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Geochemistry of Hot Spring at Cundinamarca Department, Colombia

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ABSTRACT

A preliminary geochemical study of hot springs from the Cundinamarca department was carried out in the frame of an inventory of hot springs. This study consisted of the characterization of 52 springs from which 42 are thermal springs. The distribution of these springs shows a tendency to increase their temperature towards the East of the Department, reaching a maximum of 73.6°C at Paratebueno municipality.

Low temperature resources were identified in Cundinamarca, which heat source is likely the normal geothermal gradient. The highest geothermal gradients (between 50 and 60°C/km), classified as mesothermal, were estimated for the geothermal areas of Gachetá, Tabio, Tibirita and Paratebueno municipalities (at the East of the department).

The springs show high variability in composition, between sweet and saline waters, which reach 15.700 mg/l of total dissolved solids. A contribution of saline and low temperature source is identified in the springs of highest total dissolved solids contents, located at the municipalities of Yacopí, Útica and La Calera.

From the diversity in composition of the springs of Cundinamarca, an important potential for utilization in thermalism, is inferred. Unspecific, bicarbonate, chloride and sulfate waters could be utilized for balneotherapy purposes. Some of these springs also could be used as natural mineral water for bottling.

This work was carried out through the geothermal exploration project of INGEOMINAS, during 2003.

1. INTRODUCTION

1.1 Geological Frame

Cundinamarca department is located in the central region of Colombia on the Eastern Cordillera (Fig. 1), covering an area of about 22.626 km^2. The geology consists of sedimentary rocks, from the Cretaceous and Tertiary age, overlying low metamorphism Paleozoic rocks. Structurally, the area is characterized by four (4) tectonic blocks briefly described as follows (Acosta & Ulloa, 2002):

(1) Valle Medio del Magdalena – Guaduas, located to the west of the department, between Magdalena River and the municipality of Bituima – La Salina faults. These are reverse faults with planes dipping towards the East.

(2) Anticlinorio de Villeta, located in the west center of the department, between Bituima – La Salina Fault and the scarp from the Guadalupe Group (shaped by Arenisca Dura, Plaeners and Labor and Tierna geological formations), which coincides with a thrusting fault system with faults like Fusa, Quinina and Supatá.

(3) High plateau of Sabana de Bogotá – Anticlinorio Los Farallones, located in the east center of the department, between the scarp from the Guadalupe Group and Santa María – Tesalia faults. Several thrusting faults occur, which have a vergence towards the west, in the western part of this block and towards the east, in the eastern part of it, indicating that the central sector is an uplifted block. Santa María and Tesalia thrusting faults have a vergence to the east, generating the thrusting of Paleozoic rocks over Terciary and Quaternary units.

(4) Pie de Monte Llanero (foot hill of the Eastern Cordillera), located to the east of the department, between Santa María and Tesalia Faults and the eastern border of the department. One of the mains features of this block is the Medina syncline which includes wide anticlines and synclines from Tertiary and Quaternary units. The most eastern structure is the Guaicaramo Fault, which was attributed to be a normal fault during Upper Jurassic to Lower Cretaceous, while during the Neogen it became a thrustinf fault with a vergence to the east.

1.2 Previous Geochemical Studies

Several thermomineral springs have been registered in the Cundinamarca Department, in the localities of Tocaima, Anapoima, Guaduas, Villeta, Bituima, Ricaurte, Quetame, Choachí, Cachetá, Guasca, Cáqueza, Zipaquirá, Tabio, Guatavita, Gachalá, Suba, Nimaima, Machetá, Pandi, Acuatá, Útica, Nemocón and Sesquilé (García, 1909, Ramon, 1913, Scheibe, 1919, Barriga, 1932, Hubach, 1938, Barriga, 1939, Royo & Gómez, 1946, Wokiteel, 1953, López & Murcia, 1957, Urquijo, 1958 and Serrato, 1958, in Forero, 1958).

During the geothermal reconnaissance study of the Republic of Colombia (OLADE, et al., 1982) which encompassed an inventory of hot springs from the Cordillera Oriental, physicochemical analyses of 6 hot springs from Choachí, Girardot, Tocaima, Anapoima and Tabio, were performed. According to their classification as bicarbonate and sulfate waters, those hot springs were proposed to belong to shallow water circuits. This study also included geological descriptions and routes of access to several springs of the department, and concluded that from the thermal point of view, the most important hot springs are located at Chocontá, Gachetá and Guasca localities, for which the recommended utilization was in agricultural and industrial low enthalpy applications.

In 1996, INGEOMINAS, The Colombian Geological Survey, conducted the called Phase Zero of the exploration of thermomineral springs, based on literature review as well as, on an inquiry to 219 municipal mayoralties from all over the Country, in order to define the occurrence of these surface manifestations (INGEOMINAS, 1996).

In the year 2000, INGEOMINAS performed the first stage of the inventory and characterization of mineral and thermal springs of Cundinamarca, which was centered in the high plateau of Sabana de Bogotá (Arcila, 2000 and Alfaro,

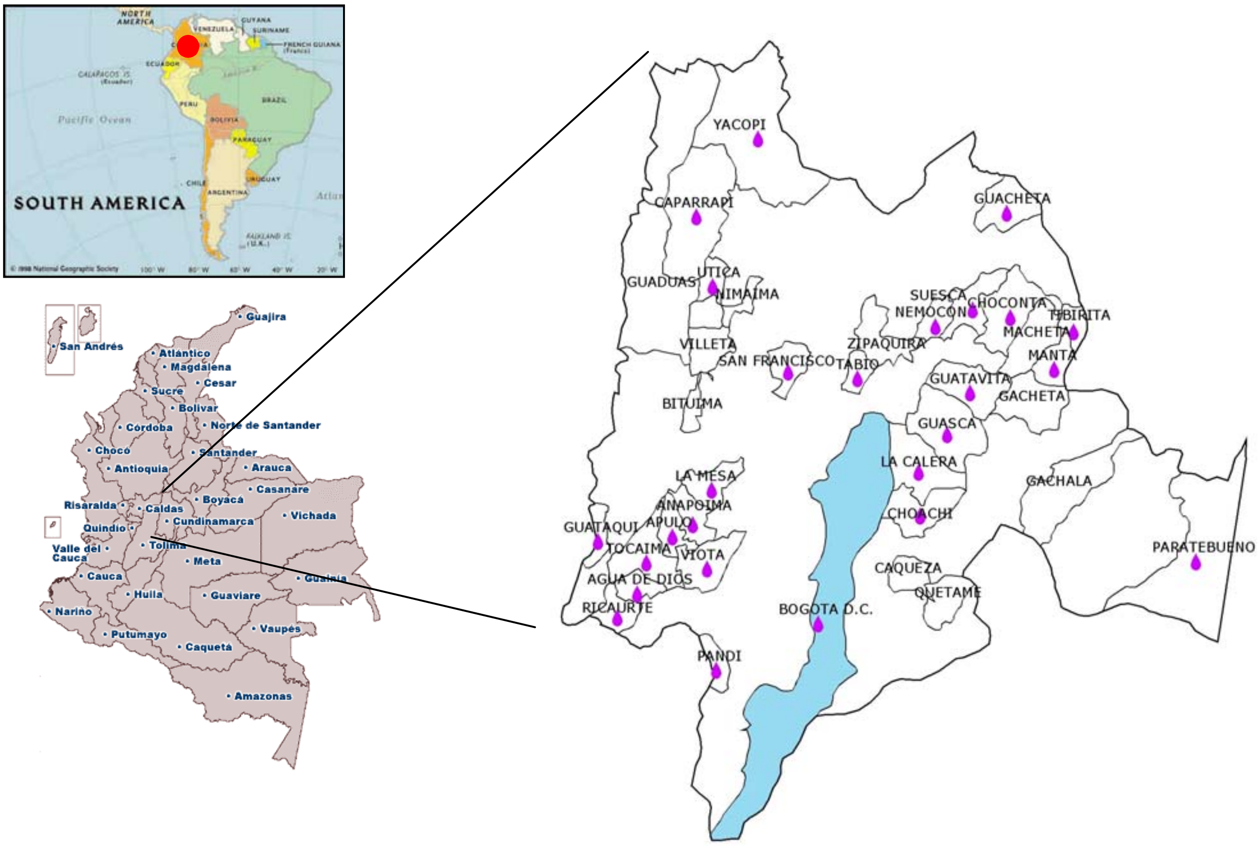

Figure 1. Location of Cundinamarca Department in Colombia. The municipalities where the occurrence of thermomineral springs has being registered, are identified. Bogotá Capital District is identified by the blue polygon. Violet drops represent the municipalities where the springs included in this study are located.

2000). The chemical characterization in springs located at Bogotá, Tabio, Choachí, Guasca, La Calera, Guatavita, Nemocón, Chocontá, Gachetá, Tibirita, Suesca, Sesquilé and Suba, allowed to estimate a deep temperature of 100-110°C, at most, around the localities of Gachetá, Tibirita and Tabio.

1.3 Objectives

The objectives of this work are to accomplish the first approach of the geothermal resources of the Cundinamarca Department, based on an inventory and characterization of hot springs and to identify in a preliminary way, the possibilities of utilization of these resources, particularly in thermalism.

2. METHODOLOGY.

2.1 Sampling

Five type of samples were collected as follows: (1) 500 ml of preserved sample by microfiltration and acidification to pH below 2, for cations, silica and boron analyses, (2) 1000 ml of untreated sample for sulfate, alkalinity, chloride, pH and conductivity determinations, (3) 250 ml of preserved sample by addition of $K_2Cr_2O_7$ 2g/l in nitric acid 1:1 solution, for mercury analysis, (4) 100 ml of untreated sample for stable isotope analysis and (5) 500 ml of untreated sample in sterile glass bottles for microbiological analysis.

2.2 Analyses

The chemical analysis included pH, Na, K, Ca, Mg, Li, Sr, Ba, Fe, B, SiO_2, Al, Sb, As, Cd, Cs, Cr, Cu, Pb , Mn, Hg, Rb, Se, Cl, F, Br, SO_4 HCO_3, NH_4, NO_3, I, Ptotal, CN and TDS. They were analyzed by instrumental techniques such as AAE, EAS, ICP-MS, ion chromatography, ion potentiometry, spectrophotometry, titration and gravimetry. The analyses of stable isotopes were performed by the International Atomic Energy Agency (IAEA), through a cooperation project.

The microbiological analysis orientated to establish possible contamination, included count aerobic mesophiles, total coliforms, fecal coliforms, *pseudomonas aeruginosa*, fungus and yeasts by membrane filtration and sowing in specific cultures in agreement with the Resolution 414 of the Health Ministry of Colombia. These analyses were performed by a commercial laboratory.

2.3 Interpretation

The geochemical analysis was based in relative compositions (Giggenbach, 1991) and graphical methods like the Enthalpy- silica model (Nicholson, 1994). Taking into account the sedimentary geology of the area and the low temperature of the springs, alkaline geothermometers were excluded of calculations and geochemical temperatures were estimated based only on silica geothermometers: quartz and chalcedony (Fournier, 1981). Additionally, the geothermal gradient was estimated following the Swanberg & Morgan methodology (1980), from the quartz geothermometer.

3. RESULTS

3.1 General Description

About 60 springs were located in 26 localities of Cundinamarca Department (Fig. 1). Sampling and analysis were performed for 52 springs, from which the highest density of occurrence corresponds to 29 springs located in the central east of the department (tectonic block of Sabana de Bogotá-Anticlinorio Farallones).

The majority of the thermal springs (42) are just warm springs. As can be observed in Fig. 2, the discharge temperature seems to follow an increasing trend towards the east of the Department, reaching the highest temperature (74°C), in one of the hot springs from Paratebueno municipality. Additionally some of the springs from the east of the department, seem to be aligned in at least two trends, which relate similar discharge temperatures. This could be an indicative or their association with faults, fractures or contacts, following the NE direction of the tectonic axis defined by the Cordillera Andina at this latitude, and with a comparable infiltration depth. It is observed for both, warm and hot springs.

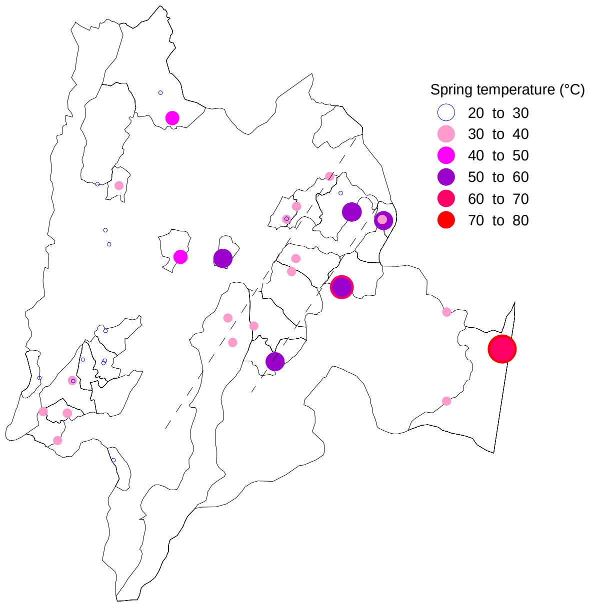

Figure 2. Surface temperature variation in mineral and thermal springs of Cundinamarca Department. A trend to increase towards the east is observed.

About half of the springs, including warm ant hot (even those with the highest temperatures from Paratebueno), are sweet water springs with a TDS lower than 1g/l. On the other hand, low temperature springs from Útica, La Calera and Yacopí have high TDS (5 to 15 g/l); that is, their main saline source is not geothermal fluid. Their salinity is due to sodium chloride, mainly, which source could be related to saline deposits, which would not be rare in the sedimentary environment that dominate the geology of this department. The chemical analyses of these springs reveal significant differences in the composition of the saline sources. Cold springs from Útica register the highest concentrations in calcium (820 mg/l), bicarbonate (820 mg/l) potassium (40 mg/l) and some minor elements such as lithium (7 mg/l), fluoride (1.7 mg/l), strontium (28 mg/l) and boron (11 mg/l).

The concentration of other trace elements is in general, lower than the quantification limits. Also, the measured heavy metals in general, are lower than the quantification limits or do not exceed the limits for drinking water, used as reference as possibilities for bottled water were being observed. The highest concentrations in anthimony and arsenic, equivalent to 0.0048 and 0.037 mg/l, were found in the springs of highest salinity at Yacopí. Total chrome overcomes lightly the limit of 0.01 mg/l (with concentrations of 0.011, 0.016 and 0.012 mg/l) in springs from Bogotá and Guatavita, as well as manganesum, which limit is also 0.01 mg/l that reaches 0.4 mg/l in the saline springs from Útica municipality.

3.2 Classification

The classification based on the relative dominant anions contents is presented in the Fig. 3. There are 30 bicarbonate springs (including 5 non thermal), 6 sulphate springs (4 non thermal) and 15 chloride water (2 non thermal)**.** The pH of all of them varies in a neutral range (6-8). The sulphate springs are located just in the west region of the department while the bicarbonate springs are wide spread, excepting the east of the department (Pie de Monte Llanero tectonic block). The chloride hot springs are located in the central-east area of the department, mainly, in the municipalities of Paratebueno, Tibirita and Tabio. As stated before, low temperature chloride springs of Yacopí, Útica and La Calera, denote the contribution of a saline non geothermal source.

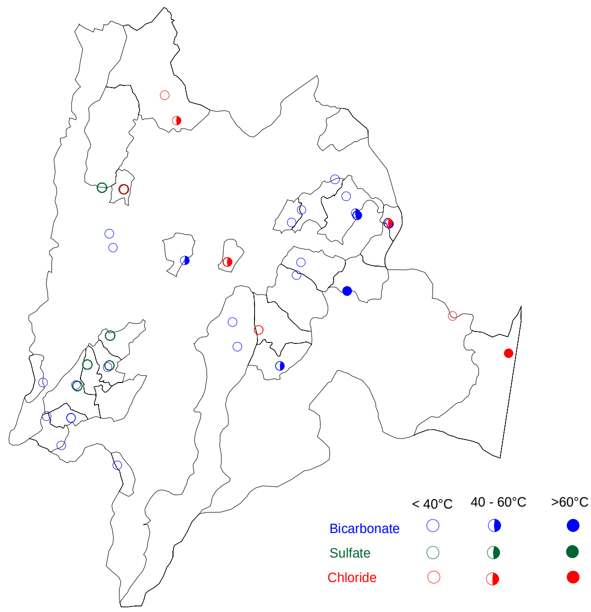

Figure 3. Classification of springs from Cundinamarca from their relative Cl-HCO$_3$-SO$_4$ composition.

3.3 Temperature Estimation

Considering the sedimentary geological environment of the area, the relatively low surface temperatures of the springs, in the main and, the relative dominant anions composition (most of them classified as bicarbonate water), application of geothermometers is limited for the springs of Cundinamarca, particularly those based on alkaline species. However, as an attempt to establish the temperature at depth and considering the dependence of the silica contents on the temperature in neutral pH conditions as in the case of these springs, the geothermometers based on silica contents (quartz and chalcedony) were applied. The silica contents and quartz geothermometers are illustrated in the Fig. 4. The

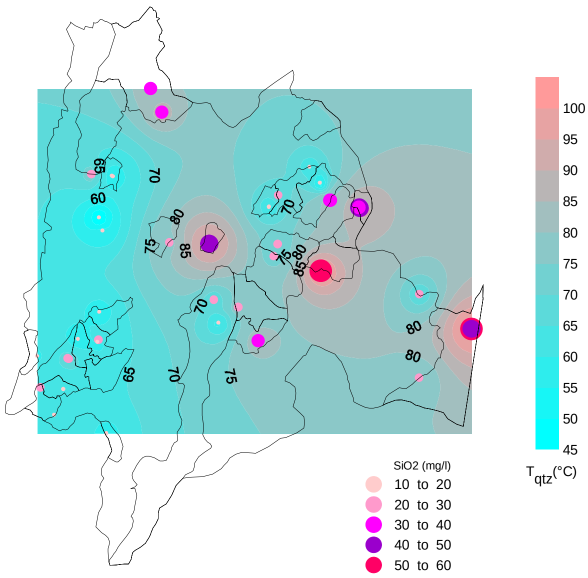

Figure 4. Deep temperatures estimated with the quartz geothermometer. The silica contents of the springs are also indicated.

highest estimated temperatures (100-110°C) are found in springs from the east of the department in Gachetá, Paratebueno, Tibirita and Tabio municipalities. If quartz is the species controlling the silica solubility and the dilution correction by the Enthalpy-Silica model is applied on the basis of non conductive heat loss nor boiling, an intermediate temperature (at most 190°C) would be estimated for springs from the east of the department (Tibirita) (Fig. 5). On the other hand, considering the resulting low temperature range, probably chalcedony or other silica species different from quartz, controls its solubility. In this case, the highest temperature of these springs would be found at Gachetá (95°C) and the temperature of the deep water feeding other hot springs from the department would be close to the discharge temperatures, as it is observed in the Table 1.

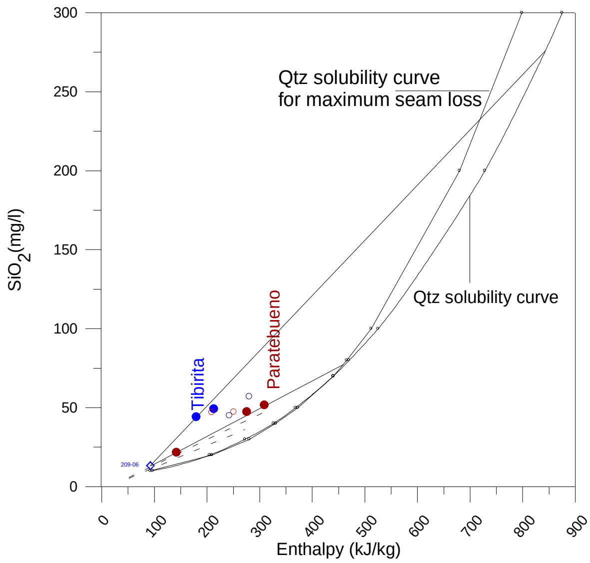

Figure 5. Enthalpy – Silica model. The highest temperature estimated at Tibirita is around 190°C, assuming cooling only by dilution and, quartz as the species controlling the silica solubility.

Additionally, the quartz geothermometer was calculated for all the springs, in order to estimate the geothermal gradients presented in Table 1, from the Swanberg and Morgan's equation[1]. Most of them are normal geothermal gradients with values between 20 and 40°C/km. Mesothermal gradients (between 40 and 70°C/km) are found in the localities of Yacopí, La Calera and in those springs with the highest discharge temperatures, located at the east of the department: Tibirita, Manta, Tabio, Gachetá and Paratebueno. The highest geothermal gradient equivalent to 63°C/km corresponds to the area of Gachetá.

3.4 Stable isotopes

The isotopic composition of deuterium and oxygen-18, presented in the Fig. 6, shows a dominant meteoric water contribution, since most of the springs plot along the meteoric line. The springs from Útica show an isotopic enrichment possibly due to evaporation processes to which also the high total dissolved solids register by these springs, might be related. As can be seen the springs from the same tectonic blocks seem to be grouped by similar isotopic compositions, particularly for the blocks 1, 3 and 4, denoting similar recharge areas.

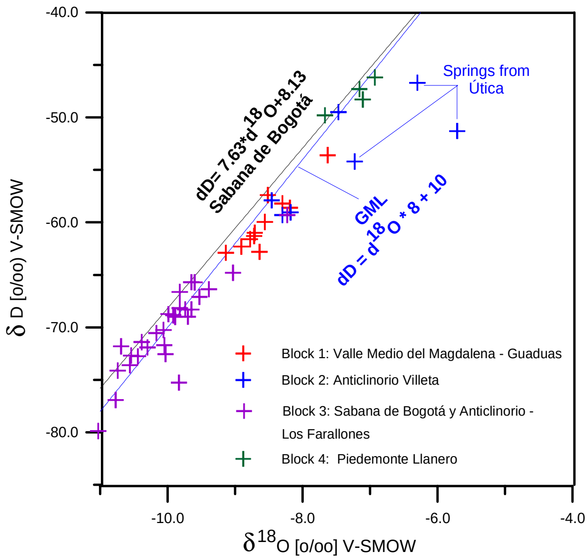

Figure 6. Stable isotopes in springs from Cundinamarca. An isotopic enrichment is observed in the high salinity low temperature springs of Útica. The local meteoric line established for the Sabana de Bogotá is included as the closest reference (Castrillón, 2001).

The Fig. 7 illustrates better the spatial distribution of stable isotopes with deuterium. The lighter isotopes are found at the Sabana de Bogotá, particularly towards the eastern side of the high plateau. From this, different processes control the precipitation water composition, at the recharge zones, at west and east of the plateau. The possible contribution of precipitation from north-east promoted by the predominant direction of the wind, in the area (specifically at Bogotá)[2] should be evaluated in future research.

[1] $T°C_{SiO2}$= mq + b, where $T°C_{SiO2}$= qtz geothermometer, m= angular coefficient (680±67°C m^2/W), q= Terrestrial heat flow (mW/m^2) and b=Linear coefficient assumed as the mean annual surface temperature.

[2] Available at http://www.ideam.gov.co/sectores/aero/climat/index44.htm

Table 1. Temperatures and geothermal gradients estimated from hot springs of Cundinamarca department.

ID	Spring	Municipality	Surface Temperature	Geothermometers Chalcedony	Geothermometers Quartz	Geothermal gradient (°C/km)
			T (°C)			
BLOCK 1: VALLLE MEDIO DEL MAGDALENA - GUADUAS						
189-01	El Hatico	Yacopí	23,8	52	83	44
208-02	La Tigrera	Villeta	20,8	11	44	14
208-04	Salsipuedes-Rio Negro	Caparrapí	27,9	42	74	37
245-01	Casablanca	Ricaurte	31,8	29	61	24
245-02	Azufrada La Quebrada	Ricaurte	31,5	32	64	26
245-03	Los Chorros	Agua de Dios	36,2	30	62	25
245-04	Los Chorros II	Agua de Dios	36,2	28	60	24
245-06	Macanda	Guataquí	28,0	27	59	22
245-07	El Gran Poza Azufrada	Tocaima	33,8	33	65	27
245-08	Los Pocitos Azufrados	Tocaima	25,6	37	69	30
246-01	Azufrada Charcolargo	Apulo	27,4	22	54	20
BLOCK 2: ANTICLINORIO DE VILLETA						
189-02	El Salitre	Yacopí	46,8	57	88	47
208-03	San Ignacio	Villeta	26,3	24	57	23
208-05	El Peñón	Útica	26,1	26	58	22
208-06	El Salitre	Útica	27,0	26	58	22
208-07	Hotel Abacoa	Útica	31,0	26	58	22
227-08	El Espino	La Mesa	24,6	24	56	24
246-02	Santa Lucia	Anapoima	26,6	33	65	28
246-03	Santa Ana	Anapoima	25,4	23	55	21
BLOCK 3: SABANA DE BOGOTÁ - ANTICLINORIO LOS FARALLONES						
209-01	Nápoles	Chocontá	46,7	39	71	41
209-02	Los Volcanes	Chocontá	53,7	59	89	54
209-03	Hacienda Susatá	Nemocón	33,1	36	68	38
209-04	La Piscina Municipal	Nemocón	33,7	30	62	34
209-05	Agua Clara	Suesca	33,2	28	60	33
209-06	Repetidora	Chocontá	22,2	16	49	25
209-10	Los Volcanes 2	Chocontá	53,2	50	82	48
209-11	Los Volcanes 3	Chocontá	58,3	54	85	50
210-01	El Paraiso	Tibirita	43,3	66	96	55
210-02	El Paraiso Termal	Tibirita	50,8	71	101	58
210-03	Manta Vereda Peñas	Manta	36,8	48	80	43
210-04	El Paraiso Codecal	Manta	32,9	55	86	48
227-01	El Zipa	Tabio	50,0	69	99	60
227-02	Aguas Calientes	Tabio	37,1	67	97	58
227-03	Parque Central Bavaria	Bogotá	31,1	24	57	30
227-04	Club Los Lagartos	Bogotá	36,0	33	65	36
227-05	Finca Agua Caliente 2	Tabio	32,0	58	88	52
227-06	Finca Agua Caliente 1	Tabio	37,1	66	97	58
227-07	El Zipa 2	Tabio	59,5	69	99	60
227-09	Agua Caliente	San Francisco	49,1	47	79	41
228-01	Aguas Calientes	Guasca	35,4	41	73	42
228-02	Zoratama	La Calera	27,1	42	74	43
228-03	Spa Helena del Mar	La Calera	33,0	48	79	46
228-04	Montecillo	Guatavita	39,0	37	69	38
228-05	Quebrada El Zaque	Gachetá	57,9	85	97	54
228-07	La Rivera	Gachetá	66,9	95	108	63
247-01	Los Volcanes	Choachí	35,0	46	77	41
247-02	Santa Mónica	Choachí	50,2	57	88	49
265-01	Azufrada	Pandi	25,5	26	58	24
BLOCK 4: PIE DE MONTE LLANERO						
248-01	Aguas Calientes-Sauna	Paratebueno	73,7	73	103	53
248-02	Aguas Calientes-El Mohán	Paratebueno	66,0	69	99	51
248-03	Playas del Río Humea	Paratebueno	39,8	45	77	35
229-01	Charco Largo	Santamaría del Batá	34,0	34	66	33

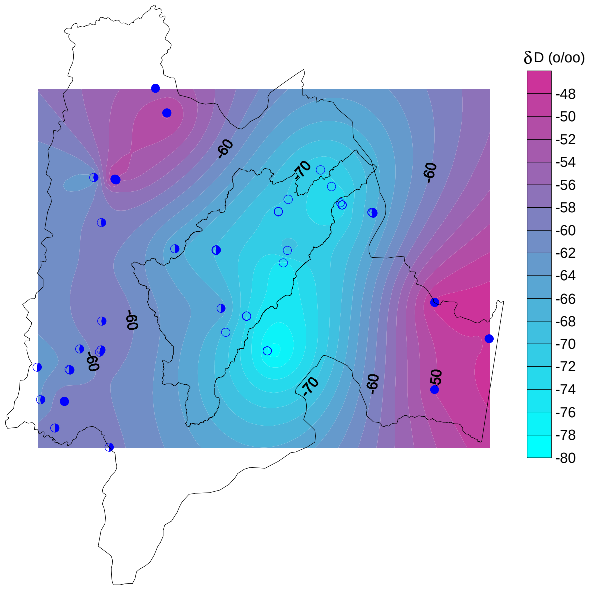

Figure 7. Variation of deuterium in springs from Cundinamarca Department. Lighter water characterizes the springs from the high plateau of Sabana de Bogotá whose schematic drawing in the central-east area of the department is showed.

3.5 Microbiological Composition of the Springs

The results of the microbiological analysis, performed for 47 samples from the Cundinamarca springs are illustrated in the Fig. 8. Although only two springs from the localities of Ricaurte and Nemocón, were totally free of the aerobic mesophiles, 14 more of the department could be considered as safe, since their aerobic mesophiles contents (assumed here as indicative of the total microorganisms that can grow for being counted), are lower than 500 Colony Forming Units (CFU)/100 ml at 37°C during 48 hours. The considered reference for natural mineral water, taking into account the autochthonous microorganisms is 500 CFU /100 ml by incubation at 37°C during 24 hours[3]. Higher concentrations should be considered as an alarm sign and from this, specific studies of organic contamination should be conducted particularly in the case of utilization as drinking water. This is the case of the springs from Ricaurte, Tocaima, Santa María del Batá, La Calera, Paratebueno, Agua de Dios, Guataquí, Apulo, Tabio, Útica, San Francisco, Chocontá, Manta and La Calera, with contents between 500 and 10000 CFU/100 ml, Caparrapí, Chocontá (Los Volcanes), Guasca, Suesca, Villeta and Tabio, between 10000 and 64000 CFU/100 ml and particularly, from one of the springs from Nemocón and Guatavita, which concentration of aerobic mesophiles reached 350.000 and 380.000 CFU/100 ml, respectively. Currently, the last 2 are not utilized at all. Even in these cases, contamination is not well determined because although they also had high total coliforms (up to 270000 in Guatavita's spring), all of them register: zero for fecal coliforms, lower than 2.2 more probably number (MPN) of *pseudomona aeruginosa*, lower than 1000 CFU/100 ml of fungus and lower than 270 CFU/100 ml of yeasts.

[3] Available at http://www.igme.es/internet/web_aguas/igme/publica/pdflib8/6_calidad.pdf

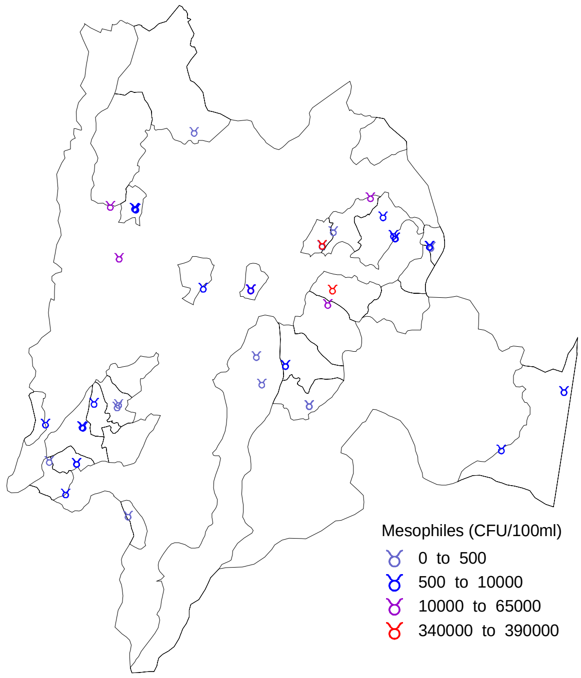

Figure 8. Aerobic mesophiles in springs form Cundinamarca as indicative of total microorganisms that can grow for being counted. Extremely high concentrations are observed in two springs from Guatavita and Nemocón municipalities.

3.6 Possibilities of Utilization

Based only on the highest estimated temperatures and by comparison with the Lindal Diagram (Gudmundsson et al., 1985), the applications of highest energy demand from the geothermal resources of Cundinamarca, are space heating and drying of organic products.

On the other hand, bearing in mind that Cundinamarca is a highly populated area and considering the benefits of the hot springs in the improvement of the quality of life and the health of the communities and also, the relative easiness of implementation, preliminary recommendations for utilization in natural mineral bottled water industry and in balneotherapy are presented (see Fig. 9). These recommendations are based on temperature, chemical and microbiological composition and organoleptic properties of the springs (clearness and lack of hydrogen sulfide odor). The Springs from Agua de Dios municipality, Nemocón (Susatá), Suesca, Chocontá (Repetidora), Santa María del Bata, which is actually located in Boyacá Department close to the border with Cundinamarca, are recommended as diuretic water due to their low total dissolved solids (lower than 200 mg/l) and sodium contents (lower than 50 mg/l). The spring Santa Ana from Anapoima municipality is recommended as calcium sulphate –iodided water with possible benefit on the digestive system.

For balneotherapy purposes, the waters were classified according to the criteria by Armijo & SanMartín (1994) in: Chloride, Sulphate, Bicarbonate water with total dissolved solids higher than 1 g/l and with the predominance of the indicated anions, undetermined water with a TDS lower than a 1g/l and, Siliceous water with more than 50 mg/l of SiO_2 (expressed as H_2SiO_3). They could be used for complementary treatments, in cases of rheumatism and other locomotive system problems and in complaints of the respiratory, dermatological, gynecological, cardiovascular and neurological systems, between others (Armijo & San Martín, 1984)

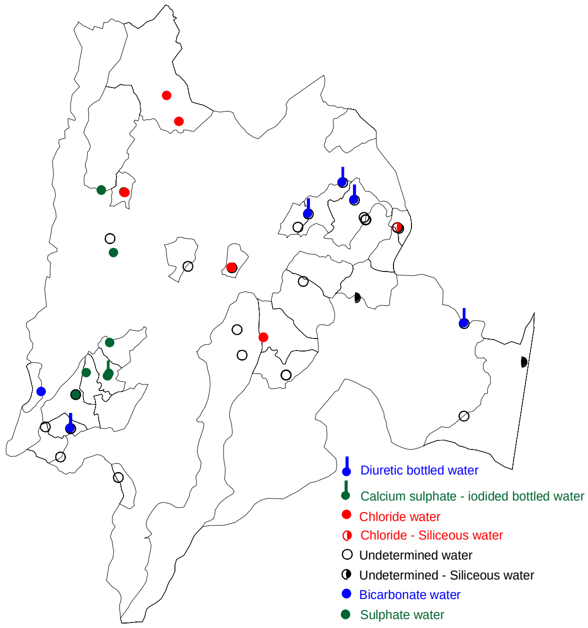

Figure 9. Preliminary utilization alternatives of thermal and mineral springs of Cundinamarca in the industry of natural mineral water and in thermalism (balneotherapy).

4. CONCLUSIONS AND RECOMMENDATIONS

- At least 42 thermal springs occur at Cundinamarca Department, from which 11 are hot springs (with temperature above 50°C). These springs register a trend to increase in temperature from west to east of the department, where it reaches 74°C.

- The hot springs of Cundinamarca point out the existence of geothermal resources of low temperature. Towards the east of the department, it is probably to find intermediate temperature systems related to the springs from Gachetá, Paratebueno and Tibirita, mainly, where the normal geothermal gradient is overcome with estimated values up to 63°C/km.

- The stable isotope composition of the springs from Cundinamarca points out evaporation occurring in some of the saline waters (springs from Útica) and lighter isotope composition in the central-east area of the department (high plateau of Sabana de Bogotá) which reveals different precipitation origins in both sides of the plateau.

- The mineral and hot springs from Cundinamarca could have application in the industry of natural mineral bottle water and also in balneotherapy. A complete exploration study should be carried out before any development, to identify the dimensions of the resources and the recharge zones for defining protection areas, which imperious need is inferred from the high microbiological load registered in some of the springs. Detailed microbiological studies are also required to differentiate between contamination and autochthonous microorganisms, which could represent an additional resource. The determination of *Legionella pneumophila* is highly recommended considering its high risk for human health and the favorable conditions of the thermal springs for growing these species of microorganisms. Clinical, pharmacological and medical studies should also be conducted for a precise determination of the therapeutic value of these springs.

5. ACKNOWLEDGMENT

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