REUNION NACIONAL DE GEOTERMIA | RENAG Bogotá 2018
ASOCIACIÓN GEOTÉRMICA COLOMBIANA

TEMA DEL ARTÍCULO.

- Ciencia y tecnología

Evidence of Mixing of geothermal fluids and groundwater in the Quaternary Aquifer in the Paipa Area, Boyaca, Colombia

Oscar Garcia-Cabrejo, Eliana Medina, Laura Barrantes

[1]School of Geological Engineering, Universidad Pedagogica y Tecnologica de Colombia, Sogamoso, Boyaca, Colombia

ABSTRACT

The hot springs located near the city of Paipa Boyaca, Colombia are an important touristic attraction and they have been an important part of the local economy during most of the XX century. The occurence of springs in this area is associated to the presence of faults that creates a pathway for fluid migration towards the surface. During this vertical migration it is expected the ocurrence of mixing with the groundwater in the shallow aquifers present in this area or even with water from rainfall. However, currently there is no hydrogeochemical evidence of the existence of these mixing processes and the magnitude of the interaction between the geothermal fluids and groundwater. In this paper, a combined dataset from chemical composition of hot springs and groundwater collected by the Servicio Geologico Colombiano was compiled and analyzed using multivariate statistical tools and evidence of fluid mixing is found.

INTRODUCTION

Paipa is a town located in the central part of the Boyaca state in Colombia, where the use of the geothermal resources represented by hot springs has been an important economic activity during most of the XX-th and XXI-st centuries. Previous studies have focused on the chemical and isotopic composition of the geothermal fluids (Alfaro, 2001) without considering the hydrogeological framework where these fluids occur. Specifically, there is no clear indication on how the rainwater and groundwater interact with the geothermal fluids and how this interaction affects the chemical composition determined in previous studies. The spatial variation in chemical composition of the geothermal fluids is of critical importance to understand the occurence and evolution of the geothermal activity in the area and the degree of interaction between groundwater and geothermal fluids (mixing) to productively conserve and use of geothermal and groundwater fluids in the Paipa area.

This paper tries to define the hydrogeochemical features of the geothermal and non-geothermal fluids in the Paipa area, focusing on the reconstruction of the mixing processes that might explain the variations in the chemical composition observed in the data collected so far. To achieve this goal, a mixed dataset of chemical compositon of geothermal and groundwater is assembled from public sources and analyzed using multivariate techniques.

GEOLOGICAL SETTING

Paipa is a city located in the central part of Boyaca State (Fig. 1) on the Altiplano CundiBoyacence on the Eastern Cordillera of Colombia. In this area, the Quaternary is mainly composed by alluvial, colluvial and glacial deposits, where the alluvial deposits are associated with the activity of the Salitre and Tota Rivers which creates the Paipa Valley. The coluvial deposits are mainly located near Iza whereas the glacial deposits are found around Cuitiva and Tota. The Neogene sequence is composed mainly by clays originated in continental deposits such as the Bogota Formation, Upper and Lower Socha Formations, Picacho Formation, Concentration Formation and Tilata Formation. In addition there are several andesitic and riolitic rock bodies near Paipa and other riolitic to riodacitic rock bodies near Iza that cut accross the cretacic sequence in the area. The cretaceous rocks were formed in marine conditions and are represented by the Ritoque, Une, Churuvita, Conejo, Ermitaño, Plaeners, Labor y Tierna and Guaduas Formations.

In structural terms, the Paipa area is located on the norhtern end of the Tunja Sincline and it is bounded by the Boyaca and Soapaga faults. These are inverse faults with a trend of NE-SW that corresponds with the main tectonic trend of the Eastern Cordillera. There are other structures such as the Arcabuco Anticline, the Salitre and Sochagota Faults which are interpreted by some authors as part of the same structure as the Tunja sincline. These faults have been identified as potential conduits for geothermal fluids in the Paipa area.

GEOCHEMICAL SAMPLING

in this work, two different geochemical datasets are combined to study the mixing processes between geothermal and non-geothermal fluids. The first dataset was obtained by Alfaro(2001) and deals with the chemical composition of the hot springs in the Paipa area. These springs occur in the southern part of Paipa and are aligned NNE-SSW following the trend of the Salitre Fault.

The second dataset comes from the report of the hydrogeological conceptual model of the aquifer part of Boyaca, (SGC, 2017) where a total of 92 samples of chemical composition of groundwater in the alluvial aquifer were acquired. The samples in this dataset located near Paipa are selected and integrated with the geothermal samples previously mentioned.

METHODOLOGY

The methodology followed to undertand the mixing processes associated with the geothermal and non-geothermal fluids is the composed by 3 steps.

1.Dataset creation: The information required to study the mixing processes is

2.Exploratory Data Analysis:

3.Application of the M3 Algorithm: The M3 procedure to study mixing of different types of groundwater was originally proposed by Laaksoharju, C. et al (1999) and it is composed of 5 substeps:

- Standarize the concentrations of the major ions
- Apply Principal Components Analysis to the standarized concentrations
- Plot the samples coordinates in the two dimensional space defined by the first two principal components
- Identify the end-members as the samples with the extreme compositions in the plot of the first two principal components.

- Identify the mixing lines using the samples located along straight lines in the plot of the first tow principal components.

RESULTS

The Piper diagram of these samples discriminated by source type is shown in Figure 2. This diagram clearly shows the existence of at least three different groups of geothermal samples (green points). Group number 1 is located on the line of Ca and Mg on the central diamond and it is composed of samples PP23, PP-24, PP-16 and PP-06. This group is characterized by a Ca enrichment when compared to the rest of the samples and high concentrations concentrations of SO4 and Cl. Thse samples belong to the Calcium-Chloride and Sodium-Chloride types. The second group is characterized by low concentrations of Ca and high concentrations of SO4 and Cl and it is composed by most of the geothermal samples. These samples can be classified as Sodium-Chloride type. This group is shown as a cluster on the right corner of the central diamond. The third group is characterized by low concentrations of Ca, SO4 and Cl and it is composed of only two samples PP-26 and PP15. These samples can be classified of mixed type. The groundwater samples are shown as pink, blue and purple points and are scattered in the upper part of the central diamond. From the diagram, the samples 52691-I and 52777-I are located towards the left corner of the central diamond and therefore are assumed as representative of surface-water conditions. The samples 55704-I and 52802-I are closer to the samples of the third group previously mentioned. This result suggest the contribution of geothermal fluid to the water extracted from these wells.

The results of the application of the M3 methodology to study the mixing processes in the dataset analyzed are shown in figure 3. The hydrogeochemical dataset has five end-members which are represented as the extreme points in the diagram that encloses most of the samples. These end-members correspond to the samples PP-21, PP-16, 52691-I, PP-23 and PP-22 where the sample 552691-I is the only one representative of surface water conditions. The mixing of water of different chemical composition can be easily spotted when samples lie on a straight line on the plot. The end-members PP-16, 52691-I and PP-23 lie on a straight line, where all the groundwater samples are aligned between the endmembers PP-16 and 52691-I. This implies that the chemical composition of these these groundwater samples have a contribution of geothermal fluid with composition represented by the sample PP-16. The samples located inside the polygon shown in figure 3 correspond to the tight cluster seen in map (figure 1) and on the left corner of the central diamond in the Piper diagram (figure 2). The chemical composition of these samples can be explained as mixing of the geothermal fluids represented by samples PP-21 and PP-22 and surface water with a chemical composition similar to the sample 52691-I.

DISCUSSION AND PRELIMINARY CONCLUSIONS

There is mixing between geothermal fluids and groundwater in the Paipa area as seen from the results of the M3 algorith shown in figure 3. This figure clealy shows that there are four different geothermal fluids with a characteristic chemical composition, and that there are two types of geothermal fluid involved in mixing with surface water. The first type of geothermal fluid is represented by the sample PP-16 that corresponds to a hot spring called El Herbidero with a temperature of 22 C (Alfaro, 2002) that is located on the country side on the southern part of Paipa (see figure 1). The fact that there is a mixing line between the sample PP-16 and the sample 55691-I (surface water) is interpreted as a contribution of surface water to El Herbidero sample that reduces its temperature. This process also explain the chemical composition of the cold sample PP-06 (finca Elvira Ochoa, temperature of 18 C). This explanation assumes that the composition of the precipitation water is closer to the characteristics displayed by the sample 55961-I. The samples PP-23 and PP-24 appear isolated at the other end of the mixing line, which implies that their composition is not related to water surface. Their chemical similarities and their location can be explained as a result of the vertical flow on the same structural discontinuity that follows the regional trend (see figure 1). The second process detected in the analysis is the mixing between a sulfate geothermal fluid represented by samples PP-21 and PP-22 and surface water. This mixing process defines the chemical composition of the hot springs located near the airport and the public swimming pools.

An unexpected finding is the chemical composition of sample PP-01 is similar to the samples in the cluster but this sample is closer to the samples PP-16 and PP-06. This observation implies that there is a point geothermal discharge zone in this location that is not associated with the source that is related to samples PP-01 and PP-06.

The results and interpretation in terms of the mixing processes between geothermal and non-geothermal fluids depend on the amount of data used in the analysis. In this case, a dataset of 35 samples was asssembled from the geochemical sampling done by Alfaro(2001) and the hydrogeochemical data collected by the Colombian Geological Survey in the framework of the project called “Hydrogeological conceptual model of the aquifers in the central part of Boyaca”. At first sight, 35 samples seem to be enough for the use of the M3 multivariate technique but additional groundwater samples are required in the urban area of Paipa in order to understand more about the flow system of the Quaternary aquifer.

The existence of interaction between geothermal and non-geothermal fluids (groundwater) is critical to define a water management strategy in Paipa. In recent years, there has been an increased demand for water resoures in this area due to the increase in the intensity of the ENSO due to climate change. A proper water management strategy must be based on a detailed knowledge of the aquifer and geothermal systems and their interaction. Therefore additional studies on the hydrogeology and geothermal characteristics of this area are required in the near future.

This is the first time that evidence of mixing of geothermal and non-geothermal fluids (groundwater) in Paipa area is presented. This evidence was obtained through a multivariate analysis of the hydrogeochemical characteristics of geothermal fluids and groundwater chemical compositions. The results presented in this paper were obtained using the GQAnalyzer, a package developed in the R programming language to study the chemical composition of groundwater and geothermal fluids. This tools is being developed at the School of Geological Engineering, Universidad Pedagogica y Tecnologica de Colombia, Sogamoso, Boyaca, Colombia and its source code is available from the authors.

REFERENCES

Alfaro, C: Geoquímica del Sistema Geotérmico de Paipa. Reporte Técnico INGEOMINAS. 97 pp. (2002).

Laaksoharju, C. et al: Multivarariate mixing and mass balance M3 calculations, a new tool for decoding hydrogeochemical information. Applied Geochemistry, 14, 7, pp 861-871. (1999)

Servicio Geológico Colombiano:. Modelo Hidrogeológico conceptual de los acuíferos de la parte central de Boyacá. Informe elaborado para CorpoBoyacá. 256 pp. (2017).

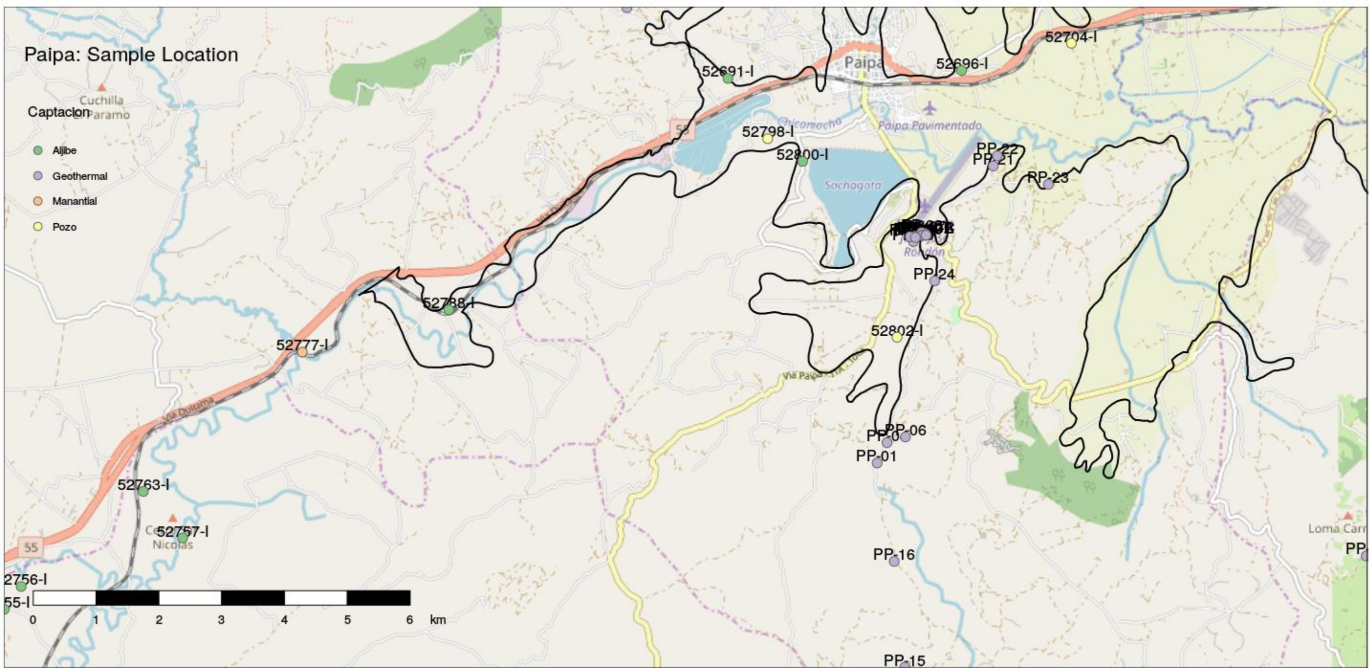

Figure 1. Location of the samples used in this study near the town of Paipa, Boyaca, Colombia. The black line marks the limit of the main quaternary valley in the area. There are few samples outside the main quaternary valley and these are located in smaller alluvial quaternary valleys. These samples are included in the analysis to have more information about the chemical composition of groundwater in the area of study.

Paipa Waters

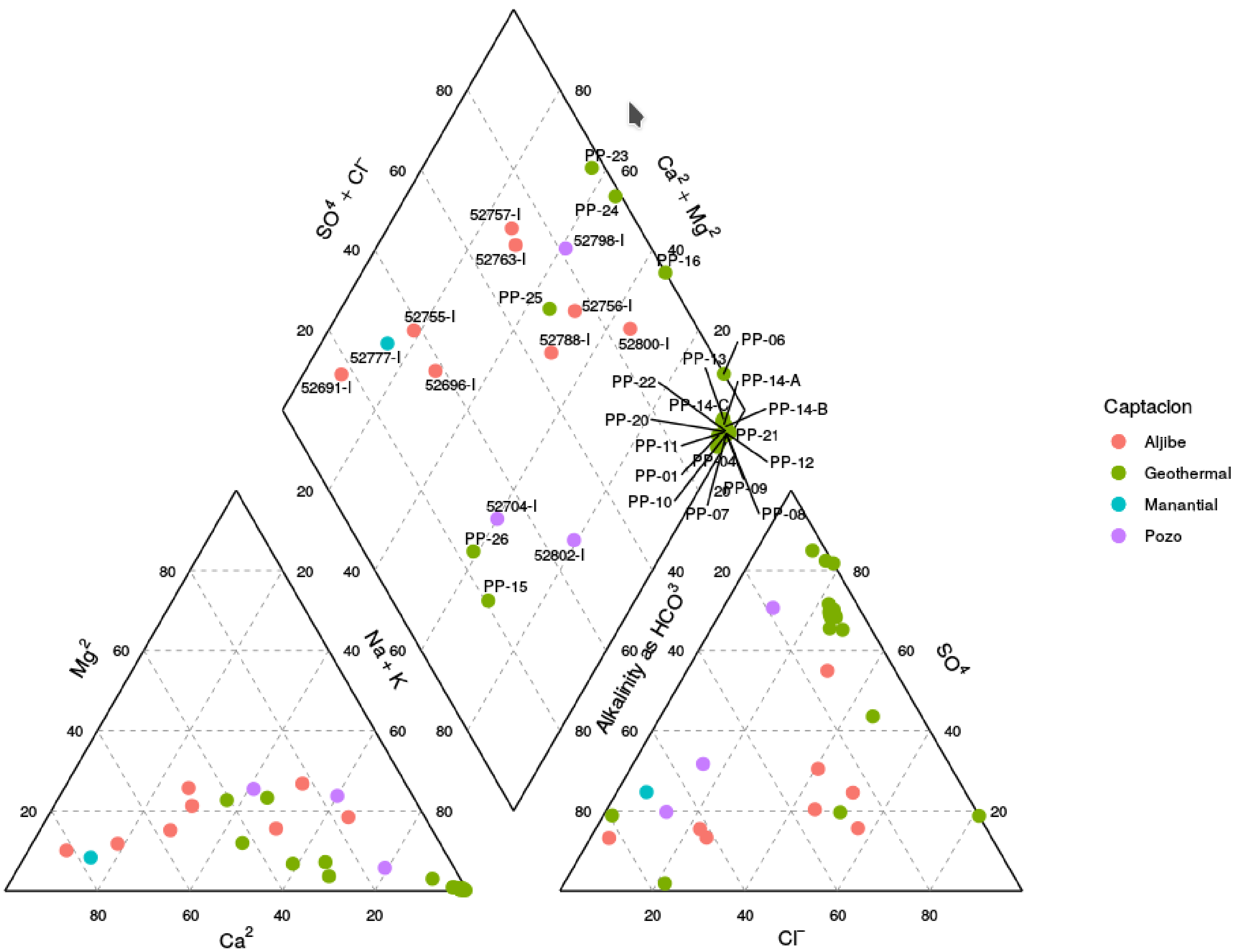

Figure 2. Piper diagram of the geotherma fluid and groundwater samples collected in Paipa, Boyaca, Colombia. The source type is shown in different colors. The diagram shows three different groups of geothermal fluids where most of the samples belong to the cluster seen in the left part of the central diamond. The samples PP-23, PP-24 and PP-16 form another group located on the limit of the upper part of the diamond. The last group is composed of two samples PP-26 and PP-15 located in the lower part of the diamond.

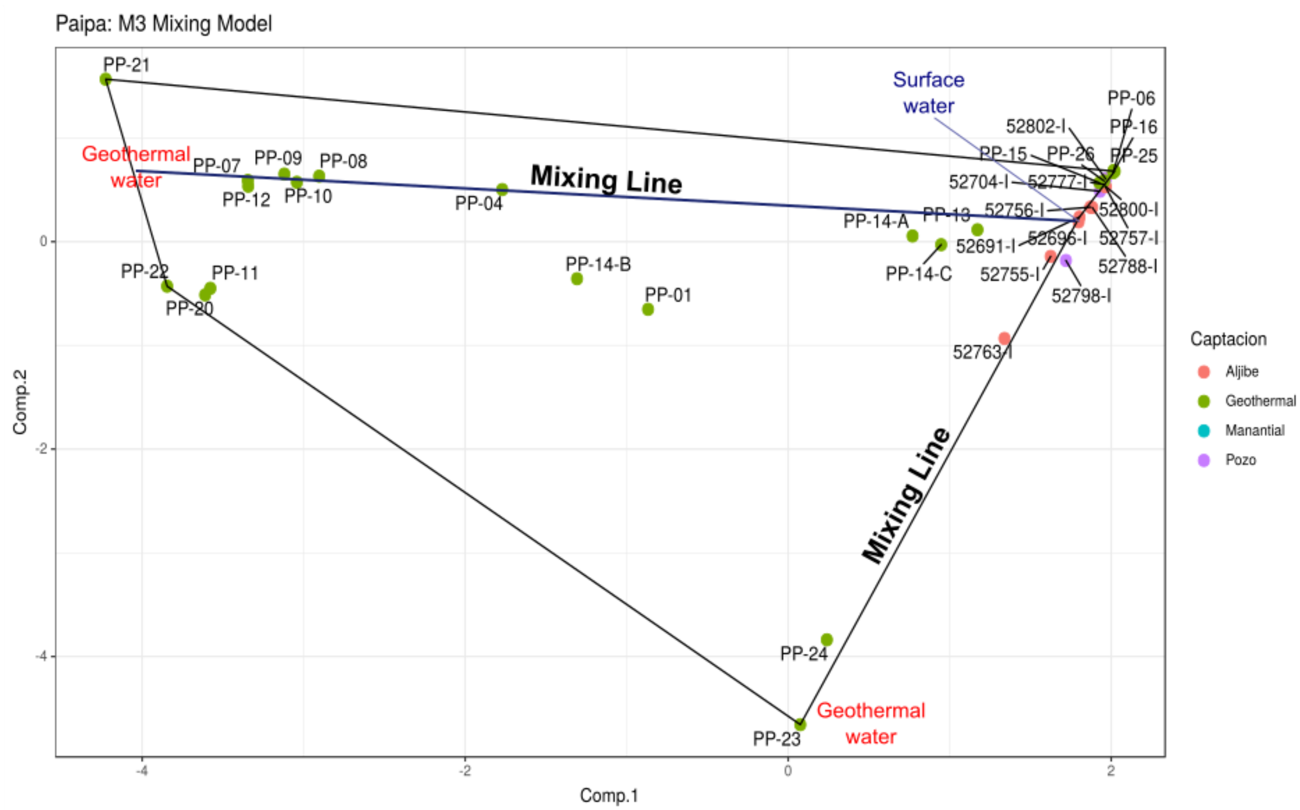

Figure 3. M3 modeling of hydrogeochemical data at Paipa, Boyaca, Colombia. The hydrogeochemical dataset contains samples from geothermal fluids (green points) and groundwater (pink, blue and purple points). The x and y axes represent the first and second principal components of the original hydrogeochemical dataset. The extreme compositions in this diagram are selected as the compositional end-members and these represent the sources of water that are mixed. The mixing processes are shown as straight lines joining end-members.