del grado de saturación, se da el caso que una grava saturada puede tener una resistividad similar a la de una arena seca, o bien que un limo desecado puede ser igual de resistivo que una arena saturada. La situación se complica aún más si se agrega que el contenido de sales del agua intersticial es inversamente proporcional a la resistividad. Una arena saturada con agua salobre puede poseer igual resistividad que una arcilla. (García & Castro, 2018)

The electrical resistivity of ρ of any substance is determined numerically by the resistance obtained in a cubic centimeter of that substance, taking the form of a cube, to the electric current directed perpendicular to one of the edges of this cube. The reverse magnitude of resistivity is called electrical conductivity. (Figuera Martínez, 2010) (See Table 1).

Table 1. *Electrical Resistivity by Rock Type*

Rock Type	**Resistivity Ω-m**
Seawater	<0.2
Sands and gravels with salt water	0.5-5
graphite schists	0.5-5
brackish waters	1-10
clays	1-20
Groundwater in limestone and carryover	20-200
Groundwater in granite and metamorphic rocks	20-100
volcanic tuffs	20-100
surface drinking water	20-300
slimes	30-500
quartz sands	30-10000
clayey sands	50-300
sands	50-500
Sands and gravels with fresh water	50-500
sandstones	50-5000
marls	50-5000
Clay and altered schists	100-300
blackboards	100-1000
Genesis and Altered Granite	100-1000
Volcanic Breccia	100-2000
gravels	100-10000
healthy shale	300-3000
Granite	300-10000
basalts	300-10000
limestones	300-10000
Dry sands and gravels	1000-10000

Conglomerate	1000-10000
healthy genesis	1000-10000
Distilled water	>500

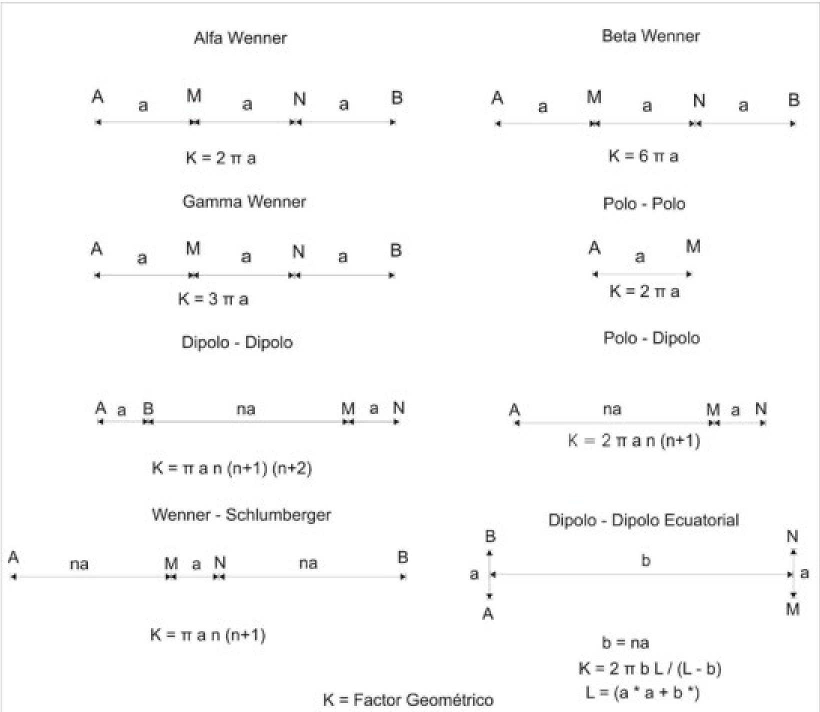
Note: These are resistivity values according to the type of material.

The resistivity varies depending on the characteristics of the terrain. Some of the factors that influence it are:

- The degree of soil saturation.
- Temperature.
- Porosity and the shape of the pores.
- The salinity of the fluid.
- The type of rock.
- Geological processes that affect materials.
- The presence of clayey materials with a high capacity for cation exchange.

The way of arranging the electrodes through which the current is introduced and those with which the potential is recorded on the surface of a medium whose resistivity is to be investigated, gives rise to different devices or electrode arrangements. The importance of these devices is that their mathematical formulations condition the work in the field, allowing greater or lesser agility in the development of operations or enabling measurement in places that have natural conditioning. See figure 4.

Figure 4. *Various Electrode Devices*



Note: The different electrode devices for geophysical prospecting are presented.

Results and Discussion

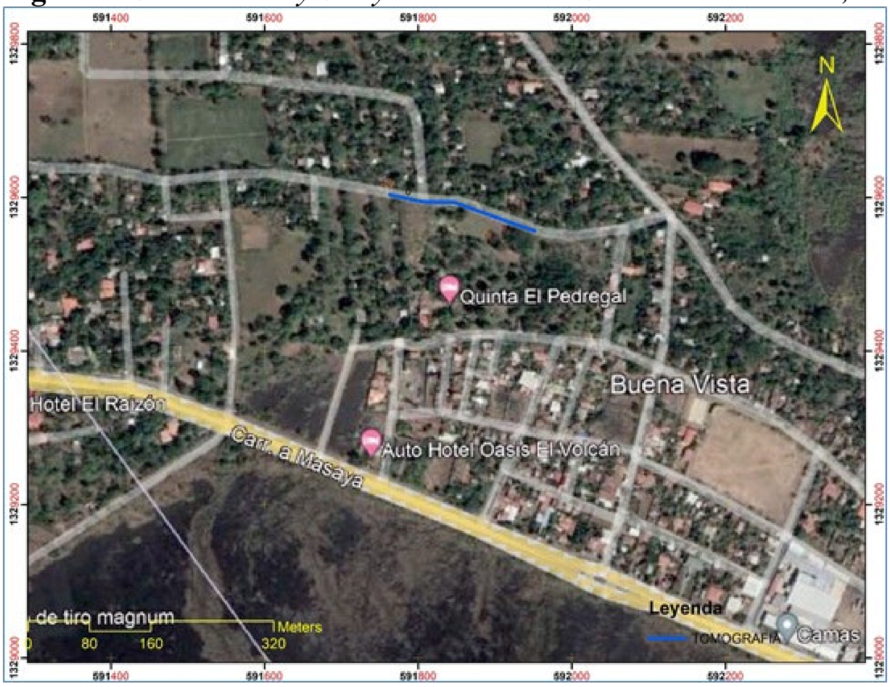
Geologically, the area under study is located in pyroclastic flows and fallen pyroclastic deposits, which belongs to the Quaternary Masaya volcanic group. This area is formed by several layers of ash, tuff and volcanic slag.

The areas around the Masaya volcano have been subject to volcanic processes from the Pliocene epoch to recent times. The Las Sierras group shows that volcanism covered a very wide area with ignimbrite and agglomerate deposits that in some sectors are thicker than 250 m; On these materials is the series of lavas and pyroclasts with different thicknesses that are genetically associated with volcanism in the Masaya complex. (Comisión Nacional de Energía, 2001)

Geoelectric Tomography

The following figure 5 shows the trace of the longitudinal profile of the geoelectrical tomography carried out at the site of interest.

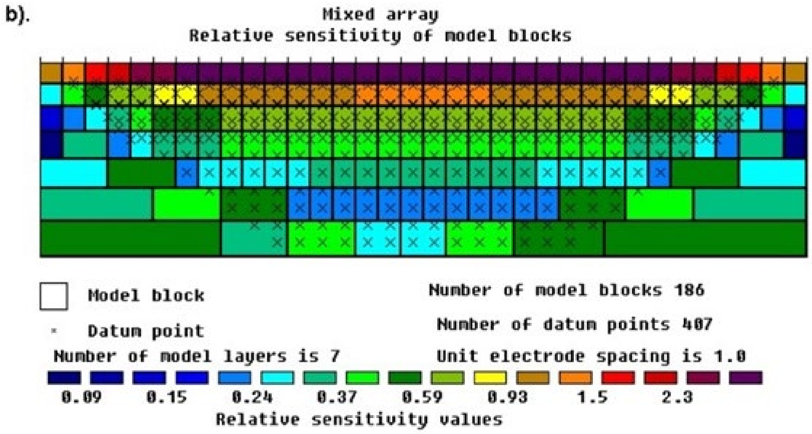
Figure 5. *Geo-electricity Study Location Area Carried out at Km 21, Burned Stone*



Note: Owner Norwin Ramírez, 1 tomography with a length of 200 meters was carried out, with the Schlumberger method.

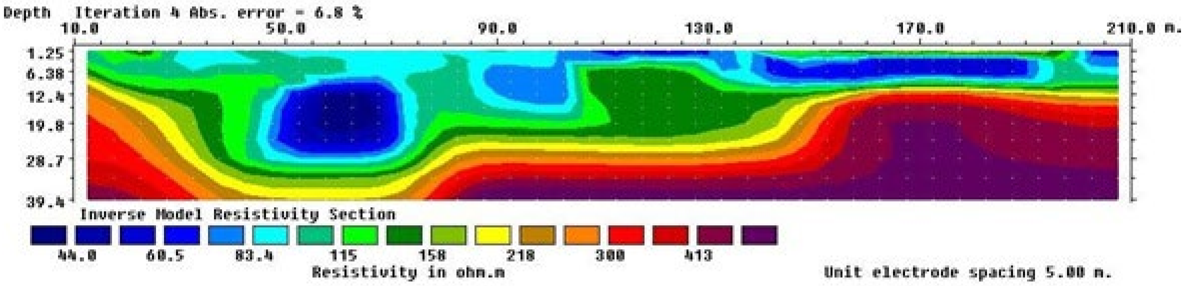
From the acquisition point diagram for the Wenner-Schlumberger arrangement (ARES I, 2019) the following result is obtained. See figure 6 and 7

Figure 5. *Diagram of Acquisition Points for the Wenner-Schlumberger Array (ARES I, 2019)*



Note: The dot diagram is obtained from the Geoelectrical Tomography Survey.

Figure 6. *Tomography Corresponding to the Sounding in a West-East Direction*



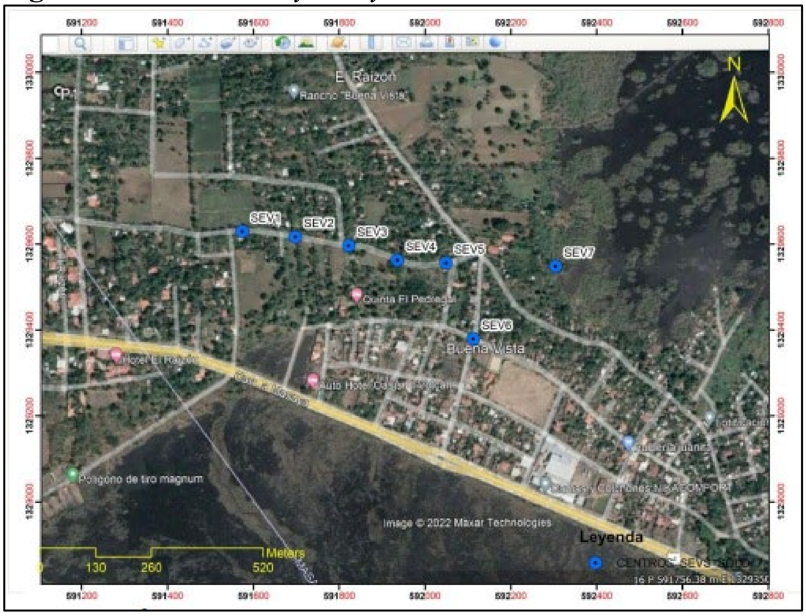
Note: Result of acquisition points for Wenner-Schlumberger arrangement (ARES I, 2019).

The resistivity intervals in the pyroclastic flow zone present vertical variability in terms of electrical resistivity values, since strata with important lithological differentiation can be found locally. The Tomography corresponding to the sounding in the west-east direction presents resistivities in the ranges 45 to 70 Ohm x m. But it is not an anomaly that can be associated with the presence of water. In general, up to 28 meters, the soil layers have a resistivity range between 70 and 150 Ohm x m; after the depth of 28 meters the resistivities increase up to 450 Ohm x m.

Vertical Electrical Sounding (SEV)

Figure 8 shows the outline of the longitudinal profile of the seven vertical electrical soundings (SEV) carried out at the site of interest.

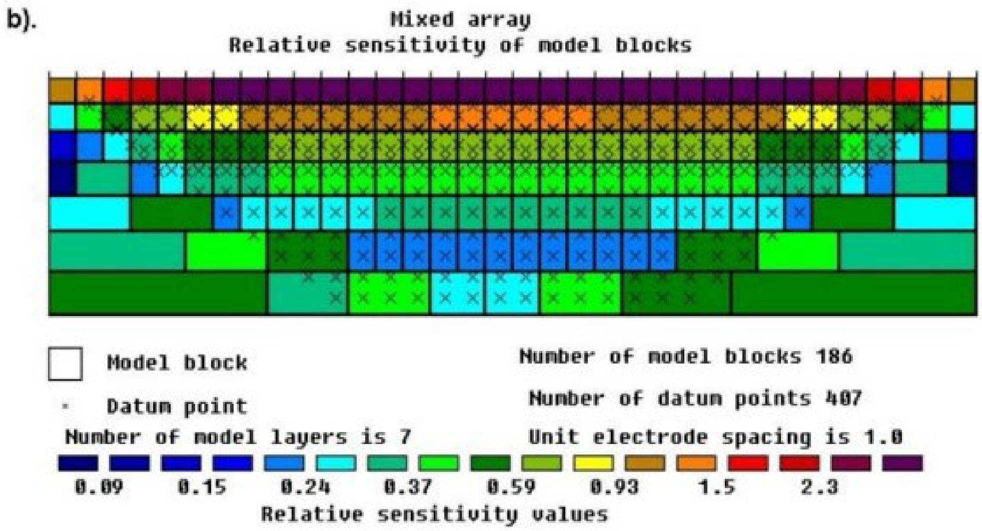
Figure 7. *Geo-electricity Study Location Area Carried out at km 21, Burned Stone*



Note: 7 SEVs of 888 meters in length and separated by their centers at 135 meters were carried out to generate a tomography of 810 meters in length, after interpolating data between each 2 SEVs, with the Schlumberger method.

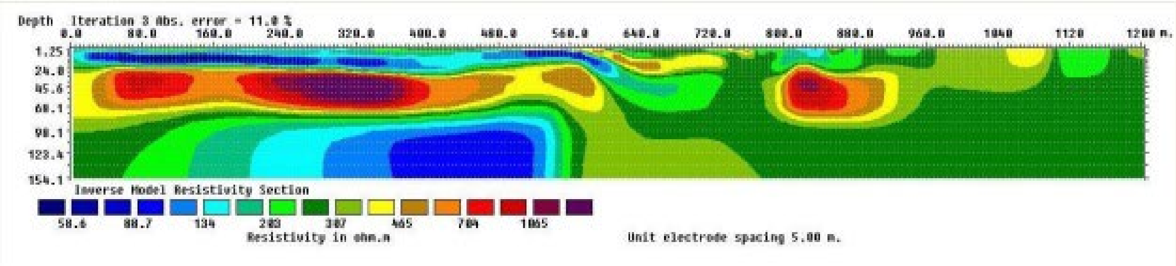
From the acquisition point diagram for the Wenner-Schlumberger arrangement (ARES I, 2019) the following result is obtained (See Figure 9 and 10).

Figure 8. *Diagram of Acquisition Points for the Wenner-Schlumberger Array (ARES I, 2019)*



Note: The inversion routine used by the program is their least squares, which is based on a quasi-newton optimization, which allows to reduce processing time (Loke and Barker, 1996).

Figure 9. *Tomography Corresponding to the Analysis Carried out on the 7 SEV*



Note: boreholes in a west-east direction, parallel to the road located in the northern part of the study site.

In this second campaign it was found that at a depth of 24 meters the resistivities are between 59 and 140 Ohm x m, from 24 meters to 98 meters the resistivities are between 200 and a maximum of 1100 Ohm x m, indicating the presence of volcanic slag; Later, at depths of 98 to 160, resistivities between 60 and 140 Ohm x m were measured, as well as no faulting and/or fracturing that could be associated with an aquifer.

As expected, in the study area the depth of the aquifer mantle is greater than 150 meters, compared with the hydrogeological sheets of (Instituto Nicaraguense de Estudios Territoriales (INETER), 2009), the existence of water corresponding to the Sierra aquifer is verified. As stated (Empresa Nicaraguense de Acueductos y Alcantarillados Sanitarios (ENACAL), 2022). The depths oscillate between 50m to 150m, however, the results of tomography and SEV at 160m indicate high resistivities in the order of variation of levels 60, 140, 200 up to 1100 Ohm, so no anomalies were observed that characterize the presence of an aquifer

The results obtained on high resistivities are mostly conditioned by the geological context of the study area, showing homogeneity in the geological composition of the materials.

In relation to the application of each of the methods, it can be assumed that geoelectric tomography according to Wenner-Schlumberger arrangement is recommended to be applied to places where there are indications that the water is shallow. Regarding the vertical electrical sounding tomography with Wenner-Schlumberger arrangement, it is applied to sites where the level of the aquifer mantle is deep, since the scope of study with this method was 160 m deep. The application of different geophysical methods in the search for water showed us that the results are coherent and complementary; in the case of SEVs, obtain deeper information and correlate it well with geological information.

Conclusions

In the study area, measurements with both geophysical methods, vertical sounding and tomography, show high resistivities, indicating the absence of water and a homogeneous geological material.

In both campaigns, the information provided by each of the survey and tomography methods is coherent and complete information, no method replaces the other, assuming that each of them has its advantages and disadvantages.

Gratitude

To the American University (UAM) and the Faculty of Engineering and Architecture (FIA), for opening the doors of knowledge in this new stage of my life.

To Mr. Norwin Ezequiel Ramírez Conde and Olivier Cordey, owners of Quinta El Pedregal for their financial support.

References

Comisión Nacional de Energía. (2001). *Plan Maestro Geotérmico de Nicaragua, evaluación de.*

Empresa Nicaraguense de Acueductos y Alcantarillados Sanitarios (ENACAL). (2022). *Estudio preparatorio del proyecto para mejoramiento del suministro de agua en la ciudad de Managua.* Managua: Agencia de Cooperación Internacional de Japón (JICA).

EVEREST, Geophysics. (6 de enero de 2023). *https://everestgeophysics.com/es/metodos/electricos/sondeo-electrico-vertical/.* Obtenido de https://everestgeophysics.com/es/metodos/electricos/sondeo-electrico-vertical/.

Figuera Martínez, M. (2010). *Metodo geofísico aplicados en la exploración del agua subterránea, caso: acuífero de Villa Hidalgo, S.L.P.* San Luis Potosí: Insituto Potosino de Investigación Cietífica y Tecnólogia, A.C.

García, R., & Castro, E. (2018). *Apuntes sobre exploración geofísica y técnicas de perforación.* Buenos Aires, Argentina: Secretaria de Infraestructura y política hídrica, consejo hídirco federal.

Gómez Rave, J. (2009). Geología, geofísica, hidrogeoquímica e isotopos, como herramientas para definir un modelo conceptual hidrgeológico, caso de aplicación: acuífero costero municipio de Turbo. *Escuela de Geociencias y Medio Ambiente*.

Instituto Nicaraguense de Estudios Territoriales (INETER). (2009). *Estudio caracterización hidrogeologica e isotopica del lago de Nicaragua.* Managua, Nicaragua: Dirección General de Recursos Hidricos.

NICASOLUM. (2022). *Estudio Tomografias Geoelectrica a traves de SEV.* Masaya: NICASOLUM.

Sampieri, H., Fernández Collado, C., & Baptista, L. P. (2014). *Metodoligía de la investigación.* México D.F.: McGraw-Hill/Interamericana Editores, S.A. de C.V.

Zunino, E., & Ainchil, J. (2000). Evaluación geofisíca del Acuífero Guaraní en la Argentina. *Aguas Subterráneas*.