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The Geothermal Potential in Isla Campuzano, Nicaragua

Minor Field Study
Bachelor of Science Thesis

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El Potencial Geotérmico en Isla Campuzano, Nicaragua

Den geotermiska potentialen vid Isla Campuzano, Nicaragua

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Abstract

Nicaragua has a geothermal potential of 1519 MW (CNE 2001) due to its volcano chain created by the tectonic activity between the Cocos plate and the Caribbean plate. The Ministry of Energy and Mines in Nicaragua has the ambition to have 91% of Nicaraguas energy consumption from renewables energy for 2027 where geothermal energy will constitute 22%. In June 2016 an earthquake of magnitude 6.1 occurred in the region of Chinandega with an epicenter in Isla Campuzano. This volcanic activity led to an increase of the water level in the hot springs in the area which captured the attention of UNAN-Managua, IGG-CIGEO and led to this bachelor thesis.

The aim of this work was to determine if there is a geothermal potential in the area of Isla Campuzano by performing a geochemical analysis in hot springs. Another objective was to asses the advantages and disadvantages of geothermal energy in Nicaragua.In order to estimate the geothermal potential field work, interviews, laboratory work, geological mapping and geochemical calculations were performed. To gain geological background information a geological mapping of the area was performed by using QGIS. The field study was conducted by first collecting 17 water samples at 6 different locations and measuring the pH, conductivity and temperature. Moreover, the concentrations of Na, Ca, K and SiO_2 in the water samples were determined by an ICP-OES.

The results showed high concentration of sodium which could be an indication that the water also contains high concentration of Cl which is characteristic for geothermal water. As the water samples were collected in superficial water the concentration of Ca was high and SiO_2 low. The sub geothermal temperature used to determine the geothermal potential was calculated with two Na-K-Ca geothermometers: Fournier & Truesdell (1973) and Fournier (1981). Five out of six sampling locations showed a sub temperature between 110-200 °C. According to Sveinbjörnsson (2016) this temperature range means a medium enthalpy geothermal source, which can generate electricity through a binary power plant.The uncertainties from the results were that only six sampling locations were studied and four geothermal chemical indicators were analyzed, and therefore only two geothermometers were suitable to use. The results from these geothermometers showed a difference of 20°C. Additionally the geology and the geophysics of the area were not studied in detail. This means that the results can only be used as an estimation and further investigations in all three geosciences has to be done in order to confirm the results.

From the interviews it was concluded that the main barriers of geothermal energy in Nicaragua is the difficulty of finding financial help for the projects and the overestimation of the potential due to technical errors. The main advantages are that it is a renewable energy source, with a high potential, a low variability meaning that no storage technology is needed.

In conclusion, there is a geothermal potential of medium enthalpy in the area except for sampling location 1. In other words, there is a potential of generating electricity with a binary power plant. These results should be used as an estimation as only the geochemistry has been analyzed and only two geothermometers have been accurate to use. An investment on this type of energy in the area of Isla Campuzano could both lead to an improved infrastructure and positive development of the socio-economic situation.

Keywords: Geothermal Potential, Geochemistry, Geological Mapping, ICP-OES, QGIS, Hot Springs, Waters Samples, Na-K-Ca Geothermometer, Medium Enthalpy, Nicaragua.

Resumen

Nicaragua tiene un potencial geotérmico de 1519 MW (CNE 2001) debido a su cadena de volcanes creada por la actividad tectónica entre la placa del Coco y la Placa del Caribe. MEM tiene un Plan indicativo de expansión para la generación eléctrica donde las energías renovables van a constituir 91% del mix energético para el año 2027 y en este porcentaje la energía geotérmica constituirá un 22%. En junio del año 2016 un terremoto de magnitud 6,1 se produjo en la región de Chinandega con el epicentro en Isla Campuzano. Este seísmo provocó un aumento del nivel del agua en los hervideros de la zona lo cual capturó la atención de la UNAN-Managua, IGG CIGEO y como consecuencia se desarrolló este trabajo de fin de grado.

El objetivo de este estudio ha sido determinar si existe un potencial geotérmico en la zona de Isla Campuzano mediante un análisis geoquímico en los hervideros. Además, se ha querido determinar las ventajas y desventajas de la energía geotérmica en Nicaragua. Estos dos objetivos se han llevado a cabo mediante trabajo de campo,entrevistas, trabajo de laboratorio, cartografía geológica, y cálculos geoquímicos.La información geológica se obtuvo a través de un mapeo geológico realizado con QGIS. El estudio de campo se llevó a cabo mediante la recopilación de 17 muestras de agua en seis lugares diferentes donde se midió el pH,la conductividad y la temperatura. En el laboratorio de biotecnología se determinó las concentraciones de Na, Ca, K y SiO_2 mediante un ICP-OES.

Los resultados mostraron una alta concentración de sodio, lo cual puede indicar altas concentraciones de cloro, elemento característico de las aguas geotérmicas. Como las muestras de agua se recogieron en aguas superficiales, la concentración de Ca era alta y la de SiO_2 baja. Las temperaturas subterráneas se calcularon con dos geotermómetros Na-K-Ca: Fournier& Truesdell (1973) y Fournier (1981). Cinco de los seis sitios de muestreo mostraron una temperatura entre 110-200C°. De acuerdo con Sveinbjörnsson (2016) este rango de temperatura se refiere a una fuente geotérmica de media entalpia de la cual que puede generar electricidad a través de una planta de generación binaria.Estos resultados solo se pueden utilizar de manera indicativa puesto que solo se analizaron seis lugares de muestreo y cuatro indicadores químicos, lo cual resultó en solo dos geotermómetros convenientes para los cálculos.Los resultados de estos dos geotermómetros mostraron una diferencia entre ellos de 20 ° C. Para futuras investigaciones es necesario analizar más lugares e indicadores químicos además de calcular más específicamente la geología y la geofísica de la zona para confirmar los resultados de este estudio.

Mediante las entrevistas se concluyó que las principales desventajas de la energía geotérmica en Nicaragua son la dificultad de encontrar financiamiento para los proyectos y la sobreestimación del potencial geotérmico debido a errores técnicos. Las principales ventajas son que es una fuente de energía renovable, con un alto potencial en Nicaragua y una baja variabilidad lo cual evita la utilización de tecnologías de almacenamiento energético.

En conclusión, existe un potencial geotérmico de media entalpía en el área con el cual se puede generar energía eléctrica a través de una planta binaria, excepto para el lugar de muestreo 1. Estos resultados deben utilizarse como estimación del potencial geotérmico ya que sólo la geoquímica ha sido analizada y sólo dos geotermómetros se han podido usado. Una inversión económica en este tipo de energía podría conducir a una mejor infraestructura y a un desarrollo de la situación socioeconómica de la zona.

Palabras clave: Potencial Geotérmico, Geoquímica, Mapeo Geológico, ICP-OES, QGIS, Hervideros, Muestras de Agua, Na-K-Ca, Geotermómetros, Media Entalpía, Nicaragua.

Contents

1 Background

1.1 Introduction

1.1.1 The Potential of Geothermal Energy

Geothermal energy is a renewable type of energy originated from the earth. The energy is extracted by drilling wells into geothermal reservoirs. As a consequence, hot water rises as steam which is used to drive turbines generating electricity. The advantages of this type of energy are that it is environmentally friendly, provides constant power and it can be used both for electricity and hot water generation. (Ryan 2009)

More precise when refering to geothermal energy we refer to the thermal properties within the earth and the use of heat energy that can be extracted. According to World Energy Council (2016), the earth can be said to be driven by cooling of the crust and heating of the lower crust and mantle. In other words, the temperature increases with the depth beneath the surface. Usually the temperature increase is too low in order extract adequate energy but at some parts of the crust there is a very high energy increase, which could provide energy. These parts are close to tectonic plates and volcanic areas. (World Energy Council 2016)

Today the geothermal energy only contributes to a small part of the world's primary energy consumption and it produces less than 1 percent of the world's output of the electricity generation. According to World Energy Council (2016), the world's estimated stored thermal energy down to 3 km in the continental crust is around $43*10^6$ EJ. This is significantly higher than the total primary energy consumption of the world. In other words, if the thermal and geothermal energy would be widely used then a lot of today's energy consumption would be secured. However, the costs for installation and the long development periods are significantly higher relative to solar and wind solutions. Leading to, that many countries are dependent on governmental support or financial help from companies or organizations from other countries in order to invest in geothermal energy. At present the countries with the largest utilization, around 70 percent, in terms of direct use of geothermal heat in 2015 are Turkey, China, Japan, Iceland, Hungary, USA and New Zealand. (World Energy Council 2016)

Studies around the world has examined the potential and addressed the importance of the geothermal energy. In a study by Younas et al. (2016), the geothermal renewable energy potential in Pakistan was examined. Pakistan is like Nicaragua still an energy deficient country. In the study they concluded that the renewable energy generation plays an important role in the development of the country both socially, politically and environmentally. They also came to the conclusion that in the renewable sector, geothermal energy would in the long run be cheaper compared to conventional energy prices. (Younas et al 2016)

1.1.2 Nicaragua

Nicaragua is the largest country in Central America with coast towards both the Pacific Ocean and the Caribbean Sea with an area of approximately 130 000 km^2, see figure 1. It has a chain of volcanos, which many are active, situated across the country from northwest down to Lake Nicaragua, Central America's largest lake. The Climate is tropical and the yearly temperature changes very little. (Globalis 2016). The mean temperature is fluctuating between 20 and 30 °C. Furthermore, the precipitation fluctuates highly from 1 to 300 mm/month with the highest precipitation in southeast and the lowest in northwest (Landguiden 2016). The total population of Nicaragua is approximately 6.2 million and the official language is Spanish (Landguiden 2016).

Figure 1: Map over Nicragua (NSLS School 2017)

Nicaragua's energy mix is regulated by the Ministry of Energy and Mines (MEM), which has created an indicative expansion plan between 2013 and 2027. The main objective is to reduce the energy from fossil fuels to 9% in 2027 and increase the renewable energy generation to 91%. The highest indicative investment is going to be provided to hydroenergy, which is expected to constitute 52% of the energy mix in 2027, followed by geothermal energy 22%, biomass 9% and wind energy 8%. Currently at 2017, renewable energy constitutes approximately 70% of the country's energy mix and fossil fuel 30%. (MEM 2017)

Chinandega

The department of Chinandega is located in the north-western part of Nicaragua and has an area of 4 822 km^2, see the marked area in figure 2. It limits in the north with the Republic of Honduras and the department of Madriz, the south with Pacific Ocean, the east with the department of Leon and the west with the Gulf of Fonseca. It has a total population of 428 105 inhabitants with a population density of 89 inhabitants / km^2. The urban population represents 62% and the rural 38%. The department is characterized by its marked dry season between the months of November to April and its rainy period between May to October. The average temperatures are between 21°C and 30°C and the maximum temperatures goes up to 42°C (INEC 2003).

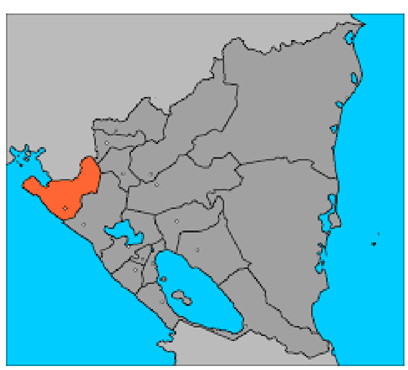

Figure 2: Map over Nicaragua showing Chinandega in orange (Luventicus 2017)

Puerto Morazan

Puerto Morazán is a municipality that belongs to the department of Chinandega. According to, demographic data from 2003 the municipality of Puerto Morazán has a population of 14 248, distributed in 3892 inhabitants in urban area and 10356 inhabitants in rural area. The annual population growth is approximately 3%. The economic activity in the municipality of Puerto Morazan is directly linked to the agricultural production. More specifically the cultivation of cane, sesame and banana are the ones with the greater territorial extension. However, the activity that yield the highest economical contribution is shrimp farming located in the mangrove areas (SINAPRED 2005). In figure 3, a screenshoot taken from Google maps can be seen where the city of Chinandega is highlighted in orange and the area of Puerto Morazán in red.

Figure 3: Map taken from google maps over the area of Chinandega and Puerto Morazán

Isla Campuzano

Isla Campuzano is a community that belongs to the municipality of Puerto Morazán, and it is the site where our field work was performed. According to, the interviews performed to the leader of the community Melvin Soriano, 67 families are living in the village, a total of 276 persons. The community was created 17 years ago and has an agricultural dependent economy. The main necessities for the village is clean water and electricity. In figure 4, a screenshoot taken from Google maps can be seen where the city of Chinandega is highlighted in orange, the area of Puerto Morazán in red and the area of Isla Campuzano in yellow.

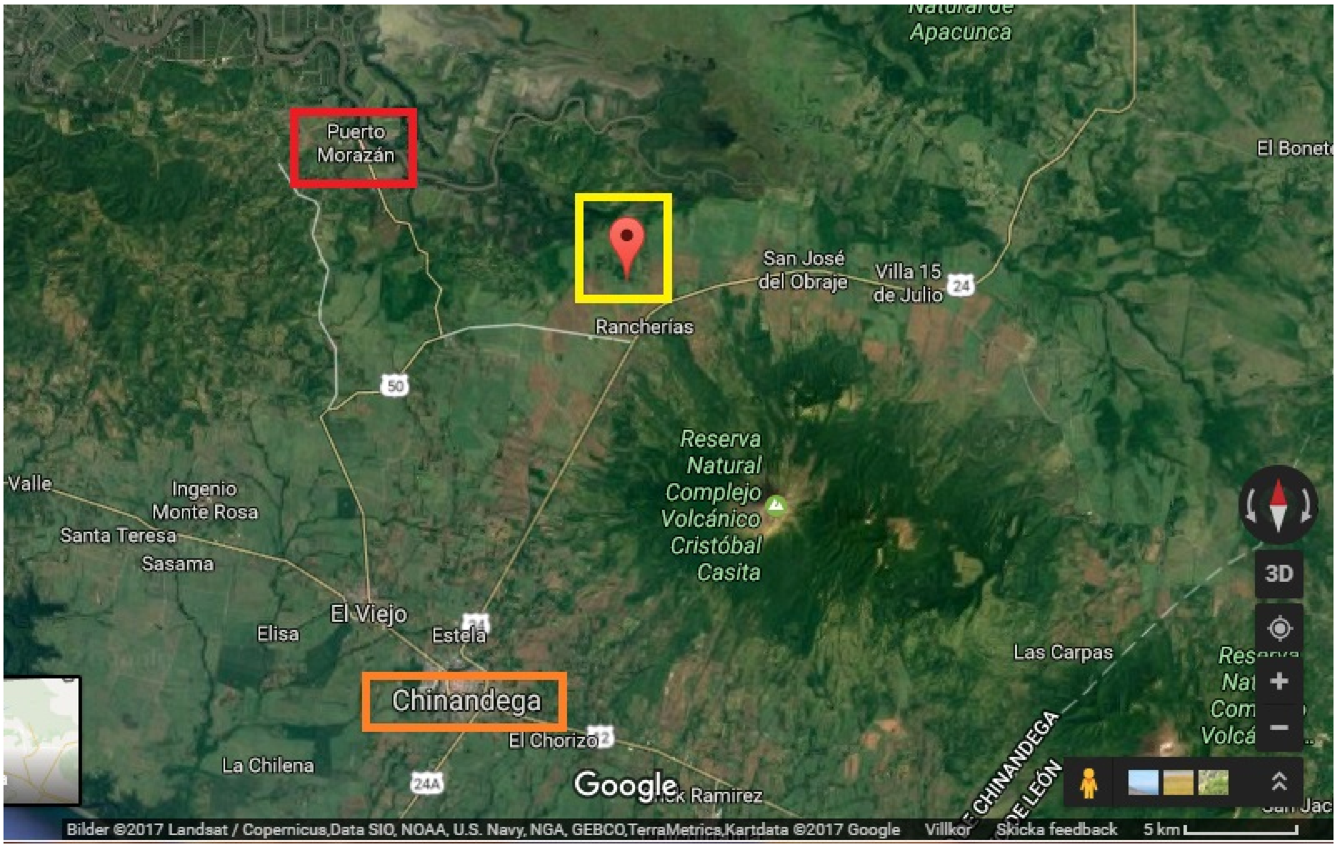

Figure 4: Map taken from google maps over the area of Chinandega (orange), Puerto Morazán (red) and Isla Campuzano (yellow).

1.1.3 Earthquake 06/09/2016

On June 9 in 2016 an earthquake of magnitude 6.1 occurred at 21:25 with an epicenter in Isla Campuzano (La Prensa 2016). The earthquake was perceived nationally and in the republics of El Salvador and Honduras. The earthquake was caused by the movement of the Caribbian Plate which is subducted by the Cocos plate. The movement has a direction northeast and an average speed of 8 cm/year (IGG-CIGEO 2016). After the earthquake the families from Isla Campuzano noticed an appearance of hot springs which captured the attention of IGG-CIGEO. In figure 5 the location of the earthquake can be seen. (Chávez 2016)

Figure 5: Map over the earthquake (La Prensa 2016)

1.1.4 The National Autonomous University of Nicaragua, UNAN-Managua

IGG-CIGEO

The Institute of Geology and Geophysics (IGG-CIGEO) was founded in October 1990 in the National Autonomous University of Nicaragua (UNAN), located in Managua. The institute was created with the collaboration of the Swedish Department for Research Cooperation (SAREC). IGG/CIGEO works within different areas in geoscience, such as research projects in earth science and disaster risk studies, both in a national and regional level taking into consideration an educational and socio-economic perspective. The Institute wants to become the reference institute in this sector, both regionally and nationally. The Institutes staff is composed of 21 persons working with the scientific and technical work and 10 administrative and support personnel. IGG/CIGEO is one of Central America's experts on risk assessment and disaster reduction and therefore teaches courses within this area in addition to professional services such as geological, geotechnical and geophysical studies. (UNAN 2016)

Laboratory of Biotechnology

The Laboratory of Biotechnology at the National Autonomous University of Nicaragua (UNAN) is a non-profit University unit that was created in 2007, located in Managua. The research is in the field of biotechnology with the support of biological and chemical techniques and methods to respond to problems and concerns of the Nicaraguan Society. Today the Biotechnology Laboratory analysis a wide range of different things such pesticides and heavy metals in contaminated ecosystems as well as the composition of natural and residual soils and water samples. Furthermore, they also perform studies of microbiological quality and macro- and micronutrients in food. Additionally, from their studies the laboratory also provides services such as: seminars, courses, laboratory practices and workshops.(Laboratorio de Biotechnologia 2017)

1.2 Objectives

The main objective for this bachelor thesis is:

- Evaluation of the Geothermal Potential in Isla Campuzano considering the geochemistry.

  Subobjectives:

- Interpretation of the accuracy of the results by analyzing the geothermal potential through a geochemical perspective.

- Assessment of advantages and disadvantages of geothermal energy in Nicaragua.

The objectives will be accomplished by performing fieldwork, interviews, lab work, calculations and a geological mapping of the area.

1.3 Limitations

One of the main limitation of the bachelor thesis is the time constraints as it is limited to 10 weeks. The limitations due to the time constraints and budget are for example that the results will not unfortunately take into account annual as well as weekly and daily variations. The time constraints also do not allow the project to include other methods than the ones planned. However, the aim of the project is to study the potential of geothermal energy which still can be shown by the method and questions of the project. The methodology is mainly based on geochemical studies, but the geology of the area has also been taken into consideration. However, there are no geophysical data available for the area which will limit the results as the geothermal potential is normally calculated by taking all three factors into consideration. Due to budget restrictions only the elements Na, K, Ca and SiO_2 were studied. However, in order to get more accurate results from the geothermal potential other chemical components such as F,B, Cl and Mg should have been analyzed. Additionally, more sampling locations could have been analyzed in order to increase the credibility of the results.

2 Theory

The theory has been divided into the following parts: field work, geochemical analysis, geochemical calculations and geothermal potential. The information of the theory is based on several scientific articles from Nicaraguan and international organizations that are experts on the geothermal energy field.

2.1 Field work

Theory from both geological mapping and sampling procedure of geochemical water samples was studied in order to gain an understanding of which methodology to use during field work.

2.1.1 Geological Mapping

According to, Mortensen (2013) the geological mapping is a key part of the surface exploration of a geothermal area before drilling is used to explore the subsurface. The aim of the geological mapping is to outline the geological setting and structure of the area e.g. to identify the fractures, outlining the potential size of the system, size, volcanic deposits and their extent. She continues to say that the outcome is presented on different types of maps to illustrate the geology and characteristics of the area. The concept of geological mapping is according to Mortensen (2013) to present the stratigraphy, rock types and structural features of the exploration area. For areas of geothermal exploration, it is also good to study the volcanic history of the area: the type of volcanic eruptions, their tectonic setting and the tectonic activity through time in the area.

More precise for a basic geological mapping the localization of warm springs, hot springs, hot and altered ground, fumaroles, faults and fractures is performed. Furthermore, the pH and conductivity of the springs and if possible the flow rate should also be measured. Before fieldwork it is common to review regional geological maps, photos from the area, remote sensing through thermal imaging etc. This in order to get an idea of where the geothermal areas could be present before going to field. At field it is valuable for the geologist to talk and be guided by a local farmer as they now the area better and where to find the springs etc.

A geological mapping gathers indications of location, size and frequency of volcanic and tectonic events and not only a first interpretation about the geology and is therefore of importance when studying geothermal potential. The geological mapping together with geochemical and geophysical surveying are used in to develop a first conceptual model of a geothermal system.

A geological mapping was performed during the field work and with help of GIS material as geological background information. The fundamental purpose of this phase was to determine whether a commercially viable geothermal resource area existed. This first part of the project was especially relevant due to the fact that no geothermal data existed in the area of Puerto Morazán. Therefore, hot water springs were localized in order to perform the water geothermometry and to choose which type methodology to use.

The geology from the sampling area was expected to be composed by rocks of volcanic origin such as Andesite and Epiclastic sediments. Andesite is an igneous rock with a light dark gray color that is found in lava flows (Geology 2016). A microscopical structure of the mineral composition of an Andesite can be seen in figure 6. According to, the geological society of America epiclastic volcanic rocks contain fragments produced by weathering and erosion of solidified or lithified volcanic rocks of any type. (Geological Society of America 2016)

Figure 6: Andesite. Photo by: IGG-CIGEO

2.1.2 Sampling Procedure

According to Ármannsson & Ólafsson (2006) the collection of water samples for a geochemical analysis is the first and one of the most important steps in order to get relevant results. This due to that it provides a theoretical base for the rest of the calculations and analysis. He continues to state that the ground may be unreliable plus that chemicals needs to be handled and it is therefore important to be careful and have a local guide in field that knows the terrain.Also in order to minimize losses of broken bottles, plastic bottles are used. Other reasons to use plastic bottles are for the roughness and lightness of them compared to glass bottles. (Ármannsson & Ólafsson 2006)

Furthermore, the samples must be preserved to minimize the changes of chemical composition in the samples. Examples of changes of the concentrations are adsorption on the walls of the bottles, biological activity, interactions with suspended matter, precipitation and redox reactions. Acidification is used to minimize the concentration changes in the samples when analyzing cations and silica. Additionally, it is required to cool the samples due to the inconvenience of handling hot water. The samples should therefore be cooled to ambient temperature after collection, using a cooling bag. (Ármannsson & Ólafsson 2006)

For collection of water samples from hot springs it is advisable that the water is taken from a free-flowing part. The bottles used during the collection should be rinsed with the water in the hot springs before the actual sample is taken. Directly after sampling the water temperature, pH and conductivity should be measured before acidification of the sample. This is done in order to get an initial characterization of the fluid. (Ármannsson & Ólafsson 2006)

2.2 Geochemical analysis

The water samples collected during field work were chosen to be analyzed with ICP-OES due to its accuracy and availability in the Laboratory of Biotechnology.

2.2.1 Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

An Inductively Coupled Plasma (ICP) is a based analytic technique that can be used to quantify a composition of different types of samples, such as solids, suspensions and liquids. The sample is acidified before analysis in order to assure comparability with calibration standards and stability. In the specific case of ICP-OES the species analyzed are detected and quantified with an optical emission spectrometer (OES). The sample is atomized into the core of an inductively coupled argon plasma. The temperature is then raised to approximately 9000 K, where the solution is vaporized and the species are ionized and thermally excited. From this the ICP-OES measures the intensity of radiation emitted at the element-specific through measuring the wavelength emitted thermally from the sample. The resulting intensity measurements are then converted to elemental concentrations by comparing with calibration standards. This is a technique widely used where standards for an area are not accessible. (EAG Laboratories 2016). An overview of the ICP-OES used in the Laboratory of Biotechnology can be seen in figure 7.

Figure 7: Overview of the ICP-OES at the Laboratory of Biotechnology. Photo by:Laboratory of Biotechnology)

2.3 Geochemical calculations

In this section water and solute geothermometers were studied as water samples were taken in field work. The different water and solute geothermometers studied are: Silica solubility and Cations. The chosen geothermometers were based on relevant scientific articles. A high variability of those were chosen as a consequence of uncertainties of the chemical elements present in the results.

2.3.1 Geothermometer

A geothermometer is a tool used during the exploration phase to estimate the subsurface temperatures using the chemical and isotopic composition of hot springs or fumaroles. The calculations are performed taking into consideration specific mineral solute reaction. Due to the uncertainties in the exploration phase, the usage of geothermometry must be taken with a lot of care otherwise human error can lead to non-accurate data.

There are three types of geothermometers: Water or solute geothermometers, Steam or gas geothermometer and Isotope geothermometer (Karingithi 2009). In this project only the water or solute geothermometer was chosen in order to determine the geothermal potential in the area.

Water or Solute Geothermometers

There are different types of water or solute geothermometers depending on the mineral composition and temperature of the studied site. The two major groups are Silica Solubility Geothermometer and Cation Exchange Geothermometer (Karingithi 2009).

Silica Solubility Geothermometer

According to Karingithi (2009) the Silica Solubility Geothermometry is based on experimentally determined variations in the solubility of different silica species in water, as a function of temperature and pressure. The following chemical reaction occurs:

$SiO_2 + 2H_2O = H_4SiO_4$ (1)

Karingithi (2009) explains that the following methods can be used depending on the different thermal assumptions seen below:

Adiabatic (Maximum steam loss) – Equation 2 compensates for loss of steam from boiling solutions and the resultant increase in concentration of silica, plus the cooling of the solution by adiabatic expansion due to decrease in the hydrostatic – hydrodynamic pressure head. This method is best used for well discharges and actively boiling springs and pools with at least a discharge rate of ($>= 2kg/s$) and when silica sinter deposits occur.

$t = \frac{1522}{5,75 - log(SiO_2)}$ - $273,15$ (2)

Where SiO_2 represents the silica concentration as SiO_2 in mg/kg.

Conductive (no steam loss) – Equation 3 applies to those waters that cool solely by conduction during ascent. The silica quartz conductive cooling geothermometer is preferably used for springs at sub-boiling temperatures (giving a maximum estimate of the reservoir temperatures based on quartz solubility), or for well data that have been calculated to reservoir conditions.

$t = \frac{1309}{5,19 - log(SiO_2)}$ -$273,15$ (3)

Where SiO_2 represents the silica concentration as SiO_2 in mg/kg. Chalcedony geothermometer: If one of the above geothermometers indicates a temperature of 120-180 °C, this might be an indication that the silica solubility is controlled by chalcedony, in this case equation 3 is used.

If the above result is in a temperature range from 100-120°C, the result is probably realistic. However, if the temperature is below 100°C the solubility may be controlled by the amorphous silica. In these cases with silicic host rocks, the abundance of volcanic glass may enable saturation of a fluid with respect to amorphous silica and equation 4 can be used.

$t = \frac{731}{4{,}52 - log(SiO_2)}$ -273, 15 (4)

Cation Exchange Geothermometer

There are two main methods for Cation Exchange Geothermometer depending on the Calcium concentration. For low Ca concentration the Na- K geothermometer is used and for high Ca concentrations the Na-K-Ca geothermometer is selected, both are presented below.

Na-K geothermometer

The cation exchange reaction between albite and K feldspar (adularia) is temperature dependent and the response of the Sodium/Potassium (Na/K) ratio is decreasing with increasing fluid temperature, the molecular relation can be illustrated by the reaction below:

$NaAlSi_3O_8\ (Albite) + K^+ = KAlSi_3O_8\ (K - feldspar) + Na^+$ (5)

When studying this method, it is suitable to have waters from high temperature reservoirs (180°C) of chloride waters. Even so, the Na-K geothermometer may be used in some cases for lower temperature reservoirs where fluids have long residence time.

Additionally, there are some advantages with this method but also some limitations. The advantages are that the geothermometer is less affected by dilution or steam loss given that the method is based on a ratio. However, this is only applicable if the diluting waters are low in Na, K and Ca. Additionally, the geothermometer is applicable up to a temperature of 350 °C, which give indications regarding the deeper part of the system comparing with the silica quartz geothermometer. However, this is of course depending on the system's hydrology. Some limitations are that the Na-K geothermometer may give vague results for temperatures below 100°C. Furthermore, the water cannot contain high concentration of calcium (Ca). Some rules for the usage of this method are:

- Use for waters indicating reservoir temperature > 100°C.
- Use if the waters contain low Ca; i.e. the value of $(log(Ca^{(1/2)}Na) + 2.06)$ is negative
- Use for near neutral pH chloride waters.

If these conditions are fulfilled the following equations can be used:

$t = \frac{1217}{1{,}438 - log(Na/K)}$ - 273, 15 (6)

$t = \frac{1390}{1{,}75 - log(Na/K)}$ - 273, 15 (7)

Na-K-Ca geothermometer

There are two different types of Na-K-Ca geothermometers: *Fournier* and *Truesdell* (1973) and *Fournier* (1981), where both the methods are used for waters with high concentrations of calcium.The main advantage of using Na-K-Ca geothermometers are that they do not give high and misleading results for cold and slightly thermal, non-equilibrated waters. Additionally, the thermometers are not independent of steam loss or dilution as the equations involves (Ca/Na). (Henley et al 1985; Karingithi 2009)

Fournier and *Truesdell* 1973

The two assumptions behind the first method, created by Fournier and Truesdell 1973 are according to Cyrus W. Karingithi that excess silica is present and that aluminium is conserved in solid phases. The following equation is used for the calculation with concentrations in $[mol/l]$:

$t = \frac{1647}{log(Na/K)+B*log(sqrt(Ca)/Na)+2{,}24}$ - $273{,}15$ (8)

If $log(Ca^{(1/2)}/Na) > 1$ and $t < 100$°C, use $B = (4/3)$ in the formula for determining the temperature. If that calculated temperature is $t < 100$ °C, then this temperature is appropriate. If the $B = 4/3$ calculated temperature is higher than 100°C, or $log(Ca^{(1/2)}/Na) < 1$, then use $B = 1/3$ to calculate the temperature. (Karingithi C W 2009)

*Fournier*1981

The second type of Na-K-Ca geothermometer, created by Fournier 1981, is similar to the above geothermometer. However, all concentrations are in $[mg/kg]$ and the measured surface temperature must be above 70°C in order for the results to be accurate. (Henley et al 1985) The equation used for the calculation is:

$t = \frac{1647}{log(Na/K)+B*(log(sqrt(Ca)/Na)+2{,}06)+2{,}47}$ - $273{,}15$ (9)

Calculate t=$log(Ca^{(1/2)}/Na) + 2.06$ if its value is positive, use $B = (4/3)$ in the formula in determining the temperature. If that calculated temperature is $t < 100$°C, then this temperature is appropriate.

If the $B = 4/3$ calculated temperature is $t > 100$°C, or $log(Ca^{(1/2)}/Na) + 2.06$ is negative, then use $B = 1/3$ to calculate the temperature.(Henley et al 1985)

2.4 Geothermal potential

According to Gudmundsson (1985), the paper "Industrial and Other Applications of Geothermal Energy" was published in 1973 by the Icelandic Engineer Baldur Lindal. In the paper the Lindal diagram was published, seen in the figure 8, illustrating the many uses of geothermal energy for low to high temperatures. The diagram demonstrates the temperatures required for different applications of geothermal energy. After the publication the diagram has been widely used and is today considered a standard diagram when discussing geothermal potential and its usages. In Lindal's paper it is describes that except from power production and district heating geothermal energy has usefulness in the agriculture and industry as well, also illustrated in the diagram. (Gudmundsson et al 1985)

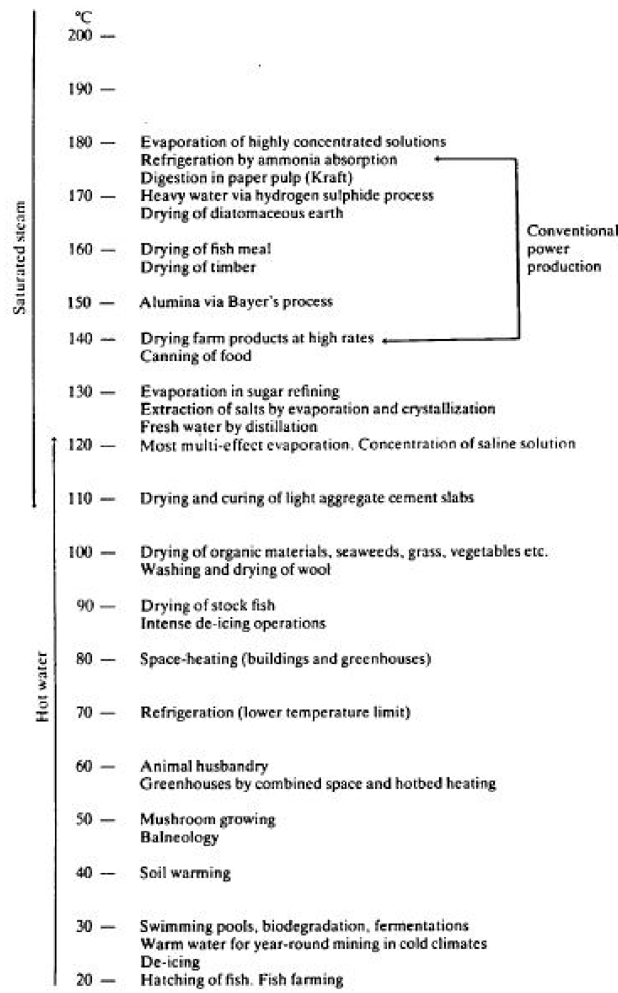

Figure 8: Lindal Diagram (Gudmundsson et al 1985)

As stated in the interview from ENEL in order to calculate the geothermal potential it is important to integrate the results from the geology, geochemistry and geophysics from the area of interest. In other words the results from the geochemical studies are not sufficient in order to estimate the geothermal potential. However, as Mayela Sanchez Molinares explained during the interview, there are several parameters that are specific for thermal waters such as: high concentration of chlorides, Si, Na, K, B and F and low concentration of Mg. Also the calculated sub temperature should be around 200 ℃ in order to have a high enthalpy geothermal source that could be used for electrification. In table 1 presents the range of reservoir temperatures needed to generate electrical energy using the data from the volcano Momotombo. The data was provided by ENEL.

Table 1: Geothermal reservoir temperature. (Sanchez 2017)

Geothermometers	**Range ℃**
Si Geothermometer	196 - 294
Na-K Geothermometer	226 - 332
Na-K-Ca Geothermometer	224 - 336

The accuracy of this temperature is supported by the International Energy Agency statement on geothermal technologies.

2.4.1 High enthalpy

According to, Sveinbjörnsson (2016) the temperature required for high enthalpy is above 200°C. The main application for this enthalpy is electricity production using flash steam turbines (Sveinbjörnsson 2016) As described by the company SULZER, high enthalpy hydrothermal resources are flashed into steam during low pressure. The steam is further used to drive a flash steam turbine generating electricity. (SULZER 2017). The IEA explains that in order to use the geothermal technology Flash steam plants the sub temperature should be around 180°C. This geothermal technology makes around two-thirds of the geothermal capacity installed today and it is used in the geothermal field of Momotombo, Nicaragua. (IEA 2017; MEM 2009).

2.4.2 Medium enthalpy

For medium enthalpy the sub temperatures should be between 150 and 200°C. This enthalpy could also be used for electricity generation through a binary power plant (Sveinbjörnsson 2016). In this power plant a heat exchanger is used in order to use the thermal water to heat up a liquid called isopentane which boils at lower temperature than water. The steam produced by the isopentane is used to drive turbine generating electricity (Yan 2011).

2.4.3 Low enthalpy

Temperatures lower than 100°C shows low enthalpy, which can not be used for electricity production. However it can be used for space heating, cultivation of plants and vegetables in greenhouses, aquaculture, industrial processing and heating and cooling through a heat pump. (Sveinbjörnsson 2016)

3 Method

The method part is based on the same structure as the theory. It creates an overview of the methodology used on the field work, lab and calculations performed in order to seek the objective of analyzing the geothermal potential of the area of Isla Campuzano.

3.1 Interviews

To gain a socio-economic and political understanding of the present situation on geothermal energy in Nicaragua, several interviews were performed. In order to get different perspectives, interviews were performed with the national authority of Energy and Mining (MEM), two electrical companies (Albanisa and ENEL) and the local community of Isla Campuzano. Before each interview background information was studied and relevant questions were prepared.The interviews were performed and recorded in Spanish and then translated to English.

3.2 Field work

Field work was performed two times and during those field trips different sample locations were chosen in order to gain a broader picture of how the geochemistry varies in the area. Additionally, during the field work the geology was also studied together with PhD. Fernando Guarin (IGG-CIGEO).

3.2.1 Geological Mapping

The geological mapping was done in order to gain a deeper understanding and to gain a background information to the results and discussion. It is presented below and was performed by studying the rocks at the field, together with Geologist Dr. Fernando Guarín. In order to sample the rocks a hammer was used. Furthermore, a handheld GPS was used to get the coordinates for the area were the water samples were taken. A GIS project was done in QGIS, which includes the following shapefiles provided by IGG-CIGEO: a geological background map, height curves, faults, lithology and the coordinates for the volcano San Cristobal. The coordinates for the water samples were added to the map to illustrate where they were taken.

The following section presents the results from the geological mapping done in QGIS. The first map is an overview of the total area were the volcano San Cristobal, the faults, height curves and an overview of the points of interests can be seen as well as the lithology of the area, see figure 9. In order to get a broader overview of the area see figures 2,3 and 4. Furthermore, in figure 9 the area of sampling locations are marked, these locations can be seen in figure 10 and 11 described below.

The second map is a more narrow picture that shows the different point of interest over the area of Isla Campuzano, see figure 10. Every point were rocks or water samples were collected has been numbered from 1 to 33, more information is found in Appendix A. Table 2 presents the geology at the different points. The third map shows were the water sampling points were collected during the two field trips, see figure 11.

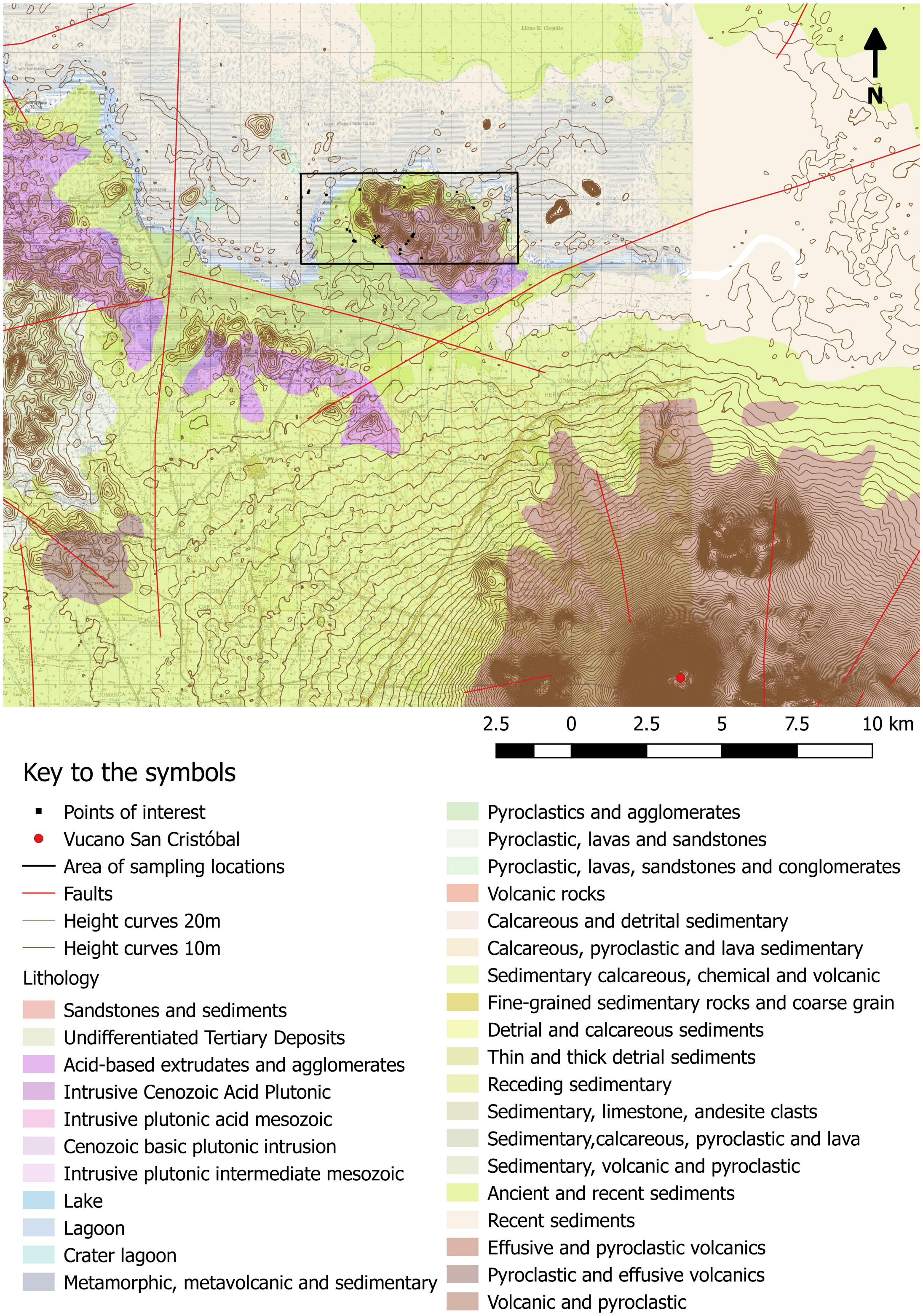

Figure 9: Overview of the area

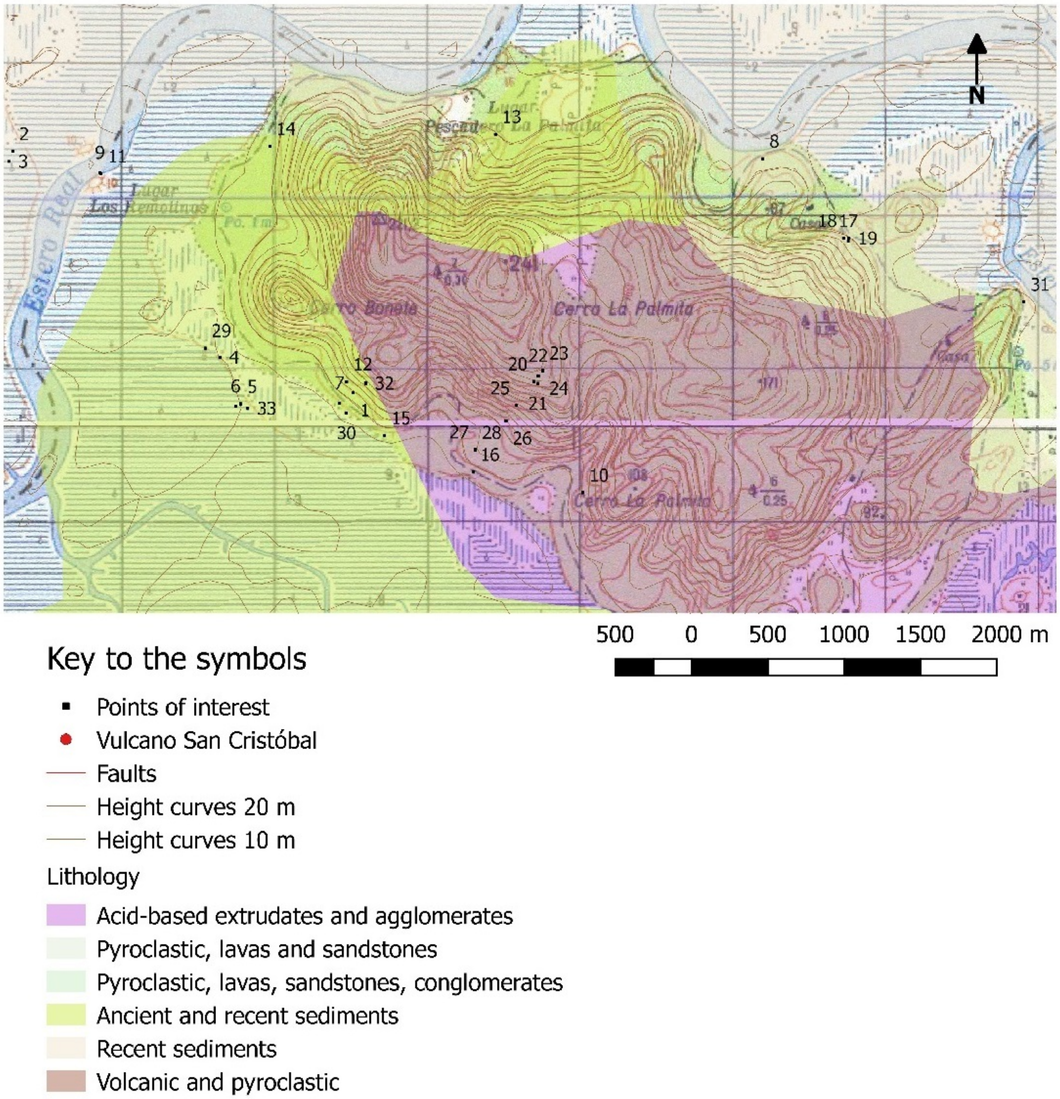

Figure 10: Points of Interest

Table 2: Geology

Points of interest	Geology
1,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,30	Andesite
2,3,4,5,6,29,31	Epiclastic Sediments

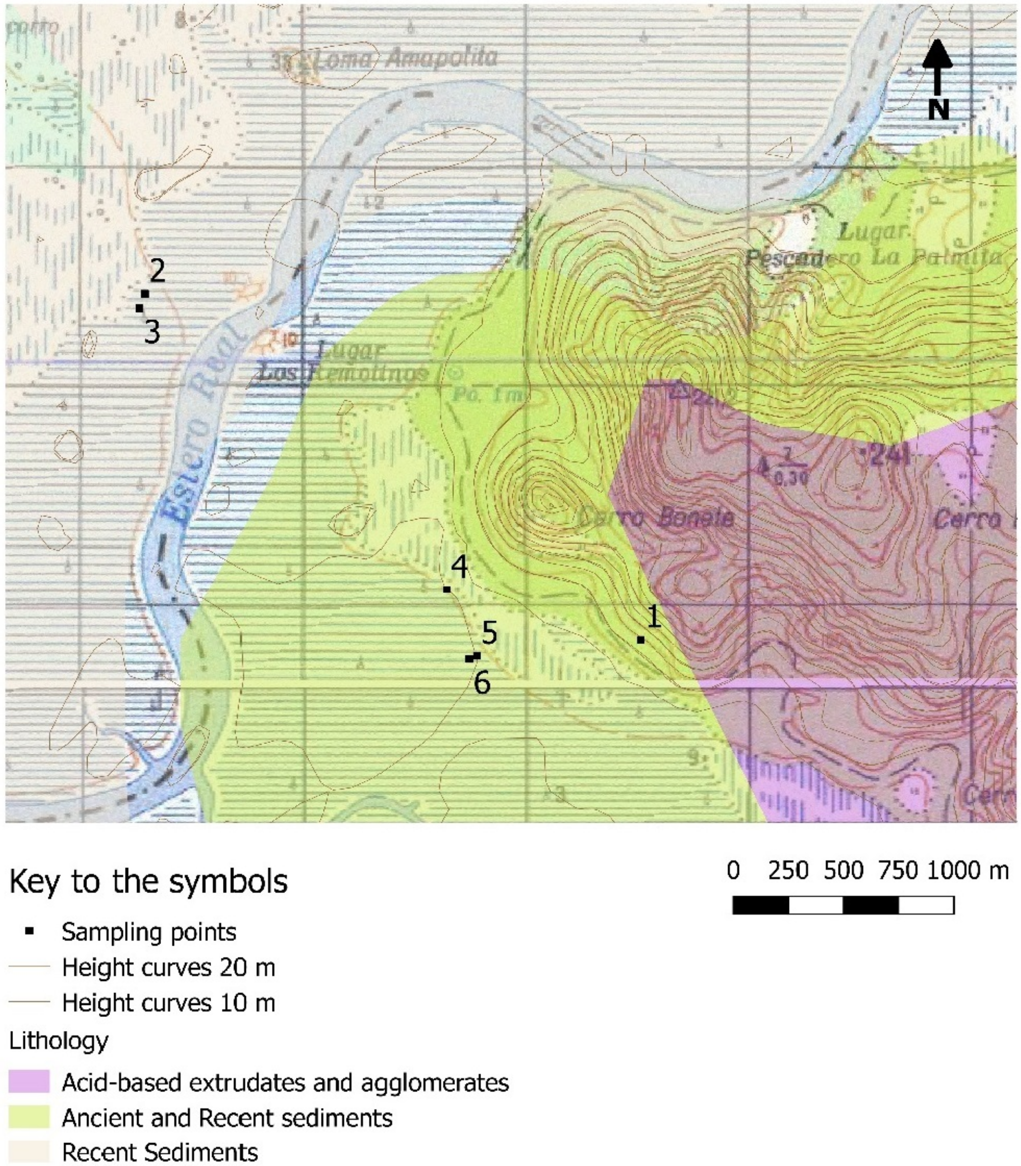

Figure 11: Sampling locations

3.2.2 Sampling Equipment

The sampling procedure described below was used in order to sample the water during both of the field studies performed. To be able to perform the sampling procedure a range of different sampling equipment was needed and provided by The faculty of Engineering Lund University, IGG-CIGEO UNAN and the Laboratory of Biotechnology UNAN. All the equipment is presented in Appendix B.

3.2.3 Sampling Procedure

The water from the hot springs where collected by constructing a stick and a glass bottle together in order to minimize injuries while collecting samples. During the collection both the glass bottle and the plastic bottles were rinsed according to Ármannsson & Ólafsson (2006) described in the theory. Before the collection of water was performed the localization (GPS coordinates) of the site, the date and time for the sampling was recorded. The glass bottle was then used to pour sampling water into the plastic bottles used for transportation and preservation of the samples. The glass bottle was introduced in the hot springs in the opposite direction to the flow at about 20 cm depth. At each site 3 samples were collected. The temperature, pH and conductivity were first measured in the 500 ml untreated samples. The equipment for the pH and conductivity was calibrated before each time of measurement.After the measurements the preservation of the samples were performed by adding 1 ml of HNO_3 followed by storing the samples in a cool bag with ice sheltered from the sun.

The first two samples (1a and 1b) were taken from a spring used for water consumption, located in Isla Campuzano by Doña Goyas house. The second location where the samples 2a,2b and 2c were taken was located at the Manglar Estero Real. In order to reach the hot water a hole was digged in order to reach the natural hot water spring. The third location where the samples 3a,3b and 3c were also located at the Manglar Estero Real. On this sampling point the hot water spring was present as a puddle. Location 4 (4a,4b,4c) 5 (5a,5b.5c) and 6 (6a,6b,6c) were all three located at the Cooperativa Gregorio Santos in Isla Campuzano, situated by the shrimp farm. All three hot spring samples were present by natural puddles. In figure 11 the six different sampling locations can be seen. Furthermore, pictures from all six locations can be seen in Appendix C.

3.3 Geochemical analysis

Water or solute geothermometer was chosen as the methodology due to our chemical knowledge in our bachelor and the high usage of this methodology to estimate subsurface temperatures in order to analyze the geothermal potential. The water samples were analyzed by an ICP-OES (Inductively coupled Optical Emission Spectroscopy) in order to specify the mineral composition and as a consequence determine which chemical geothermometer that will be more suitable in this specific area.The analyses of the collected water samples was done in cooperation with the Laboratory of Biotechnology at the University of Managua, UNAN-Managua. The analysis were done for Silica, Sodium, Calcium and Potassium with help of the ICP-OES and together with the personnel at the Laboratory of Biotechnology. The methodology of the geochemical analysis was provided by the Laboratory of Biotechnology.

3.2.1 ICP-OES

In order to start and prepare the samples for the analysis of the ICP-OES, all the water samples were each placed in falcon tubes, as seen in figure 12. The ICP-OES was calibrated with the help of the software Agilent 7 15-ES. First the performance of the wavelength was performed with a wavelength calibration solution during approximately 5 minutes. Afterwards, the detector of the ICP-OES was also calibrated with 5 ppm of Mn during approximately 10 minutes. After the calibration it is important to do a quality control, which was done by using 4 standards with known concentration of the minerals of interest (Na, K, Ca and Si). From these standards the ICP-OES creates a calibration curve that shows that the apparatus has a good quality and is ready for the measuring procedure.

Figure 12: Automatic Sampler, ICP-OES, (Laboratory of Biotechnology)

After the calibration and quality control, the autosampler lines, organizes and recognizes the different samples in the falcon tubes. The water from the falcon tubes passes through the peristaltic pump and further on to the nebulizer and the spray chamber, as seen in figure 13. Once in the spray chamber the atoms are separated and transported further on to the plasma room where the detector is.

Figure 13: Peristaltic pump and spray chamber (Louise Selméus)

Here the atoms are excited to their maximal energy level with a heating temperature of 5540 °C. When the atoms reach their maximum level of energy, they emit an intensity with a wavelength which the different element are sensible to. The detector detects the wavelength of each atom and from that calculates the intensity of each atom.

The software then analyzes the different intensities of the atoms and produces a linear curve for each element (Na, K, Ca and Si). From the equation of the straight line presented below, the software ICP Expert II, directly calculates the concentration of each element according to the intensities emitted at the wavelength corresponding to each element:

$y = mx + b$ (12)

Where, y is the intensity, m is the slope of the curve, x is the concentration of the elements (Na, K, Ca and Si) and b is the intercept. From the equation the concentrations of the different elements can be read and calculated.

Under and after the procedure the ICP-OES is cooled down by a refrigerator LYRON from 10 000 F to 68 F (20 degrees Celsius). This is done in order to prevent the ICP-OES and the detector from overheating. During the procedure argon gas is used as fuel for the plasma room. The argon gas is suitable due to that it does not interact with the other compound and that it is an inert and noble gas. At last the Laboratory of Biotechnology has a battery, Smart Online UPS, that can be used during power cuts in order to prevent disruptions during the analysis. The Smart Online UPS can store energy up to 8 hours and an important part of the analysis as power failures are usual.

3.4 Geochemical calculations

The Laboratory of Biotechnology provided the results from the water samples collected in field analyzed with the ICP-OES. For each water sample the element concentration of Na^+,K^+,Ca^{2+} and SiO_2 was calculated. The concentrations were given in mg/l, however to get an understanding of the relation between the elements in each sample the concentrations were recalculated to mmol/l. Furthermore a diagram of the average element concentrations for all six sampling locations was plotted in Excel as seen in figure 20.

3.5 Geothermal potential

The geothermometers Fournier and Truesdell (1973) and Fournier(1981) were chosen for the calculations of the geothermal potential based on the results from the geochemical analysis. These geothermometers were decided as the only two appropriate to use due to a low concentration of SiO_2 and a relevant concentration of Ca^{2+}. The decision was discussed with Mayela Sanchez Molinares from ENEL who is an expert in the geochemical field for geothermal potential. In the calculations of Fournier (1981) it was assumed that the water samples only contained water and therefore 1 mg/l equals 1mg/kg. The average calculated sub temperatures for each sampling location was plotted in a diagram for both geothermometers using Excel, seen in Chapter 4.

4 Results

The following section presents the results from the performed interviews, field work, geochemical analysis and the assessment of the geothermal potential. These different parts complement each other and helps to gain an understanding of the socio-economic, political and technical potential of geothermal energy in the area of Puerto Morazan.

4.1 Interviews

The results from the interviews are presented first with a short presentation followed with a structure of question and a summarized answer.

4.1.1 Ministry of Energy and Mines (MEM)

Presentation of Mario Gonzalez

Geothermal director in the Ministry of Energy and Mining.

According to the Energy expansion plan of Nicaragua, geothermal energy is only going to constitute 22% of the national energy mix by the year 2027. What is the reason for this lower investment in the geothermal sector compared to the other renewable energies?

The expansion plan is variable, it can change with time as it is directly related to meteorological factors. If we compare with the other renewable energies, the wind power is not a base energy due to its variability, biomass is dependent on the production of sugar and peanuts and hydro power varies with the country's drought. Geothermal on the other hand, could be presented as a base energy with low environmental impact, but its main disadvantage is its large investments risk. An example is the geothermal plant of Montegalan where 20 MUSD were invested but no results were obtained. As a consequence there are problems on finding financiation for geothermal energy. Though there are several geothermal projects in Nicaragua such as: the volcano Casita San Cristobal where the world bank is investing on trying to mitigate risks for the well drilling; the volcano Cosigüina where a pre-feasibility study is being done with 103 MUSD. In Laguna de Apoyo the Japan International Cooperation Agency (JICA) is investing in geothermal potential studies. In conclusion the geothermal potential in Nicaragua needs more economical investment and risk studies.

According to the Nicaraguan energy plan for 2013 the nominal installed capacity of geothermal energy was 11.98% ie 154.5 MW however the effective installed capacity was 7.11% ie 69.34 MW. What accounts for this difference?

This difference can be explained by taking the geothermal plant of Momotombo as an example. The national plant of Momotombo was created in 1983. Due to a historical technical error the nominal potential was calculated to 72 MW. This potential was never reached due to interference between several wells which were installed very near each other. Moreover the production diminishes with time.

Nowadays the geothermal plant generates 28 MW but measures are been taking in order to create an investment plan to recover the potential to at least 35-40 MW.

We have been informed through a former ISOR (Iceland Geosurvey) employee Thrainn Fridriksson, that the Governments of Iceland and Nicaragua had a geothermal capacity building project in 2008. Which were the accomplishments from this collaboration?

Indeed, the collaboration lasted from 2008 until 2012. The main objectives were to strengthen the geothermal capacity and train an expert geothermal staff in Nicaragua. Therefore during this period a laboratory equipment for geothermal potential was donated, and training courses on geochemistry were performed.This laboratory is the only one in Nicaragua that has been accredited by the national accreditation office. The main objective of the laboratory was to determine the geothermal potential in the areas that were not present in the national Geothermal Plan 2001. In consequence field studies, sampling and analysis were completed all along the 16 volcanos of the Pacific ridge and as a result from this project the geothermal potential for high enthalpy of Nicaragua was calculated to 1519 MW. Other projects for medium and low enthalpy were also performed but the results has not been published yet.

4.1.2 Albanisa - Alba Petróleos de Nicaragua

Presentation of Lucrecia Cruz Gamez

Figure 14: The interview at Albanisa (Rosa Maria Maliaños)

Lucrecía Cruz Gámez is a Geology Engineer with a master in Risk Management and a wide experience in geothermal energy. She worked during four years for the company Polaris where she worked with different projects as a geologist specialized in wells in the two volcanic areas Momotombo and San Jacinto in Nicaragua. In the projects she worked with lithology and analysed the minerals present in the wells. Today she works at Albanisa (Alba Petróleos de Nicaragua) which is a private entity that manages investment funds in Nicaragua, where she work with geothermal projects in the area around Managua.

Which are in your opinion the advantages and disadvantages of geothermal energy in Nicaragua?

Advantages are that geothermal energy is a long term clean energy. Additionally, it has a constant energy, which means that no storage technology is needed. Disadvantages are that the costs for these type of projects are high and that sometimes the objectives of the project is not reached. An example could be that you are drilling for geothermal water but it cannot be found and then you have high expenses but no income. This has given rise to that investors have a lot of fear of investing in this type of projects. It has therefore led to that when projects are to be started, help from externals are always searched from other countries.

If the area of Puerto Morazan has a geothermal potential do you know who will be interested in financing the project?

As mentioned before if you want to do a project you need to find an external partner, as financial support is not given by the government of Nicaragua. If the country would have invested in geothermal energy the country would have had a positive development. It would lead to that new jobs would be created and also that a lot of the rural population would be able to get electricity from the geothermal energy. Additionally, new roads would be built and the electricity grids would expand due to the new plant of geothermal energy. However, it is difficult to plan and estimate how the electricity would affect the rural areas because its development is dependent on large electricity companies.

Collaboration with Iceland

Polaris had a project together with Iceland that lasted for four years. Together they created a laboratory that is still in use today at the Ministerio de Energía y Minas. Even so, the most complete laboratory in the whole Central America is located in El Salvador.

Are there any other laboratories in Nicaragua?

In Nicaragua the company ENEL also has another laboratory in Managua. Enel is the company that explores the geothermal energy from the volcano Momotombo. In their laboratory they perform chemical analysis both from water and gas samples to use for geothermometers. However, the work is limited as the lab is not complete it does not have all the materials needed for the analysis.

According to the paper: Volcanos the energy future of Nicaragua, Nicaragua has a geothermal potential of 1519 MW which is three time the current total consumption. Therefore the country is only using 10percent of its geothermal potential, 152 MW. Why is geothermal energy only considered in the energy mix of Nicaragua for 2027 as 22 percent with a very low increase in comparison to the actual potential of it?

The first reason is the economical cost but also that the geothermal potential is overestimated. For example, San Jacinto normally has a nominal potential of 167 MW but the real potential is not more than 61 MW. Additionally, in Nicaragua today there are not many people working with geothermal potential as projects are not usually financed. Furthermore, in the north part of Nicaragua it is hard to access and therefore several projects with solar and hydropower has been performed instead. This has led to that these two energy sources are the ones that has been used in the rural parts of the country. In these rural areas both solar and biomass energy has been partly financed by several different NGO's (non-governmental organisation). However, the financial help from NGO's has decreased recently. Nicaragua had a geothermal top during the last government and the interest for the geothermal energy started in the 1980's.

4.1.3 ENEL - Empresa Nicaraguense de Electricidad

Presentation of Mayela Sanchez Molinares

Mayela Sanchez is a chemical engineer from the UNI-Nicaragua. She has been working in the ENELs Geochemical laboratory for 25 years and is therefore an expert on the field. The laboratory performs the reconnaissance and monitoring of the different geothermal resources identified in the country such as: Momotombo, San Jacinto Tizate, Caldera de Apoyo, Mombacho Volcano, Tipitapa and Isla de Ometepe. The analysis is performed with the objective of monitoring areas of geothermal interest by means of inorganic parameters. In figure 15 a picture from the interview can be seen.

Figure 15: The interview at ENEL. Photo by Rosa Maria Maliaños

In your opinion which are the advantages and disadvantages of geothermal energy in Nicaragua?

The advantages are the high potential which is according to El Plan Maestro Getermico de Nicargua is 1520 MW. The main disadvantage is economical due to its high cost and need of funding. The funding is normally received from a foreign organization in Nicaragua. In the moment there are several projects such as the volcano Cosiguina and la Casita financed by International Bank for Reconstruction and Development (IBRD)

Which methodology does ENEL use to study the geothermal potential of a site e.g. Momotombo?

Firstly, we found areas that present the following characteristics: thermal manifestations, boiling mud, fumaroles and soil color alterations. Then a geological mapping is performed with all the wells, springs and rivers present in the area of interest, normally around 2-3 km^2. Thereafter the sampling procedure is performed and the sample is analyzed in the laboratory. In parallel both geological and geophysical analyses are performed. If the results show a high enthalpy for geothermal potential financing is searched.

Which methodology does the laboratory use for the geochemical studies?

If we take the geothermal plant of Momotombo as an example we start with performing monthly both water and gas samples. This analysis is performed in order to detect periodic changes. For the water samples pH, solids, conductivity and the following elements are analyzed using a spectrophotometer: Sodium, Potassium, Calcium, Magnesium, Silicon, Boron, Sulphate, Chloride, Phosphate, Nitrate, Carbonate and Bicarbonate. For the gas samples carbon dioxide, ammonium and hydrogen sulfide are studied in the laboratory. The geothermometer used in order to asses the subthermal temperature are: Na-K, Na-K-Ca, and Si.

Which are the expected results for thermal waters with geothermal potential?

When analyzing the results it is important to take into consideration the difference between thermal water and condensed steam. If the samples is a thermal water then the results from the ICP-OES will have calcium, sodium, silicate and potassium. On the other hand, if the samples is a condensed water these elements will not be present and high concentration of sulfates will be studied. The conductivity and the pH for thermal waters should be between 10 000 uS/cm and 7 and for condensed vapor 300 uS/cm and 4 respectively.

Which mathematical methodology does ENEL use to calculate the final geothermal potential of the specific area of interest?

The geothermal potential has to be calculated by integrating all three geosciences: Geological ,Geochemical and Geophysical. ENEL has another department that analyses all the results and calculates the geothermal potential. For the geochemical studies it is important to analyze if the results present the following elements in order to determine if the samples were thermal waters and not superficial waters: high Chlorides concentration, low Mg, high Si, Na, K and high B and F. The temperature for high enthalpy should be around 200°C which is the one required to create electricity.

4.1.4 Isla Campuzano

Presentation of Melvin Soriano

Melvin Soriano is the leader of the community of Isla Campuzano and has been living there for 17 years. He helped us during our second field trip to find the hots springs and organized a meeting with Marcos Ramirez who is responsible for the environmental issues mayor office of Chinandega were future projects in the area were discussed. In figure 16 Melvin Soriano and the field work team can be seen out in field at Isla Campuzano.

Figure 16: At Isla Campuzano (Fernando Guarin)

How large is the population of Isla Campuzano?

In the village Isla Campuzano there are living 67 families, a total of 276 persons and the population continues to grow. The first families arrived 17 years ago. The area can be seen in figure 4.

Which are the main necessities of the community?

- Clean water
- Electricity
- Teachers for the school, they only have one teacher for 27 students between the ages of 6 to 12 years old. And a preschool teacher.

- Community house, where they could perform meetings and a health center.
- Buildings that can stand earthquakes
- Jobs for the population. Today the majority of the population receives their income within the agriculture, and seasonal work at the shrimp farms. There are three small grocery stores in the village. In order to solve this problem Melvin is trying to encourage own projects such as a little shrimp farm for the village.
- Checkpoint at the entrance, due to security problems. The village has had several cases of property theft, two sexual assaults, and house fires.
- Road improvement, approximately 8 km.

Presentation of Doña Goya
During our first field trip an interview was performed to a local woman called Doña Goya from the area of Isla Campuzano. She owned a small grocery shop very near the sampling area.

How many families are living in Isla Campuzano? What is the main occupation of the population living in the area?

67 families, around 300 persons live in Isla Campuzano. The population has arrived during the last 15 years in the village surrounding the sampling area. The community does not have access to electricity or clean water. The village belongs to the municipality of Chinandega. The village economy is dependent on the corn agriculture and no tourism is present in the area. Several diseases such as severe flu, fever, and kidney problem occur regularly.

Where does the population take water from? Is there any access to electricity?

The water is taken from natural springs or wells which could be polluted. In order to charge the village phones Doña Goyas family has a solar panel that costed 577 USD.

4.2 Field work

The following results presents the data analyzed in field such as the pH, conductivity and temperature of the different water samples. The data from these three different types of measurement are presented in the diagrams as an average from each six sample location presented in figure 11. The specific pH, conductivity and temperature for each sample are presented in Appendix D.

4.3 Sampling Results

Figure 17 shows the average pH variation of the six sample location.

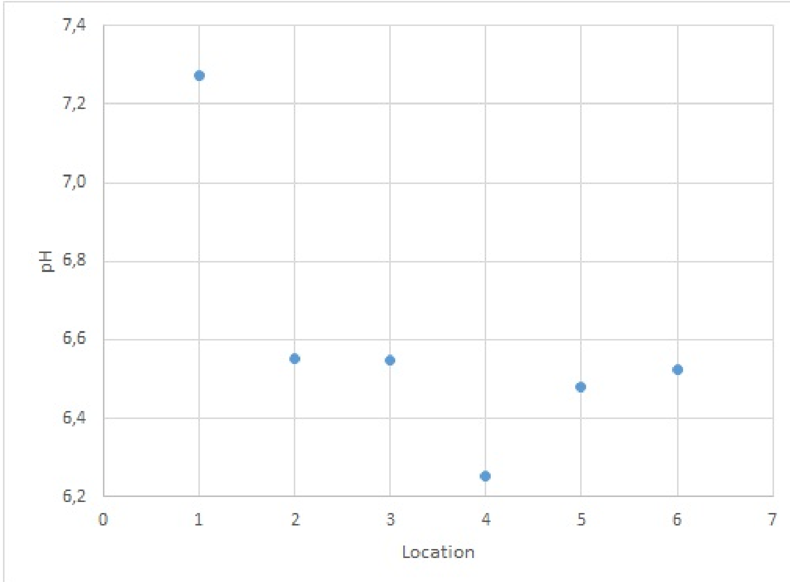

Figure 17: Average pH

Figure 18 shows the average conductivity variation of the six sample location.

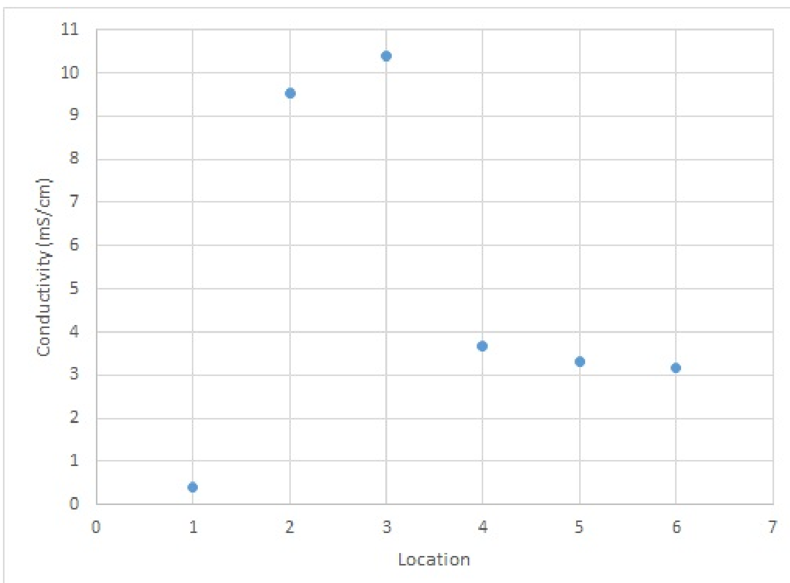

Figure 18: Average conductivity (mS/cm)

Figure 19 shows the average water sample temperature variation of the six sample location.

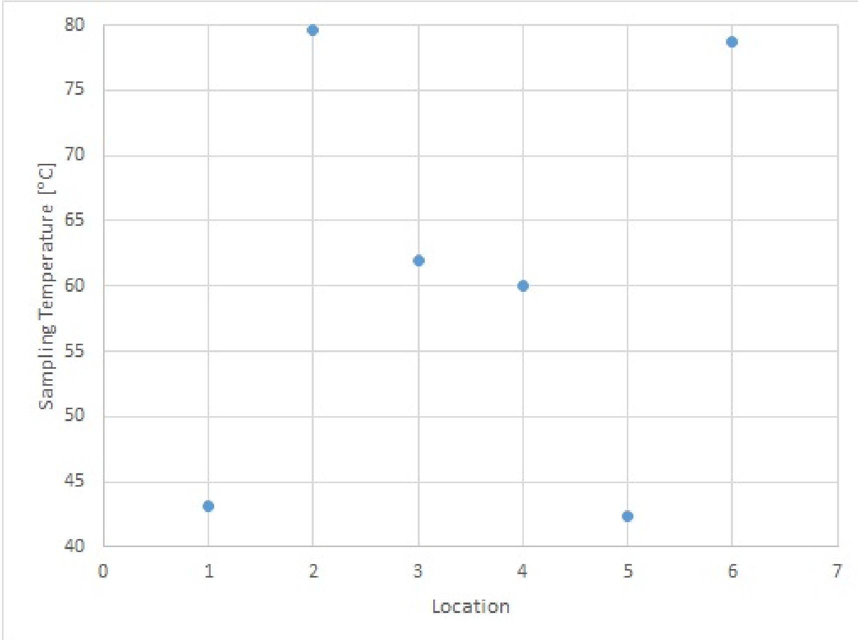

Figure 19: Average sampling temperature (°C)

4.4 Geochemical analysis

In figure 20 the four elements average concentration (mmol/l) for each location is presented. The blue dots shows the Na^{+} concentration, the orange K^{+}, the gray Ca^{2+} and the yellow SiO_2. For the specific concentration for each sample see Appendix E.

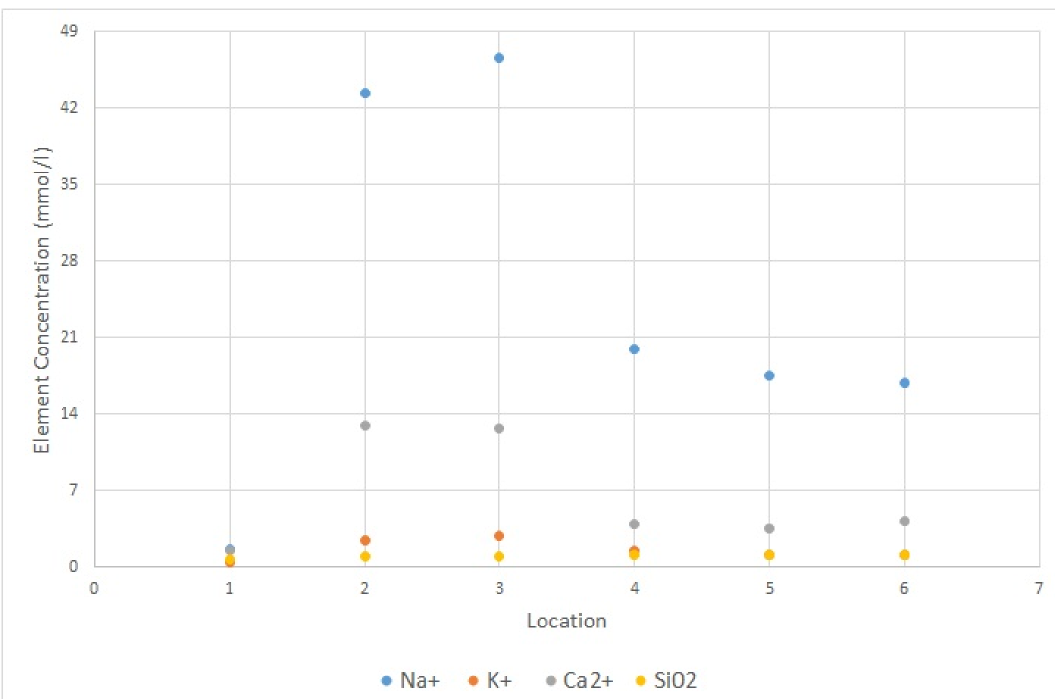

Figure 20: Average element concentration

4.5 Geothermal potential

Using the two equations Fournier Truesdell (1973) and Fournier (1981) the sub temperature of the six different locations was calculated. The results for the average sub temperature for each geothermometer and location is presented in Figure 21. For the specific temperature for each sample see Appendix F.

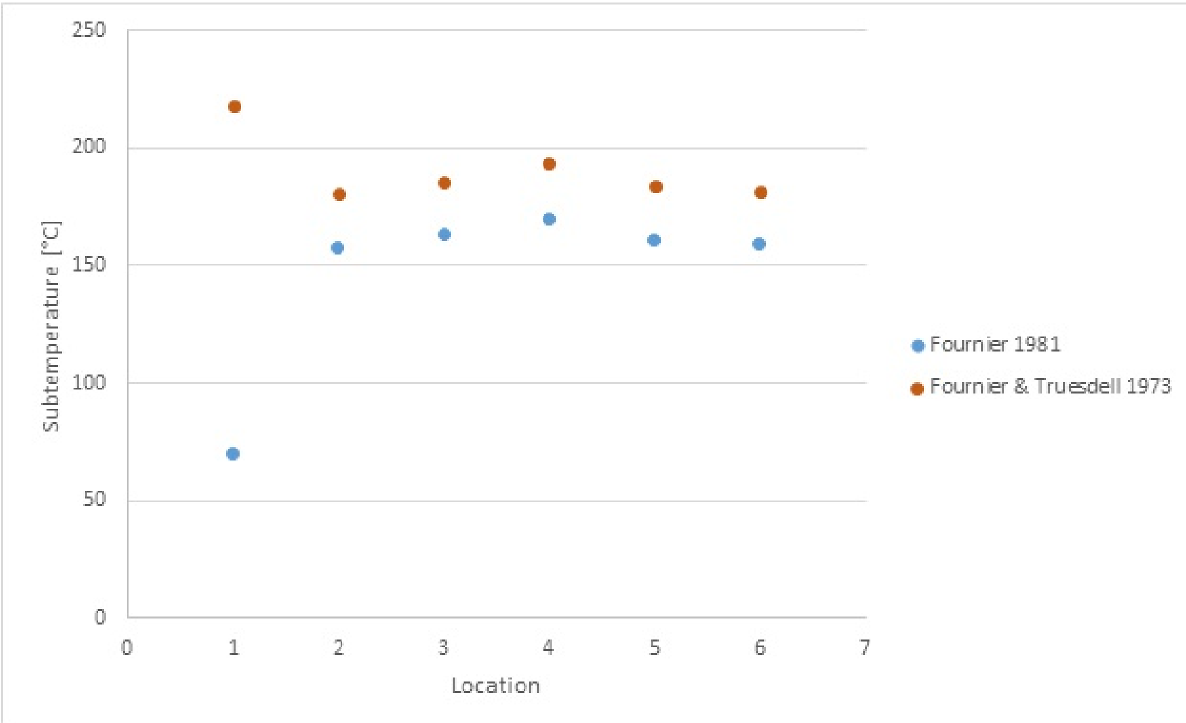

Figure 21: Average geothermometer temperature

5 Discussion

The discussion is structured as the result starting with interviews, field work, geochemical analysis and geothermal potential with an additional part concerning uncertainties.

5.1 Interviews

During the different interviews several topics were discussed. At the interviews with MEM, Albanisa and ENEL advantages and disadvantages with the geothermal energy were presented. They all agreed that a disadvantage is the need of high fundings in order to implement this type of energy which could be a difficult task due to the uncertainties linked to the the first exploration phase of this type of energy. However, all three interviewed persons agreed that the main advantage with this type of energy is that it is environmental friendly and could be used as a base energy thanks to its low variability of energy generation. Additionally, Lucrecia Cruz Gamez also stated that another advantage with this type of energy is that no storage technology is needed and that its development could lead to a positive change in the society such as new job opportunities, better roads and higher percentage of the population with electricity access.

Another topic discussed was the overestimation of the geothermal potential in Nicaragua, which both Mario Gonzalez and Lucrecia Cruz Gamez agreed on. According to, Mario Gonzalez this issue is due to a high bureaucratic system, historical technical errors such as well interference and the uncertainties of the geothermal potential on a study area. International cooperation has been needed in Nicaragua in order to help with the development of geothermal energy. The largest was the collaboration with the Icelandic Government between 2008 and 2012. During these years MEM were given courses on geochemistry, labb equipment and helped with estimating the total geothermal potential of Nicaragua which was estimated to 1519 MW by the Icelandic Government. Furthermore funding for geothermal projects in Nicaragua has also been provided by the World Bank and the International Bank for Reconstruction and Development(IBRD) as stated by MEM and ENEL.

The methodology used was discussed and supported by Mayela Sanchez. During the interview the different chemical elements analyzed for the geothermal potential of Momotombo were presented as sodium, potassium, calcium, magnesium, silica, boron, sulphate, chloride, phosphate, nitrate, carbonate and bicarbonate. Together with Mayela Sanchez we concluded that for a first geothermal potential study of the area calcium, potassium, sodium, and silica were enough in order to get a general result. Though for further researches all of the different elements should be studied in order to get accurate data. Furthermore, ENEL used Na-K, Na-K-Ca and Si geothermometer for their calculations which were all suitable for Momotombo geothermal power plant. She explained to us that for our geochemical results the Na-K-Ca geothermometer was the only one that would give us accurate sub thermal temperatures. The differentiation between geothermal water and condensed water was also discussed with Mayela Sanchez. It was concluded that for geothermal water the conductivity should be around 10mS/cm, the pH 7, high concentrations of Cl, Si, Na, K,B and F, and low concentration of Mg. Finally the limitation of estimating the geothermal potential with only a geochemical analysis was concluded to be not sufficient as the geology and the geophysics of the area has to be studied and taken into consideration. However, a rough estimation could be done in order to get an preliminar indication of the geothermal potential of the area.

The socio-economic situation of the area of Isla Campuzano was discussed with the head of the village Melvin Soriano and a local woman Doña Goya. They both agreed that the main issues in the village are the lack of clean water and electricity. Furthermore Mr. Soriano described the social problems e.g. education, unemployment, health and security. The electricity issue could be solved by the use of geothermal energy. Moreover, as explained by Lucrecia Cruz the development of a geothermal power plant would contribute to better infrastructure which would have a positive impact on the socio-economic problems in the area.

5.2 Field work

The results from the field work were pH, conductivity and sampling temperature. The pH for the different samples were all around neutral 7 ,which is according to Mayela Sanchez an indication of geothermal water. However, the first sample location had a pH around 7.3 which is higher than the other sampling locations that had a pH around 6.5. One explanation could be that this water was pumped from a spring to a container to be used as drinking water. The sampling of this water was done at the container and not at the water source as the rest of the sample locations. A source of error for the pH was that it was measured at sampling temperatures and not at 20-25°C which could have slightly affected the results.

In the conductivity results it can be seen as from the results from the pH that the first sample location differs from the other five. This first location had very low conductivity which according to Mayela Sanchez indicates condensed water vapor and not geothermal water. Looking at figure 14 a clear differentiation can be seen between locations 2-3 and 4-5-6. Location 2-3 had a conductivity around 10 mS/cm indicating geothermal water. On the other hand, 4-5-6 had a conductivity between 3 and 4 mS/cm which is not indicating a clear geothermal water. Looking at figure 7, an explanation for the conductivity change could be the distance between the sampling locations which are divided in two areas and may therefore have a different type of geology. A source of error for the conductivity was that it was measured at sampling temperatures and not at 20-25°C, which could have slightly affected the results.

The results from the sampling temperature present a high variation in temperature from 40 to 80°C. However, all samples have abnormally high temperature, higher than 30°C which according to Mayela Sanchez indicates a geothermal activity. The water from the sampling locations 1,3,4 and 5 had a temperature lower than 70°C which was a requirement for the usage of the geothermometer Na-K-Ca Fournier (1981). This error is further discussed in the geothermal potential below. Nevertheless, it is important to state that as it was the first two field trips in the area it was difficult to find hot springs relevant for the project.

In conclusion, when analyzing the results from field work it can be said that the first sampling location do not indicate geothermal characteristics. Also a correlation between the sampling temperature and conductivity is not seen, which indicates that the geology of the area has a higher impact on the conductivity than the temperature. Finally, a clear differentiation can be seen between the two sampling areas.

5.3 Geochemical Analysis

As presented in figure 16, the first sampling location differs from the rest. In the rest of the samples the correlation between the chemical elements is the same. Sodium is highest in all of them followed by calcium, potassium and silica. However a clear difference between the two locations areas (2-3 & 4-5-6) is observed.

The sodium concentration is highest for the two first sampling locations, though it is also elevated in the last three locations in relation to the other elements. High concentration of sodium could be an indication that the water also contains high concentration of chloride. This means according to Mayela Sanchez that the water is of geothermal character.

The same tendency for the two different location areas can be observed as well for the calcium concentration. For the first location area the concentration is around 13 mmol/l and for the second location 4 mmol/l. The presence of calcium concentration could be explained by the mixture of the geothermal sub water with superficial water rich in calcium which occurs during the rise if the sub water to the surface. If the samples would have been taken in wells the calcium concentration would have been lower.

All results shows low concentration of silica which is not an indication of geothermal water. However an explanation to this could be that during the rise of the sub water to the surface, agglomeration and precipitation of silica could have occurred. The results from potassium do not show a remarkable trend which affects the geothermal potential. Therefore no further discussion is needed.

5.4 Geothermal Potential

From the geochemical analysis, the geothermal potential was calculated and presented in figure 17. As previously stated sampling location one do not present geothermal characteristics and as a consequence the geothermometers give distinctly different answers to the sub temperature. On the other hand, the rest of the results are similar showing a difference between both geothermometers of approximately 20°C.

When analyzing the results from figure 17, it can be concluded that all locations except for the first one, shows a sub temperature between 150 to 200°C. According to Sveinbjörnsson(2016) this temperature range means a medium enthalpy geothermal source. The main application to this enthalpy is electricity generation through a binary power plant which is less efficient than the direct application from high enthalpy, as explained in theory.

Even though, both geothermometers indicate medium enthalpy there is a clear difference between them of approximately 20°C. There are two possible explanation for the difference between both geothermometers. The first one is that for Fournier (1981) the sampling temperature needed to be above 70°C which was only the case for sampling location 2 and 6. This may have have affected the results at the other sampling locations. Furthermore, for the calculations of Fournier (1981) we assumed that 1 mg/kg was equal to 1 mg/l, in other words the samples were pure water which was not the case, this may also have affected the results. Even though, as all geothermometers are empirical and theoretical it is important to take into consideration several of them in order to get a more accurate view of the geothermal potential of the studied area.

As this geothermometers are based on chemical elements it is important to analyze a range of different elements to be able to use as many geothermometers as possible. Finally, our results are not 100% accurate but they are sufficiently good in order to get an estimation of the geothermal potential of the area of Isla Campuzano.

5.5 Uncertainties

The uncertainties would be less if several different types of geochemical methods would have been used in order to describe the geothermal water such as a Piper Plot and Giggenbach diagram or other types of geothermometers. For this analysis additional chemical elements needs to be studied such as Mg, Cl, HCO_3,SO_4, B, F NO_3^-, CO_3^{2-} and PO_4^{3-}. Furthermore in order to get more accurate results a higher number of samples should be taken in the area of Isla Campuzano during a longer period of time and more chemical elements related to the thermal water potential should have been analyzed. As mentioned before the geology and geophysics of the area should be studied more precisely in order to get geothermal results from this geosciences to which could complement the geochemical studies.

Human errors could have been made during the whole process. One example is that the pH and conductivity was not measured at 20-25°C. Also, the methodology was decided by ourselves based on scientific articles and without a high experience on the geothermal area.

6 Conclusion

The main objective of this bachelor thesis was to determine if there was a geothermal potential in the area of Isla Campuzano considering geochemical results. It can be concluded that there is a geothermal potential in the area except for sampling location 1. By analyzing the results it is estimated that the enthalpy of the area is medium. However, a temperature difference can be seen depending on which geothermometer used. In other words, there is a potential of generating electricity through a geothermal source in the area by using a binary power plant. These results could be used as an estimation. By only analyzing the geochemistry an estimation of the geothermal potential can be done. Nevertheless, further studies of geochemistry, geology and geophysics is needed to be certain that the area has a geothermal potential that can be exploited to generate electricity.

Due to time and budget only sodium, calcium, potassium and silicate were studied, which led to that only two geothermometers could be used. Additional chemical elements should be analyzed such as magnesium, boron, sulphate, chloride, phosphate, nitrate, carbonate and bicarbonate in order to use a higher amount of different methods to analyze the geochemistry and increase the accuracy of the results.

It can be concluded from the interviews that the main disadvantage of geothermal energy in Nicaragua is the difficulty of finding financial help for geothermal projects. Also overestimation of the potential has been an ongoing problem due to technical errors. On the other hand, the main advantages are that geothermal energy is an environmental friendly energy source which has a potential of 1519 MW in Nicaragua. Furthermore, it can be used as a base energy due to its low variability and therefore no storage technology is needed. An investment on this type of energy could both lead to an improved infrastructure and positive development of the socio-economic situation in Nicaragua.

7 Recommendations

For future work in the area of Isla Campuzano the following points are recommended to take into consideration:

- For future work further analysis on the geochemistry of the area should be performed as well as geophysical and geological results. This three geosciences are important in order to gain an understanding of the geothermal potential in the studied area.
- In order to get more accurate results in the geochemistry, additional sampling locations should be explored and analyzed in order to get an understanding on how the geothermal source is distributed. Also additional elements should be analyzed in order to be able to use different method to determine geothermal water samples. Example of these elements are:Mg, Cl, HCO_3,SO_4, B, F $NO_3{}^-$, $CO_3{}^{2-}$ and $PO_4{}^{3-}$.
- It is also important to make a more extensive risk assessment for the field work in order to be well prepare for the sampling procedure as handling with hot water and an unknown terrain.
- When analysing pH and conductivity it is important to do the measurement at a temperature around 20-25 °C. This is due to that the apparatus functions more accurately at these temperatures. Another recommendation is to bring at least two apparatus of each type in case of breakdown.
- For future analysis the water samples should be located in both superficial water and wells in order to analyze the difference in the chemical concentration such as calcium and silica.
- The measurements should have been taken during a longer period of time and with a larger budget as the chemical analysis is expensive.
- An expert in the geochemical area could be helpful in order to gain a better understanding of the whole process considering the methodology, fieldwork and laboratory work.
- If geothermal potential is found it is important to have a dialog and seek financial help with the municipality as they are the ones in charge of the electricity and water consumption of the area.

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10 Appendix

10.1 Appendix A. Geological Mapping

Table 3: Geological Mapping (Fernando Guarin 2017)

Point	Coordinate x	Coordinate y	Elevation (masl)	Geology	Water Source
1	489524	1419037	27	Andesite	Spring
2	487291	1420620	6	Epiclastic Sediments	Spring
3	487267	1420554	3	Epiclastic Sediments	Spring
4	488649	1419268	2	Epiclastic Sediments	Spring
5	488786	1418964	7	Epiclastic Sediments	Spring
6	488752	1418949	8	Epiclastic Sediments	Spring
7	489432	1418970	31	Andesite	Spring
8	492207	1420572	65	Andesite	Spring
9	487862	1420480	5	Andesite	Rock sample
10	491027	1418382	0	Andesite	Rock sample
11	487871	1420473	12	Andesite	Spring
12	489479	1419110	33	Andesite	Rock sample
13	490455	1420732	64	Andesite	Rock sample
14	488976	1420654	122	Andesite	Spring
15	489729	1418757	8	Andesite	Well
16	490312	1418517	9	Andesite	Spring
17	492767	1420033	15	Andesite	Well
18	492736	1420051	11	Andesite	Well
19	492770	1420050	8	Andesite	Andesetic basement
20	490707	1419111	146	Andesite	Rock sample
21	490733	1419098	154	Andesite	Rotational sliding
22	490736	1419149	175	Andesite	Rotational sliding
23	490765	1419182	176	Andesite	Clasts
24	490764	1419179	117	Andesite	Hill
25	490592	1418953	99	Andesite	Change of slope
26	490524	1418852	58	Andesite	Change of slope
27	490324	1418665	60	Andesite	Change of slope
28	490324	1418665	60	Andesite	Mister Melvins House
29	488552	1419329	44	Epiclastic sediments	Shrimp farm
30	489478	1418905	15	Andesite	Spring
31	493918	1419632	44	Andesite	Miss Goya House
32	489603	1419099	57	Andesite	Rock sample
33	488832	1418934	8	Epiclastic sediments	Spring

10.2 Appendix B. Sampling Equipment

Table 4: Sampling Equipment

Equipment	**Quantity**
Digital Thermometer: Range -20 to +100 Degrees Celsius	1
HANNA HI 8733: Electrical conductivity probe plus batteries: Range 0 - 50 Degrees Celsius	1
Thermo ORION 4 STAR pH DO Portable: pH plus batteries Range: 5 - 50 Degrees Celsius	1
60 ml pH Electrode Storage Solution plastic bottles	4
Labels	50
1x60 ml Conductivity/TDS Standard NaCl 1413 mikroS/cm	1
Hammer, for collecting rock samples	1
Measuring tape	1
Handheld GPS	1
Tweezers	1
Glass Container	500 ml
Supporting sticks for sampling water	1
High Temperature Gloves	2 pairs
Ice	bought after time
Rubber boots	2 pairs
Duck tape	1 roll
HNO_3	1 ml per sample collected
Distilled water	1 L
Pipettes	2
Cool bag	1
500 ml Plastic bottle	9
Beaker	3

10.3 Appendix C. Pictures sampling location

Figure 22: Location 1

Figure 23: Location 2

Figure 24: Location 3

Figure 25: Location 4

Figure 26: Location 5

Figure 27: Location 6

10.4 Appendix D. Results Field Work

Table 5: Results from Field Trip.

Sample	Location	Date	Time	pH	Cond	Temperature	GPS
1a	Isla Campuzano Real	3/2/2017	11.40h	7.24	0.42 mS/cm	43.3	0489524/141903 7m
1b	Isla Campuzano Real	3/2/2017	11.40h	7.31	0.40 mS/cm	42.9	0489524/141903 7m
Average 1	Isla Campuzano Real	3/2/2017	11.40h	7.28	0.41 mS/cm	43.1	
2a	Manglar Estero Real	2/2/2017	14.25h	6.53	9.53 mS/cm	79.6	487291/1420620 6m
2b	Manglar Estero Real	2/2/2017	14.25h	6.54	9.51 mS/cm	79.6	487291/1420620 6m
2c	Manglar Estero Real	2/2/2017	14.25h	6.59	9.59 mS/cm	79.6	487291/1420620 6m
Average 2	Manglar Estero Real	2/2/2017	14.25h	6.55	9.54mS/cm	79.6	

Table 6: Results from Field Trip.

Sample	Location	Date	Time	pH	Cond	Temperature	GPS
3a	Manglar Estero Real	2/2/2017	14.30h	6.48	10.5 mS/cm	62.6	487267/1420554 3m
3b	Manglar Estero Real	2/2/2017	14.30h	6.57	10.28 mS/cm	61.3	487267/1420554 3m
3c	Manglar Estero Real	2/2/2017	14.30h	6.59	10.42 mS/cm	62.0	487267/1420554 3m
Average 3	Manglar Estero Real	2/2/2017	14.30h	6.55	10.40 mS/cm	61.96	
4a	Cooperativa Gregorio Santos	14/2/2017	12:43h	6.252	3.68 mS/cm	60.5	488649/1419268 2m
4b	Cooperativa Gregorio Santos	14/2/2017	12:43h	6.252	3.63 mS/cm	59.1	488649/1419268 2m
4c	Cooperativa Gregorio Santos	14/2/2017	12:43h	6.252	3.63 mS/cm	60.5	488649/1419268 2m
Average 4	Cooperativa Gregorio Santos	14/2/2017	12:43h	6.252	3.68 mS/cm	60.03	

Table 7: Results from Field Trip.

Sample	Location	Date	Time	pH	Cond	Temperature	GPS
5a	Cooperativa Gregorio Santos	14/2/2017	13.00h	6.48	3.31 mS/cm	42.1	488786/1418964 7m
5b	Cooperativa Gregorio Santos	14/2/2017	13.00h	6.48	3.30 mS/cm	42.5	488786/1418964 7m
5c	Cooperativa Gregorio Santos	14/2/2017	13.00h	6.48	3.32 mS/cm	42.4	488786/1418964 7m
Average 5	Cooperativa Gregorio Santos	14/2/2017	13.00h	6.48	3.31 mS/cm	42.3	
6a	Cooperativa Gregorio Santos	14/2/2017	13:15h	6.52	3.12 mS/cm	78.4	488752/1418949 8m
6b	Cooperativa Gregorio Santos	14/2/2017	13:15hh	6.52	3.19 mS/cm	79.1	488752/1418949 8m
6c	Cooperativa Gregorio Santos	14/2/2017	13:15h	6.52	3.20 mS/cm	78.7	488752/1418949 8m
Average 6	Cooperativa Gregorio Santos	14/2/2017	13:15h	6.52	3.17 mS/cm	78.7	

10.5 Appendix E. Geochemical analysis and potential

Table 8: Results Geochemical analysis

Sample	1a	1c	Average 1	2a	2b	2c	Average 2
$Na^{+}(mg/l)$	38,79	36,91	37.85	998,32	990,70	990,58	993.20
$Na^{+}(mmol/l)$	1.69	1.61	1.65	43.59	43.26	43.26	43.37
$K^{+}(mg/l)$	5,91	11,42	8.66	70,47	48,70	49,90	56.36
$K^{+}(mmol/l)$	0.26	0.50	0.38	3.08	2.13	2.18	2.46
$Ca^{2+}(mg/l)$	35,85	35,14	35.49	304,83	277,65	302,94	295.14
$Ca^{2+}(mmol/l)$	1.57	1.53	1.55	13.31	12.12	13.23	12.89
$SiO_2(mg/l)$	40,04	40,22	40.13	56,15	52,72	57,85	55.57
$SiO_2(mmol/l)$	0.67	0.67	0.67	0.93	0.88	0.96	0.92

Table 9: Results Geochemical analysis

Sample	3a	3b	3c	Average 3	4a	4b	4c	Average 4
$Na^{+}(mg/l)$	1105,09	995,75	1099,33	1066.72	465,95	440,59	462,15	456.23
$Na^{+}(mmol/l)$	48.26	43.48	48.01	46.58	20.35	19.24	20.18	19.92
$K^{+}(mg/l)$	87,06	52,39	56,3	62.25	37,97	33,06	33,72	34.91
$K^{+}(mmol/l)$	3.80	2.29	2.46	2.85	1.66	1.44	1.47	1.52
$Ca^{2+}(mg/l)$	301,84	267,33	297,34	288.84	105,88	80,60	85,75	90.74
$Ca^{2+}(mmol/l)$	13.18	11.67	12.98	12.61	4.62	3.52	3.74	3.96
$SiO_2(mg/l)$	57,98	48,86	55,48	54.11	62,87	63,43	63,64	63.31
$SiO_2(mmol/l)$	0.96	0.81	0.92	0.90	1.05	1.06	1.06	1.05

Table 10: Results Geochemical analysis

Sample	**5a**	**5b**	**5c**	**Average 5**	**6a**	**6b**	**6c**	**Average 6**
$Na^{+}(mg/l)$	401,03	392,87	411,97	401.96	384,57	393,48	374,89	384.31
$Na^{+}(mmol/l)$	17.51	17.16	17.99	17.55	16.79	17.18	16.37	16.28
$K^{+}(mg/l)$	26,02	25,91	26,66	26.20	24,96	25,64	24,78	25.13
$K^{+}(mmol/l)$	1.14	1.13	1.16	1.14	1.09	1.12	1.08	1.10
$Ca^{2+}(mg/l)$	80,56	81,22	80,56	80.78	87,47	110,77	87,68	95.31
$Ca^{2+}(mmol/l)$	3.52	3.55	3.52	3.53	3.82	4.84	3.83	4.16
$SiO_2(mg/l)$	66,91	66,47	67,30	66.89	62,52	64,76	61,62	62.97
$SiO_2(mmol/l)$	1.11	1.11	1.12	1.11	1.04	1.08	1.03	1.05

10.6 Appendix F. Geothermal potential

Table 11: Results Geochemical analysis

Sample	**1a**	**1c**	**1**	**2a**	**2b**	**2c**	**2**
$T(Na/K/Ca)$(°C) Fournier 1981	59	80	70	169	152	152	158
$T(Na/K/Ca)$(°C) Fournier and Truesdell 1973	196	240	218	193	174	174	180

Table 12: Results Geochemical analysis

Sample	**3a**	**3b**	**3c**	**3**	**4a**	**4b**	**4c**	**4**
$T(Na/K/Ca)$(°C) Fournier 1981	177	156	155	163	173	170	169	170
$T(Na/K/Ca)$(°C) Fournier and Truesdell 1973	202	178	177	186	197	194	192	194

Table 13: Results Geochemical analysis

Sample	**5a**	**5b**	**5c**	**5**	**6a**	**6b**	**6c**	**6**
$T(Na/K/Ca)$(°C) Fournier 1981	161	161	161	161	160	158	160	159
$T(Na/K/Ca)$(°C) Fournier and Truesdell 1973	184	184	184	182	182	181	183	182