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Comparison of Geophysical Methods by Electrical and Electromagnetic Tomography to Determine Water Anomalies, in the Year 2023

Victor Rogelio Tirado Picado
ROCID: 0000-0002-7907-0006
American University (UAM), Managua, Nicaragua

ABSTRACT

The main objective of comparing the methods for carrying out geophysical studies is to establish the benefits of each of them according to their theory, their implementation and action on the geological and soil characteristics. The two geophysical methods were implemented: electrical tomography and electromagnetic geophysical, implemented in the Bonanza area and in Managua, country of Nicaragua. As a result, the assessment, from a scientific point of view, the two methods that were used are suitable to carry out geological soil in any part, the advantages of both methods are the agility and time to obtain the results immediately. It must be considered that the methods must be carried out in the same place and not separately. To have an unbiased evaluation of the methods, they must be carried out under the same geological and soil conditions.

Keywords: Electrical resistivity, electrical tomography, electromagnetic, geology, hydrogeology

INTRODUCTION

The present geophysical study has been prepared to study the behavior of underground water, using the electrical resistivity method in the Electrical Tomography (ET) modality, to evaluate the geo-electrical characteristics of the subsoil in depth and determine the stratigraphic sequence of permeable layers. , non-permeable, affected by geological faults, fractured and non-fractured to associate them WITH groundwater flows (aquifers) or WITHOUT groundwater flows (aquitards) with the purpose of locating favorable sites for the location of wells for drinking water supply, located in the area. The study area is located in the municipality of Bonanza, Autonomous Region of the North Caribbean Coast (RACCN), Nicaragua. On the other hand, the results of the electromagnetic (EM) geophysical study are presented in the city of Managua, department of Managua, precisely in the place known as the second entrance to the Hills, with the purpose of determining the geophysical-geological geometric characteristics of the stratigraphic sequence. of the subsoil based on the distribution of the electric potential field in depth, identifying non-permeable layers (Aquitards) and permeable layers that could be related to water flows (Aquifers).

The main objective of the research is the comparison of geophysical methods, by electrical tomography and electromagnetic. To develop the above, first the information will be organized and synthesized conceptually, and then the studies will be put into practice in two different places in Nicaragua. Finally, the importance as well as its advantages and disadvantages of using the methods presented above will be assessed.

METHODOLOGICAL DESIGN

This research work was designed under the quantitative approach, since this is the best one that adapts to the characteristics and needs of the research. The quantitative approach used data collection and analysis to answer the research question and answer the general question previously established, and results in

> *"The sequential and evidentiary. 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 limited and, once delimited, objects and research questions are derived, the literature is reviewed and a framework or theoretical perspective is built. Hypotheses are established from the questions and variables are determined; a plan is drawn up to test them (design); variables are measured in a certain context; The measurements obtained are analyzed using statistical methods, and a series of conclusions are drawn regarding the hypothesis(es)". (Hernández Sampieri, Fernández-Collado, & Baptista Lucio, 2006), (page. 4-5).*

Geophysical Study by Electrical Tomography

In accordance with (Ackworth, 2001) and (Bernstone & Dahlin, 1997) the Electrical Resistivity Method (ITRE) is a geophysical technique used for the study of the subsoil with the specific objective of determining the real distribution of the electrical resistivity of the subsoil, from apparent resistivity values obtained from measurements made on the surface of the land. As a general rule, an electrical tomography study requires obtaining a very high number of data, with a small spacing between measurements in order to obtain the necessary lateral resolution.

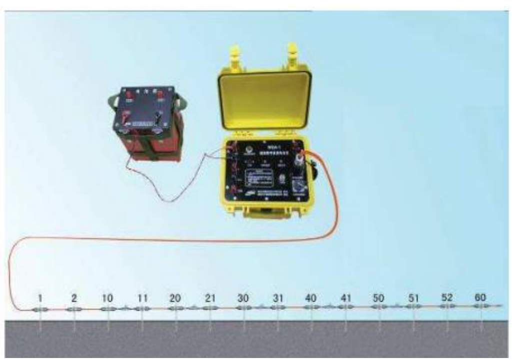

Illustration 1: Diagram of the position of cables and electrodes for performing Electrical Resistivity Tomography.

Source: self-made. (2023).

On the other hand, the author (Dahlin, 1996), (Dahlin, On the automation of 2D resistivit surveying for engineering and environmental applications, 1993) the geophysical method of electrical tomography (ET) is based on the implantation of a number of electrodes (60) along profiles (Illustration 1), with a specific separation that will be conditioned by the degree of resolution that is needed and that in This case is one meter at a research depth of 15 meters;

The smaller the electrode separation, the higher the resolution and the lower the depth of the investigation and vice versa.

With all the electrodes connected to the measurement equipment and through a specific program that is created for each objective, the electrical tomography equipment (WDA-1 Super Digital DC Resistivity/IP Meter) selects the set of electrodes that will work for each current injection.

It is important to mention that (Griffiths & Baker , 1993) from the correlation between the injected current value, the measured voltage and a geometric coefficient associated with 4 electrodes, the "apparent electrical resistivity" of the subsoil corresponding to the required depth and/or thickness is obtained (Illustration 2).

According to (Li & Oldenburg, 1992) a multielectrode investigation, as is the case of electrical tomography, with the Wenner electrode arrangement, is carried out by injecting current into the ground through electrodes with separation “(s+2) a” and simultaneously or sequentially measuring all potential differences. between the potential electrodes with spacing “a”.

Here, the separation factor “s” is an integer that corresponds to the maximum number of potential readings where the midpoint “m” is taken as the position to the potential dipole closest to the midpoint between the two current electrodes.

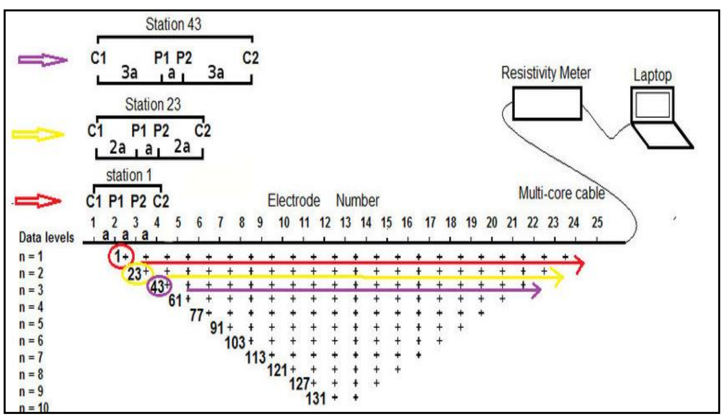

Illustration 2: Sequence of measurements for the construction of a pseudo electrical resistivity section.

Source: self-made. (2023).

The final result of this type of study is a distance-depth image with the distribution of the real resistivity of the subsoil, easily understandable in geological, geotechnical or environmental terms (Illustration 3).

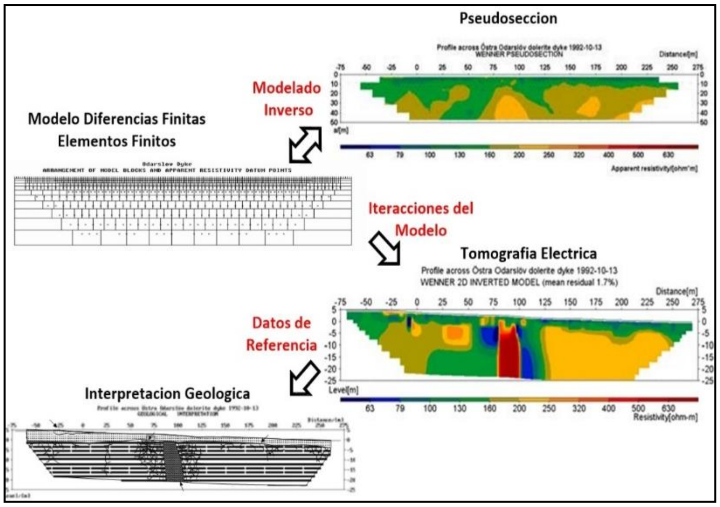

Illustration 3*:* General outline of the Electrical Tomography method and its Interpretation

Source: self-made. (2023).

Electromagnetic Geophysical Study

Information Gathering:

The first stage of the study consisted of the collection, review, selection and interpretation of existing information such as reports, topographic, geological, geotechnical, hydrogeological and geophysical maps of the study area that have contributed to improving the interpretation of the electromagnetic results.

Field Work:

A geophysical prospecting survey was carried out in 3 profiles called PEM1 L110, PEM2 L111 and PEM3 L112 respectively, which consisted of the application of the natural electric field method, based on the contrast of the electrical resistivity between the rocks. and the minerals of the subsoil or between rocks and groundwater based on the measurement of the component of the natural electric field of N frequencies that circulate in the subsoil, to study anomalous variations produced by geological bodies to study the characteristics of the subsoil.

The author (Sequeira, 2011), in this study, the natural field Electromagnetic (EM) method was used, which consists of inserting two electrode bars into the ground separated by a constant distance of 10 meters linked by a cable that is coupled to the instrument. The distance between measurements is 5 meters.

Measuring Instrument

The example given by the authors (Sequeira & Rubí, Estudio geofísico electromagnético en finca Nuevo Carnic para ubicación de pozo de abastecimiento de agua., 2021), the equipment PQWT-T300C series geophysical prospecting instrument (Illustration 4). The use of a natural electric field source as a working method, with contrast of the electric potential between rocks and subsoil minerals or between rocks and groundwater, based on the measurement of the natural electric field component of N (37) different frequencies on the surface of the land, according to their different variations, to study anomalous changes produced by geological bodies, resolving geological problems through electromagnetic prospecting methods.

Because this method measures the electrical component of the earth's electromagnetic field, called the natural electric field method in which we choose or select the corresponding frequencies according to the depth of study; It is commonly called as frequency selection method or as natural potential frequency method. According to this theory, the design and production of equipment is called detection potential frequency instruments, referring to natural electric field instruments of frequency selection for exploration work.

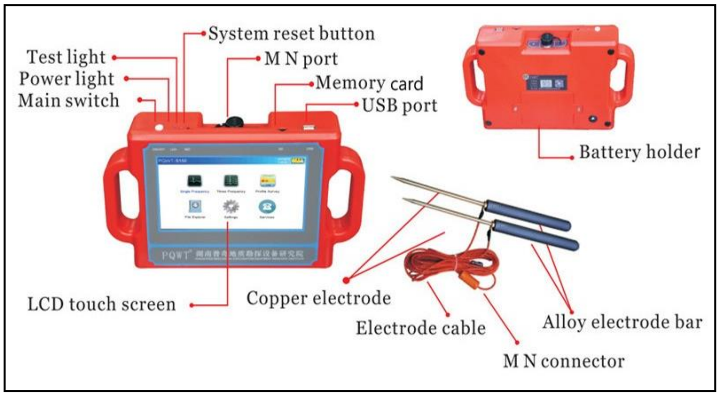

Illustration 4: PQWT-T300C measuring instrument with its accessories.
Source: self-made. (2023).

The data acquisition system used is manufactured in China; includes a WDA-1 device that is designed with two cable sockets that allow configuration of the electrode array without switching control unit and thus makes the measurement process much simpler and easier. The complete device consists of what is described below:

Multiple functions: the range of voltage and current and the precision of small signals; allows it to increase dramatically, making it suitable for working with rock.

Therefore, from a professional point of view to classify it as geological equipment; The equipment must belong to the category of electrical geophysical instruments. From the application point of view; To classify it, it can be called prospecting instrument, water detector, vacuum detector, prospecting equipment, instrumental engineering exploration equipment, geothermal detector, archeology artifact detector, logging tools. From the perspective of measurement field source classification, also known as natural electric field instrument, audio electric field instrument, ground audio instrument.

The instrument makes use of natural terrestrial field sources and is therefore a simple and lightweight instrument.

After data acquisition using the built-in computing functions, the instrument can automatically draw the curve graph and profile map (Output Files) with an instruction from the instrument menu. It can clearly reproduce the geological structure and quickly determine the location of rock mass, karst cave, aquifer, geological structures, etc. The following illustration (5) shows the equipment used in this research.

The measurement methodology used consists of inserting two copper bars (electrodes) into the ground separated by a constant distance of 10 meters, joined by a cable that is coupled to the instrument. The sampling or measurement sequence for this case was 5 meters. The sampling or measurement sequence is shown in illustration 5.

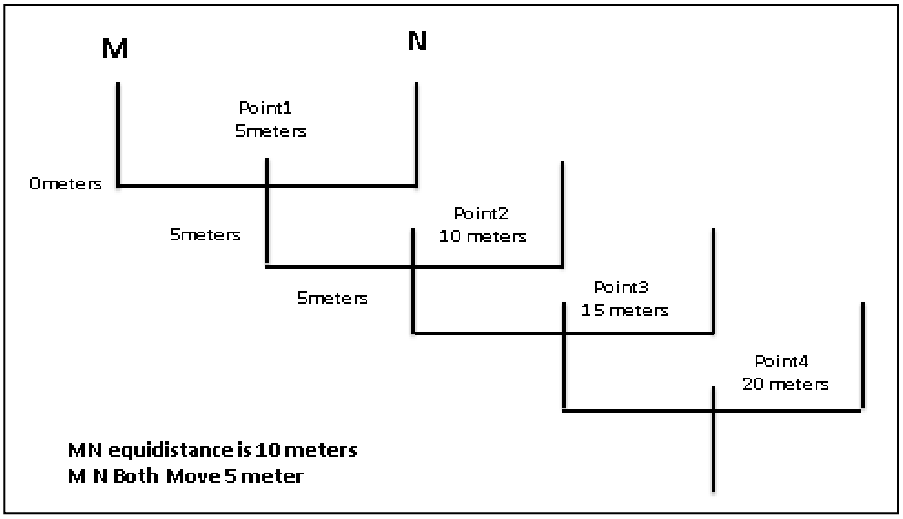

Illustration 5: Field measurement scheme of electromagnetic data.
Source: self-made. (2023).

The acquisition of electrical potential data is carried out point by point, however, the output is a two-dimensional graph or inverted electrical section like the ones presented in this report.

For the present electromagnetic survey, three (3) profiles were made in the study area in order to establish the depth and thickness of the permeable and non-permeable layers. These were designated as PEM1 L110, PEM2 L111, and PEM3 L112, in different addresses. The length of the profiles was greater than 100 meters with a separation between potential electrodes of 10 meters and using 37 frequencies in the window of 27 Hz - 170 Hz, guaranteeing an investigation depth of 300 meters (Table 1).

The distribution of profiles was drawn based on criteria such as: existing geological formations on the site and in the environment, direction of possible faults and direction of groundwater flow.

A very important criterion in this arrangement of EM profiles is based on the application of the study in more productive groundwater hydrogeological formations.

RESULTS AND DISCUSSION

Geophysical Study by Electrical Tomography

An Electrical Resistivity Tomography was performed, called TE PINAR illustration (6), with a length of 600 meters each. The separation between electrodes was 10 meters, reaching a maximum investigation depth of 150 meters.

The electrode arrangement used in the measurements was the Wenner Alfa in multichannel measurements).

Table 1 presents the general characteristics of Electrical Resistivity Tomography.

Illustration 6: Location of electrical tomography at, Bonanza.
Source: own elaboration, from Google Earth. (2023).

Table 1: General characteristics of electrical tomography.

Electrical Tomography	Coordinates				Length (m)	Course	Depth(m)
	Start		End				
	East	North	East	North			
TE POINTS	751665	1547027	752138	1547389	600	SW-NE	150

Source: self-made. (2023).

Subsoil Electrical Response on Plantel Pinar Highway

In general, in the inverted electrical section within the study area, the horizontal line represents the length of the electrical tomography (ET) given in meters, and the vertical line represents the maximum depth of investigation achieved. The color scale represents the electrical resistivity values obtained by inverting the measured resistivity data.

For easy interpretation of tomography scans; The same electrical resistivity scale is used for all tomography (illustration 7).

Illustration 7: Location of electrical tomography at Bonanza.
Source: Own elaboration, based on the team's results. (2023).

Electrical resistivities less than 15 ohm.m (intense blue colors) are associated with deposits of pyroclastic rocks, lavas and very clayey, non-compact humid sandstones.

Electrical resistivities between 15 ohm.m and 70 ohm.m (light blue and light blue colors) which are associated with pyroclastic rocks, lavas and humid NON-compact clayey sandstones with a certain flow of water at depth.

Electrical resistivities between 70 ohm.m and 400 ohm.m (light green-dark green colors) which is associated with pyroclastic rocks, lavas and fractured sandstones with water flow and which constitutes the aquifer of the place.

Electrical resistivities greater than 400 ohm.m (yellow to purple colors), which is associated with pyroclastic rocks, lavas and dry compact sandstones.

TE Pinar Electrical Resistivity Tomography

It has a length of 600 meters (illustration Figure 8) with a southwest – northeast direction. The geoelectric section shows a superficial layer (dark blue colors) with electrical resistivities less than 15 ohm.m on very humid non-compact clayey rocks of the Matagalpa formation and of little lateral extension, with a thickness of about 20 meters.

A superficial layer (light blue and light blue colors) with electrical resistivities between 15 ohm.m and 70 ohm.m is observed on moist non-compact clayey rocks of the Matagalpa formation extended laterally throughout the geoelectric section, with a thickness of about 20 meters and a certain groundwater flow in the lowest part.

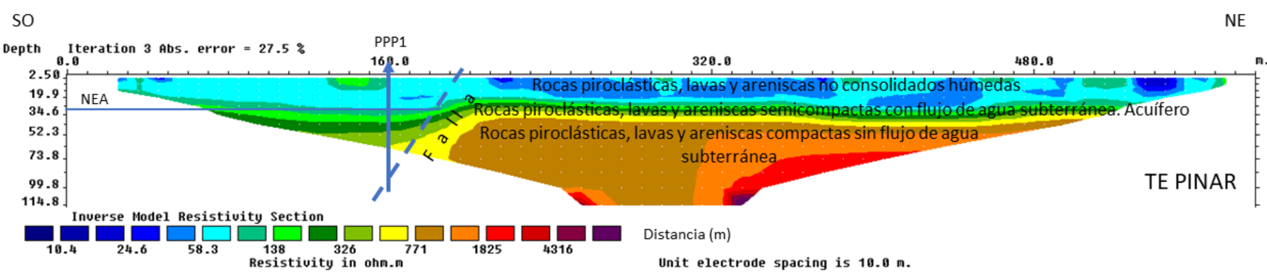

Illustration 8: TE Pinar electrical resistivity tomography.

Source: Own elaboration, based on the team's results. (2023).

At a depth of 25 meters, a third layer continues with thicknesses of about 30 meters in the first 190 meters shown in the geoelectric image and thicknesses of about 10 meters in the rest of the image. It has electrical resistivities between 70 ohm.m and 400 ohm.m. It extends throughout the geoelectric image and can be associated with fractured rocks of the Matagalpa formation. The largest groundwater flows in the area occur in this layer, therefore, it constitutes the main semi-confined aquifer of the place. The deepest layer, with electrical resistivities greater than 400 ohm.m and thickness greater than 70 m, is associated with dry compact rocks of the Matagalpa formation.

In the first 190 meters of the geoelectric section, a well-pronounced geophysical anomaly is observed that may be associated with a fracture system or a fault that crosses the site. Here it is proposed to drill a well at the coordinates utm wgs84 751808/1547098, with a depth of 80 meters. At the proposed location the NEA is about 25 meters, therefore, the thickness of the fractured aquifer is about 55 meters.

Electromagnetic Geophysical Study

Generally, se illustration 9, in the inverted electromagnetic section, the horizontal line represents the length (in meters) and the vertical line represents the investigation depth reached (in meters). The color scale represents the values of the electromagnetic field in millivolts (mV). Illustration 10.

Illustration 9: Location of the site for drilling a PPP1 well.
Source: own elaboration, from Google Earth. (2023).

Table 2 presents the general characteristics of Electromagnetic Geophysical Study.

Table 2: General characteristics of electromagnetic profiles

Electromagnetic profile	Coordinates Start		Height	Coordinates End		Height
	East	North	msnm	East	North	msnm
PEM1 L110	583551	1336642	253	583500	1336714	251
PEM2 L111	583477	1336626	253	583575	1336659	253
PEM3 L112	583418	1336667	251	583499	1336717	251

Source: self-made. (2023).

Given the characteristics of the subsoil in the study area, well-defined electrical responses were obtained, so in this case the following ranges of electrical potential have been grouped:

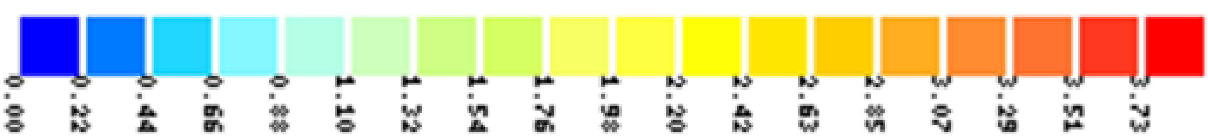

Illustration 10: Natural electrical potential scale for the study area.
Source: Own elaboration, based on the team's results. (2023).

Electric potential less than 1.32 millivolts. They are identified by blue-sky blue tones. They can be mainly associated with moist loose rock and/or moist clayey silt materials with little groundwater flow.

Electrical potential from 1.32 to 1.76 millivolts. They are identified in the electromagnetic section mainly by green tones. They are characteristics of poorly coherent porous materials with good hydraulic transmissivity. Groundwater flows (Aquifer) occur in these materials.

Electrical potential from 1.76 to 1.98 millivolts. These zones can be identified in the electromagnetic sections by the range of low yellow colors. They are characteristic of moderately coherent or fractured rocks and eventually with a certain downward flow of groundwater.

Electrical potential from 1.98 to 2.63 millivolts. These zones can be identified in the electromagnetic sections by the range of deep yellow to low orange colors. They are characteristic of coherent or fractured rocks and eventually without groundwater flows.

Electric potential greater than 2.63 millivolts. They are characteristics of very coherent materials and can be identified by the intense orange to reddish tones. In these materials the groundwater flow is negligible. These electrical potentials may also correspond to surface rocks that are not very coherent, dry and without groundwater flow.

Illustration 10 to 12 show the electromagnetic sections PEM1 L110 to PEM3 L12, which are the result of the electromagnetic geophysical survey in the study area.

Description of Electromagnetic (EM) Sections

he following electromagnetic sections (illustration 10 – illustration 12) describe the main geological-geophysical characteristics related to the occurrence of groundwater in aquifer formations and the consequent location of favorable sites for drilling wells to supply drinking water to the area. Beneficiary population.

Electromagnetic section PEM1 L110:

This electromagnetic section with southeast-northwest orientation; It is described as an area of deposits of Quaternary volcanic and pyroclastic rocks composed of lavas, tuffs, ashes, agglomerates, basaltic and andesitic to basaltic slags (illustration 10).

From 30 meters above the EM section, a superficial layer of non-compact volcanic and pyroclastic rocks, a little humid and varying in thickness between 25 meters and 90 meters, is observed. In the first 30 meters, a layer of dry non-compact volcanic and pyroclastic rocks can be seen that reaches about 70 meters thick in this part and deepens in the rest of the section to about 120 meters deep with variable thickness.

Underlying it is a powerful layer of coherent volcanic and pyroclastic rocks with no apparent groundwater flows with a maximum thickness of up to 200 meters and a maximum depth of 270 meters. In the middle of this powerful layer, there is a layer of very coherent volcanic and pyroclastic rocks without underground water flows that is identified by the reddish colors of about 35 meters thick between depths of 125 meters and 160 meters. This layer appears discontinuous in the first 30 meters of the EM section, probably revealing the fault that crosses the area in the southern part of the polygon identified as a purple line located between 150 meters and 215 meters deep.

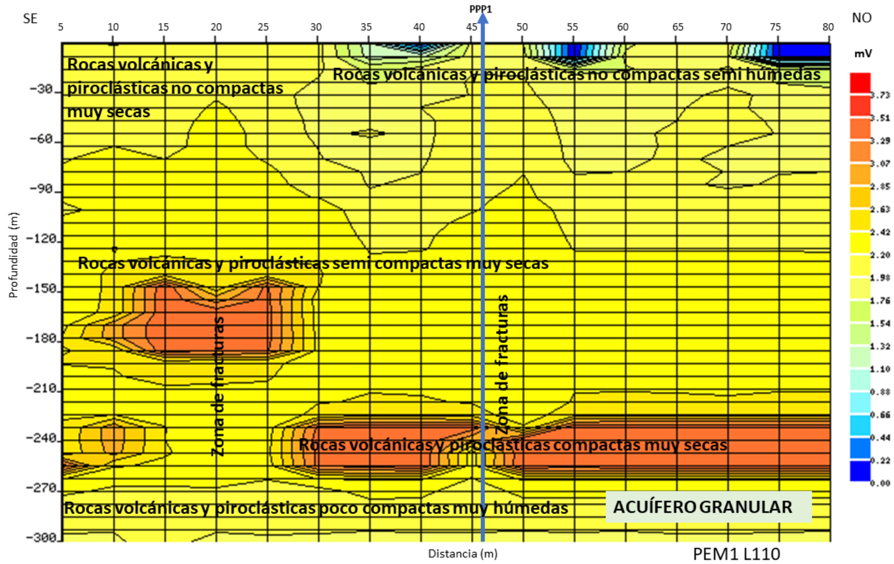

Illustration 11: Electromagnetic section PEM1 L110
Source: obtained from EM result. (2023).

The deepest layer is identified at 270 meters deep and has an undetermined thickness. It is associated with loosely compact volcanic and pyroclastic rocks with underground water flows and constitutes the main aquifer of the place.

Here a point for drilling a well (PPP1) has been proposed at 45 meters above the EM profile.

Electromagnetic section PEM2 L111:
This southwest-northeast oriented electromagnetic section; It is described as an area of deposits of Quaternary volcanic and pyroclastic rocks composed of lavas, tuffs, ashes, agglomerates, basaltic and andesitic to basaltic slags.

A superficial layer of non-compact volcanic and pyroclastic rocks, a little humid and varying in thickness between 25 meters and 75 meters, is observed extended in the EM section.

It is underlain by a layer of dry, non-compact volcanic and pyroclastic rocks, of variable thickness in the EM section that reaches about 80 meters in the central part of it.

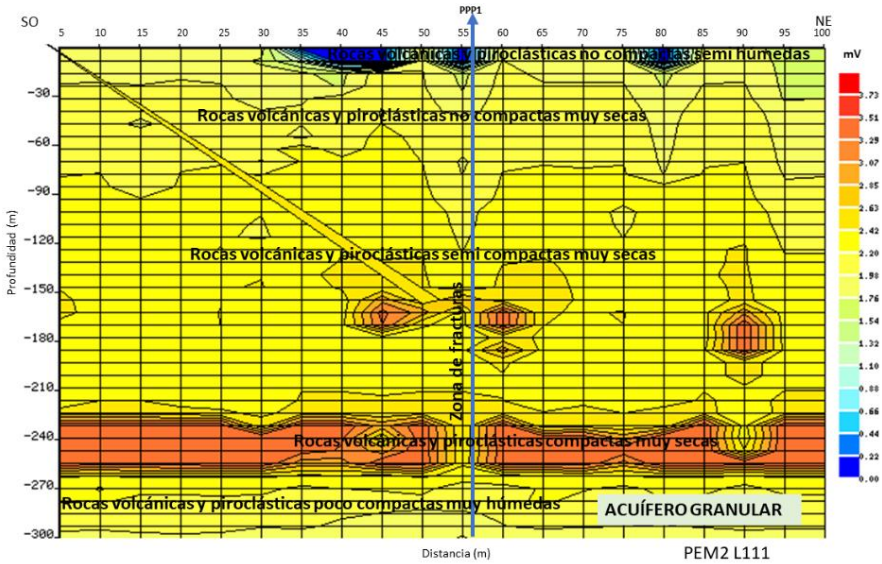

Illustration 12: Electromagnetic section PEM2 L111
Source: obtained from EM result. (2023).

Underlying it is a powerful layer of coherent volcanic and pyroclastic rocks with no apparent groundwater flows with a maximum thickness of up to 175 meters and a maximum depth of 270 meters. In the middle of this powerful layer, there is a layer of very coherent volcanic and pyroclastic rocks without underground water flows that is identified by the reddish colors of about 35 meters thick between depths of 225 meters and 260 meters. This layer appears discontinuous between 50 meters and 60 meters of the EM section, probably revealing the fault (Figure 3) that crosses the area in the southern part of the polygon identified as a purple line located between 150 meters and 215 meters deep.

The deepest layer is identified at 270 meters deep and has an undetermined thickness. It is associated with loosely compact volcanic and pyroclastic rocks with underground water flows and constitutes the main aquifer of the place.

Here a point for drilling a well (PPP1) has been proposed at 55 meters above the EM profile.

Electromagnetic section PEM3 L112:

This southwest-northeast oriented electromagnetic section; It is described as an area of deposits of Quaternary volcanic and pyroclastic rocks composed of lavas, tuffs, ashes, agglomerates, basaltic and andesitic to basaltic slags (Figure 8). A superficial layer of non-compact volcanic and pyroclastic rocks, a little humid and varying in thickness between 25 meters and 75 meters, is observed extended in the EM section.

It is underlain by a layer of dry non-compact volcanic and pyroclastic rocks, of variable thickness in the EM section that reaches about 95 meters in the first 30 meters of the EM section.

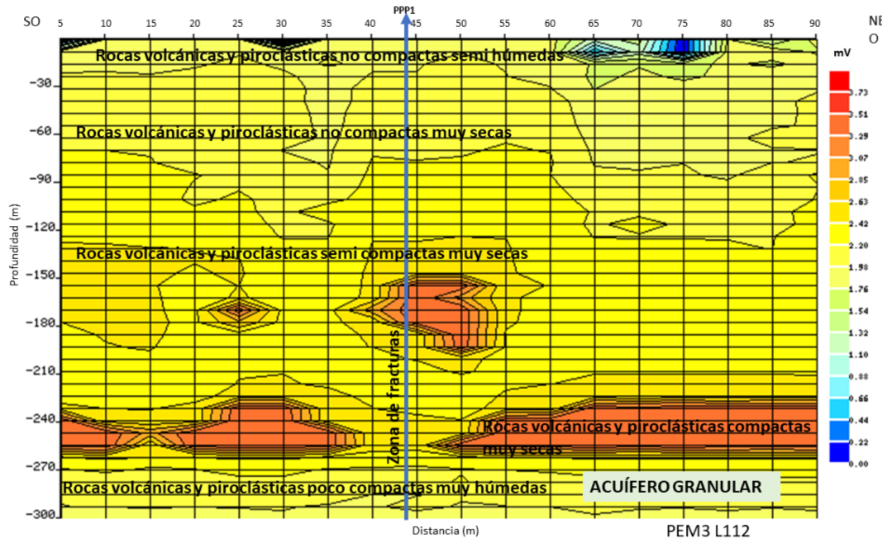

Illustration 13: PEM3 L112 electromagnetic section.
Source: obtained from EM result. (2023).

There continues a powerful layer of coherent volcanic and pyroclastic rocks without apparent groundwater flows with a maximum thickness of up to 210 meters and a maximum depth of 270 meters. In the middle of this powerful layer, there is a layer of very coherent volcanic and pyroclastic rocks without underground water flows that is identified by the reddish colors of about 35 meters thick between depths of 225 meters and 265 meters. This layer appears discontinuous between 35 meters and 50 meters of the EM section, probably revealing the fault (Figure 3) that crosses the area in the southern part of the polygon identified as a purple line located between 150 meters and 215 meters deep.

The deepest layer is identified at 270 meters deep and has an undetermined thickness. It is associated with loosely compact volcanic and pyroclastic rocks with underground water flows and constitutes the main aquifer of the place.

Here a point for drilling a well (PPP1) has been proposed at 45 meters above the EM profile.

CONCLUSIONS

Geophysical Study by Electrical Tomography

From the geophysical point of view, a sequence of four layers of Tertiary rocks of the Matagalpa formation was determined in the area: A non-extended, non-compact, very humid clayey surface layer with a thickness of about 20 meters. Underlying it is an extended, non-compact humid clayey surface layer with a thickness of about 20 meters and a certain flow of water at depth. A layer of fractured rocks from the Matagalpa formation continues with variable thicknesses between 10 meters and 25 meters thick. This layer constitutes the main aquifer of the place. The deepest layer with a thickness greater than 90 meters, compact, dry and associated with the Matagalpa formation constitutes the hydrogeological basement of the place. The static NEA water level at the site is approximately 25 meters.

In the first 190 meters on the profile, a fracturing and/or faulting zone is determined.

Electromagnetic Geophysical Study

In the area, the geological-geoelectric cut is composed of a sequence of layers associated with the Managua Group and defined by: a superficial layer of non-compact volcanic and pyroclastic rocks that are slightly humid and have a variable thickness between 25 meters and 75 meters; a layer of dry non-compact volcanic and pyroclastic rocks, of variable thickness in the EM section that reaches about 95 meters; There continues a powerful layer of coherent volcanic and pyroclastic rocks without apparent groundwater flows with a thickness of about 200 meters and a maximum depth of 270 meters; a layer of very coherent volcanic and pyroclastic rocks without groundwater flows that is identified by the reddish colors of about 35 meters thick between the depths of 225 meters and 265 meters and the deepest layer is identified at 270 meters deep and thick. undetermined is associated with loosely compact volcanic and pyroclastic rocks with underground water flows and which constitutes the main aquifer of the place.

From the geophysical-geological models, it is determined that groundwater flows are preferentially channeled through the deposits of quaternary volcanic and pyroclastic rocks composed of lavas, tuffs, ashes, agglomerates, basaltic and andesitic to basaltic slags located at a depth of 270 meters and Undetermined thickness is associated with loosely compact volcanic and pyroclastic rocks with underground water flows and which constitutes the main aquifer of the place.

According to previous hydrogeological information of the place; The depth to the groundwater is approximately 100 meters, however, the very compact layer located 225 meters deep and which is fractured in some segment gives the effect of artesianism, which when drilling the aquifer located in the deepest layer raises the water column up to 150 meters above sea level. So, the deep aquifer is semi-confined.

From the geophysical results, the highest groundwater flows occur in the areas of application of the electromagnetic profiles and indicated in the electromagnetic profiles PEM1 L110, PEM2 L111 and PEM3 L112 respectively where sites have been oriented for the drilling of the PPP1 well.

The assessment, from a scientific point of view, the two methods that were used are suitable to carry out geological soil in any part, the advantages of both methods are the agility and time to obtain the results immediately. It must be considered that the methods must be carried out in the same place and not separately. To have an unbiased evaluation of the methods, they must be carried out under the same geological and soil conditions.

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