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Local Meteoric Water Line of the Central Zone of Boyacá, Colombia

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ABSTRACT

This paper presents information on stable isotope compositions of meteoric water obtained in the period July 2014 – November 2016 for the Boyacá Central North Zone, including Paipa geothermal area. This work is based on the analysis of monthly samples collected in a network of 41 stations including 28 rainwater totalizers, 12 sampling points in rivers at different elevations, and one dam. Measurements of monthly precipitation and in situ physicochemical parameters (pH and electrical conductivity) were performed. The mean precipitation levels are relatively low, generally ranging between 200 and 350 mm with a maximum value of around 900 mm, in the eastern stations. Rainwater pH varies between 4.07 to 8.9 and the electrical conductivities, between 0.7 to 356µS/cm. From the results of stable isotope analyses, a local meteoric isotopic line was determined (δD [‰] as function of $\delta^{18}O$ [‰]) for the Boyacá Central North Zone. The resulting values are 10.37 ‰ for deuterium excess and 7.86 for the slope. The magnitude of these variables shows a significant variation with respect to the global meteoric line water ($\delta D=8*\delta^{18}O+10$), which could be related to high evaporation. Variations in the isotopic compositions of D and ^{18}O with the elevation, a correlation used to estimate the elevation of groundwater recharge, resulted in a linear function with wide scattering, when all the data were considered (typical error between 6 to 8 for D and, 0.8 to 0.9 to ^{18}O).. Assuming that the isotopic compositions of hot spring waters do not have a significant isotopic enrichment and are the result of mixing between saline sodium sulfate water (isotopically enriched) and precipitation water, a recharge between 2900 and 3000 m.a.s.l. for the hot fluid of the geothermal system, was estimated. Although the results of this work, summarized mainly in the local meteoric isotopic line of the studied zone and in the variation of isotope composition as function of elevation, can be applied to the interpretation of isotope analyses measurements for groundwater points, in future studies, the impact of El Niño phenomenon during the sampling collection period, should be taken into account. The analytical work for this study was carried out in the Stable Isotopes Analysis of the Colombian Geological Survey (SGC for its acronym in Spanish). A comparison exercise between the local laboratory and the IAEA (International Atomic Energy Agency) laboratory in Vienna show no significant variations in the results.

1. INTRODUCTION

The study of the isotopic composition of precipitation provides information that identifies the main source of natural recharge in hydrogeological systems. The characterization of its isotopic composition allows to obtain the isotopic signature of the water entering the systems, which varies in time and space.

The rainwater sampling network was designed in Boyacá North Central Zone (Alfaro and Ortiz, 2013) and was proposed in order to carry out an evaluation study of recharge zones, complementing geothermal exploration and groundwater studies being carried out in the Colombian Geological Survey.

The study area is characterized by evapotranspiration between 600 and 1000 mm, precipitation between 500 and 1500 mm and prevailing winds from the southwest and south (IDEAM, 2016). Elevations are close to 4000 meters above sea level with an average of 2500 meters above sea level in the river valley.

2. METHODOLOGY

The stages carried out for the execution of this research work are as follows: sampling network design, information gathering, totalizer design and installation andmonthly sampling during a period of 28 months, between July 2014 and November 2016. Sampling was followed by laboratory analysis, data quality assessment, calculations and interpretation.

The rainwater samplers were designed and installed based on the technical procedure of the Global Isotope Network in Precipitation (GNIP) prepared by the IAEA (IAEA, naweb.iaea.org, 2014), with a 30-day collection period following the GNIP protocol.

Stable isotope analyses were performed in the laboratories of the Technical Directorate of Nuclear Affairs of the Colombian Geological Service using High Resolution Offset Axis ICOS (Integrated Cavity Output Spectroscopy) with laser absorption in liquid water stable isotope analyzer equipment DTL100 LWIA. LGR. High productivity and automatic injection mode.

To evaluate the analytical quality of the results reported by the SGC Analysis Laboratory, a duplicate sampling was carried out for comparison with results from a reference laboratory, in this case the IAEA.

Anomalous positive concentrations were discarded. These anomalous data occurred in some of the samples mainly in the dry periods, presumably because of contamination from organic matter derived from mineral oil added to the totalizers.

3. RESULTS

The sampling network, installed in the work area with an average elevation of 2964 meters above sea level, was made up of 29 rainwater collection stations, 12 river sampling points and one sampling point in a body of water located in the La Copa dam (Figure 1).

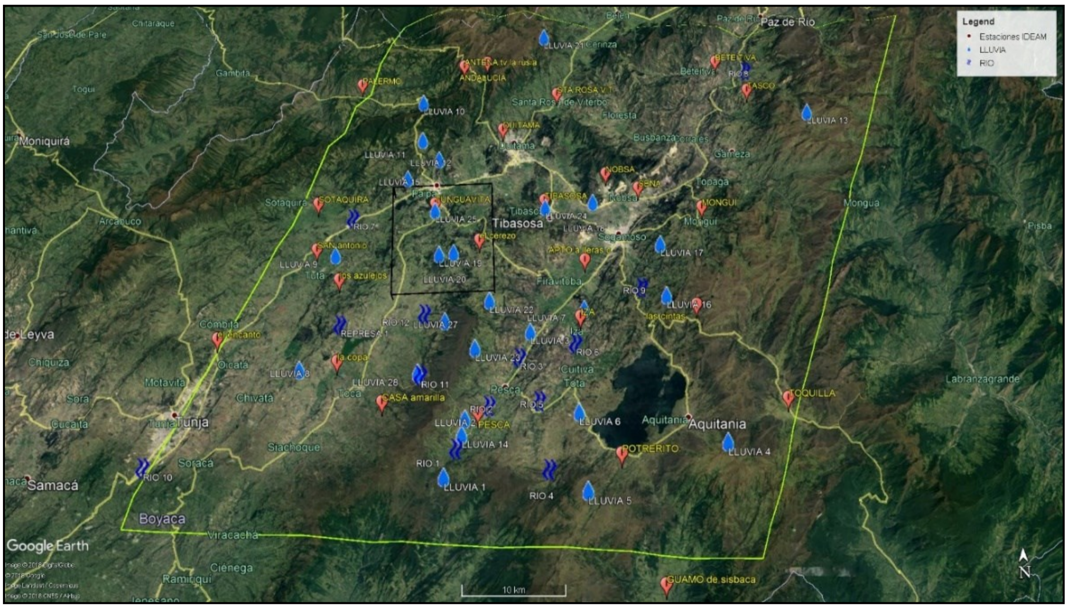

Figure 1: Network of stations for rainwater and surface water collection, for isotopic analysis. The IDEAM stations (red) in the work area and the polygon of the Paipa geothermal area (black outline) are also shown (this study).

During the sampling period (August 2014 to November 2016), the monthly precipitation values registered significant variations between seasons and at least 3 variation patterns, with a notable change in the amount of precipitation presumably associated with the El Niño phenomenon (low rainfall)in 2015. The patterns identified are bimodal, unimodal and interaction between these two.

In the southeast area of the work area, there is a pattern of unimodal rains, similar to that recorded in the Eastern Plains (Pacheco and León-Aristizábal, 2001). In the north and west, the bimodal pattern dominates. However, along a northeast corridor in the central area of the work area, east of the Tibasosa - Toledo Anticlinal, variations in the bimodal pattern possibly affected by unimodal rains in the east, results in additional peaks of greater intensity in June-July 2015.

The total number of data pairs δD and $\delta^{18}O$, from river and precipitation water samples is 862. In rainwater, the concentration of δ D varies between -108.4 and -4.1 ‰, while the concentration of $\delta^{18}O$, between -15.2 and -2.4 ‰(Figure 2). Variation in isotopic composition is cyclic and is sensitive to seasonal rain during sampling.

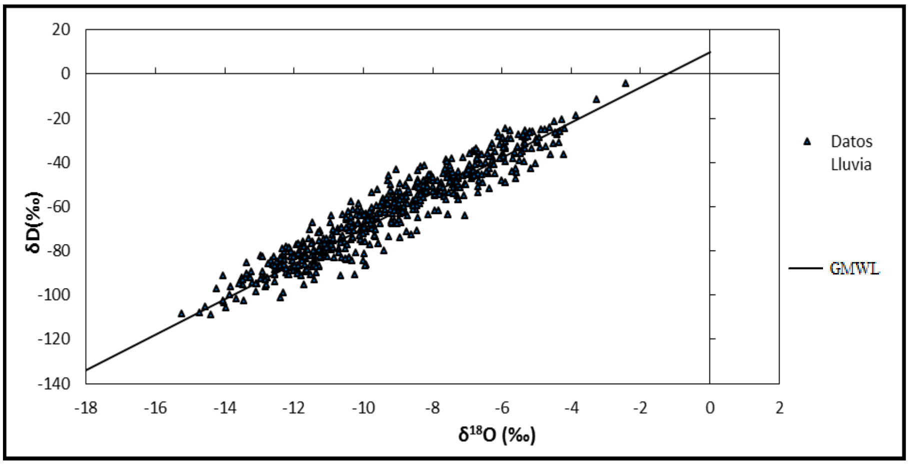

Figure 2: Isotopic composition of precipitation waters, from the sampling station network, for the entire observation period. (this study). Global Meteoric Water Line (GMWL).

In contrast to rainwater, the isotopic compositions of δD and $\delta^{18}O$ in river water samples are relatively constant (Figure 3), varying between -89.7 and -34.9 ‰, for δD and between -13 and -4.6 ‰ for $\delta^{18}O$. That is, the isotopic composition of river water did not change significantly with the sampling period.

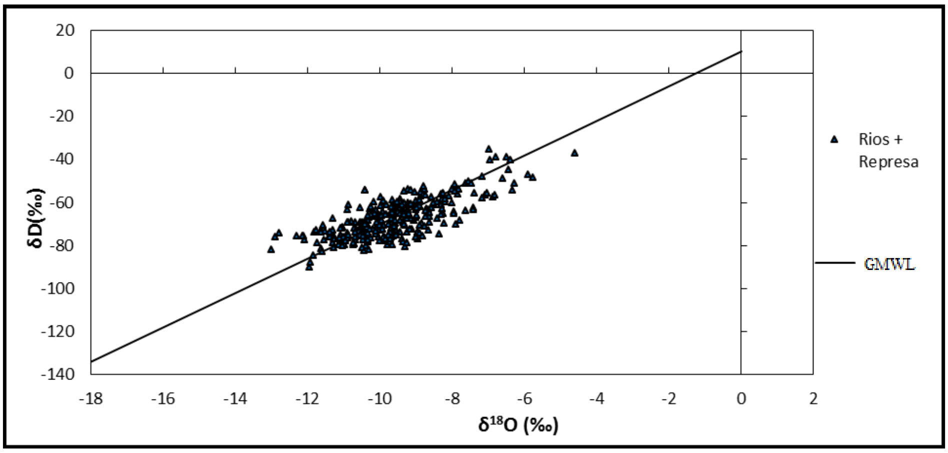

Figure 3: Isotopic composition of river and dam waters, from the sampling station network, for the entire observation period (This study).

3.1 Local Meteoric Line

The local meteoric line or variation function of δD vs. $\delta^{18}O$, was established for the entire work area for six groups of isotopic composition data, as follows: (a) rain, (b) rain after data discard (excess deuterium values calculated against the global meteoric water line equation, outside the range between -2 and 15‰), (c) rain and rivers, (d) rain and rivers after discarding, (e) rivers and (f) rivers after discarding. Figure 4 illustrates the results and presents the straight line functions with the best fit by linear regression using least squares. As can be seen in this figure, data scatter is narrower for rainwater than for river samples.

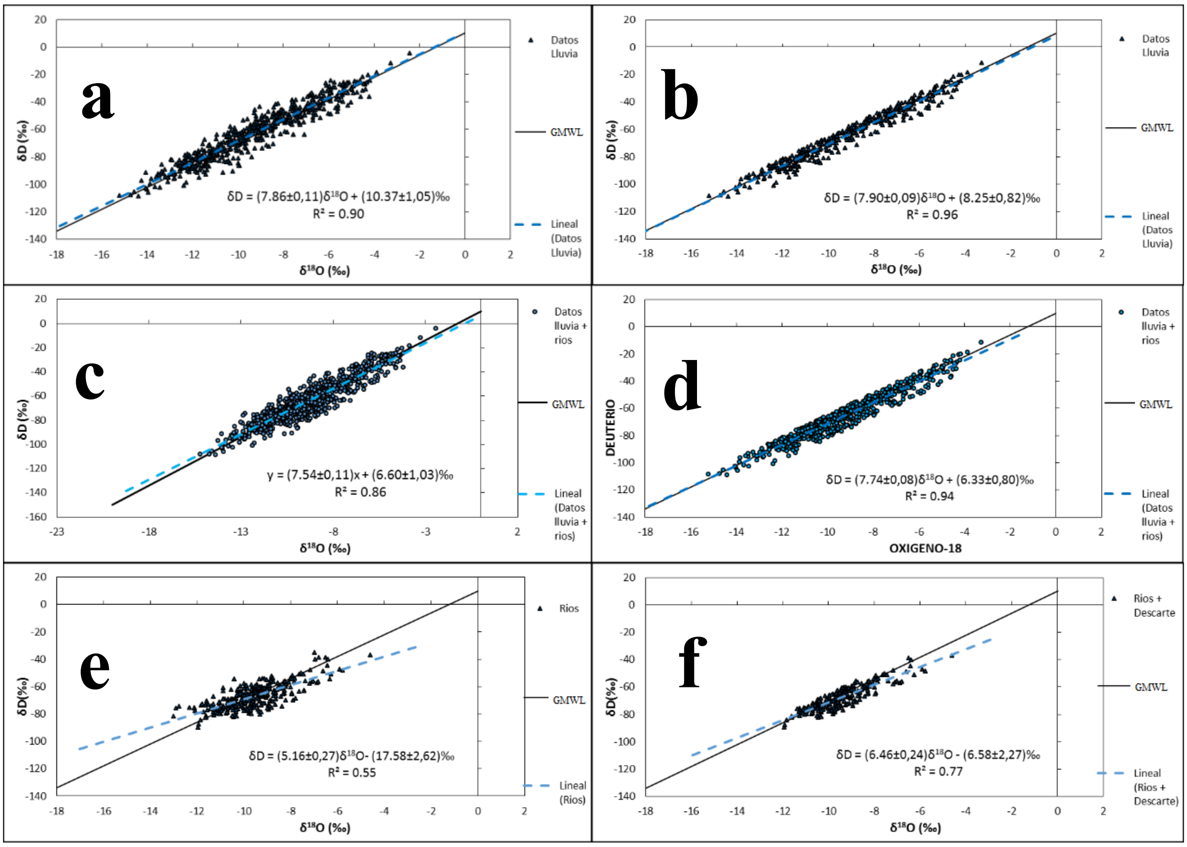

Figure 4: Linear regression lines using least squares method fitted for 6 data sets: (a) rain, (b) rain after data discarding, (c) rain and rivers, (d) rain and rivers after discarding, (e) rivers and (f) rivers after disposal (This study).

The best fit data are summarized in Table 1. As confirmed in this table, in the case of data groups that include rainwater, the slopes are very close and similar to each other but lower than the GMWL slopes (Clark and Fritz, 1997), the meteoric line for Colombia (Rodríguez, 2004) and the estimated meteorological line for the Eastern Cordillera and north front of the Andes (Saylor et al, 2009). On the other hand, excess deuterium is comparable with the reference meteoric lines, for the group including all rainfall data (function a). For the remaining cases, this value is significantly reduced after data discarding and even more so for the data groups that include the isotopic composition of rivers.

It is possible that the study area's deviation from global and regional meteoric water lines is related to high evaporation, indicated by climatic data, a variable that would significantly affect surface water isotopic compositions and, to a lesser extent, rainwater during precipitation. The evaporation of water collected in the totalizers is rejected, assuming that the measures to eliminate the evaporation effect (burial and addition of mineral oil) were sufficient. Given this result, it is not recommended to consider the isotopic composition of rivers as representative of local rainwater.

Table 1. Line functions between δD and $\delta^{18}O$ or estimated local isotopic meteoric water lines for the work area (This study).

FUNCTION *	SLOPE	INTERCEPT (EXCESS DEUTERIUM)	CORRELATION COEFFICIENT r
a	7.863±0.11	10.366±1.05	0.951
b	7.898±0.09	8.246±0.82	0.979
c	7.536±.011	6.60±1.03	0.925
d	7.744±0.08	6.333±0.8	0.968
e	5.163±0.27	-17.583±2.62	0.743
f	6.465±0.24	-6.577±2.27	0.880

The weighted isotopic compositions of δD and $\delta^{18}O$, as expected, decrease with increasing elevation (Figure 5, Table 2).. The weighting factors correspond to the relationship between the monthly amount of precipitation and the total volume of precipitation during the observation period. Although the expected inverse relationship between elevation and isotopic composition is observed, there is a large dispersion of data. This dispersion is possibly related to the contribution of local precipitation water from different bodies of water and variable circulation areas, partially dependent on the heterogeneous topography in the area.

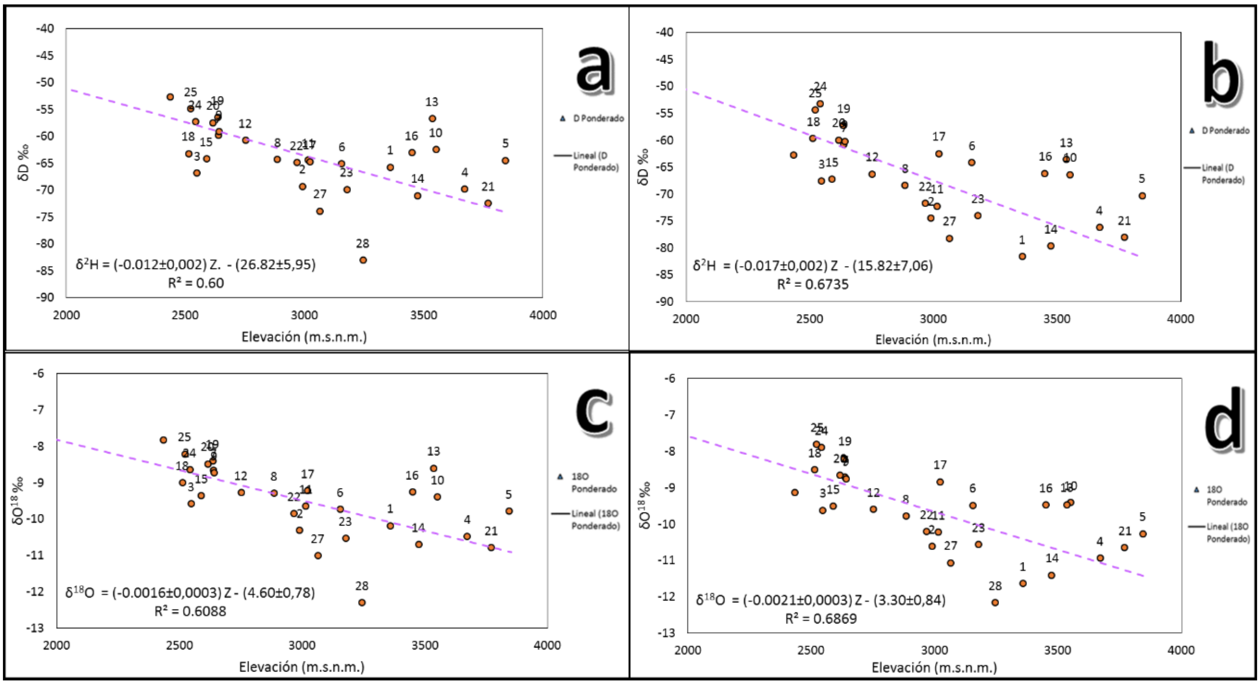

Figure 5: Weighted isotopic composition vs precipitation elevation: (a) δD, (b) δD with discard, (c) $\delta^{18}O$ and (d) $\delta^{18}O$ with discard (This study).

Table 2. Variations in the composition of stable isotopes per 100m based on linear functions between composition and elevation in Figure 5 (This study)

FUNCTION	Linear correlation coefficient	Vertical composition gradient per 100m (‰)
a (Deuterium)	0.774	1.23
b (Deuterium)	0.821	1.71
c (^{18}O)	0.780	0.16
d (^{18}O)	0.829	0.21

As seen in Table 2, both the linear correlation coefficients and the vertical gradient values of isotopic compositions with elevation are better for the data sets after discarding. These gradients are 1.71, for δD and 0.21, for $\delta^{18}O$, values that are low compared to 4 and 0.5 ‰/100m, for δD and $\delta^{18}O$, respectively, as reported by Moser and Stichler, 1970 (Clark and Fritz, 1997) at elevations between 2000 and 5000m.

4. CONCLUSIONS

The precipitation data of the IDEAM and its variation over time are comparable and give validity to the method of collection and to the data of rain collected in the totalizers used for this work.

Although six equations for the local meteoric water line were derived from different data sets, the wide data dispersion of river compositions suggests that only two equations calculated from the isotopic composition of rainwater are valid. In summary, the local meteoric water line equations for Boyacá Centro Norte for all data and data selected by discard, respectively, are:

$\delta D = (7.86\pm0.11)\ \delta^{18}O + (10.37\pm1.05)$ ‰ $\quad r = 0.95$

$\delta D = (7.90\pm0.09)\ \delta^{18}O + (8.25\pm0.82)$ ‰ $\quad r = 0.98$

Based on information from stations located to the west of the Tibasosa – Toledo Anticline and south of Chicamocha River, another meteoric water line was determined, specific to the Paipa geothermal area, with a deuterium excess of 7.15‰ and a slope of 7.7.The compositions of δD and $\delta^{18}O$ vary inversely with elevation. Despite the wide data scatter, the linear least squares regression lines could be used to estimate the recharge elevation. According to the slope, δD varies by 1.23‰/100m and 0.16 ‰/100m for $\delta^{18}O$, for all data, and 1.71‰/100m for δD and 0.21‰/100m for $\delta^{18}O$, for filtered data.

There is a possible relationship between the isotopic composition of precipitation water and the dominant direction of the winds (SE-NW). Isotopic compositions are heavier in the southeast than in the northwest.

The isotopic composition of rainwater from the study area responds to the amount of precipitation. Lighter composition values (more negative) are measured at times of greater rainfall and vice versa, confirming the effects of precipitation quantity.

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