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Natural contamination by arsenic in the groundwater of the rural community "La Fuente", to suggest and promote the use of alternative sources of safe water, municipality La Paz Centro, León, Nicaragua

MSc. Maximina Altamirano
Laboratory of metal pollutants. Center for Research in Aquatic Resources of Nicaragua UNAN-Managua
maximina.altamirano@cira.unan.edu.ni

MSc. Valeria Delgado
Teaching Area. Center for Research in Aquatic Resources of Nicaragua
UNAN-Managua
valeria.delgado@cira.unan.edu.ni

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ABSTRACT

Previous studies have revealed that in Nicaragua the presence of arsenic is of geogenic origin, so it is common to find it in both, surface, and underground waters, soil, rocks and sediments; besides being found within volcanic complexes, fumaroles, hot springs, gases and geothermal fluids. It was until 2010, when arsenic was detected in volcanic and sedimentary materials of the Quaternary present in the volcanic arc front of Los Maribios Mountain Range. Thus, in the La Fuente community located NE of the Momotombo-El Hoyo volcanic complex and near the Monte Galán volcanic caldera, where 112 families are supplied by groundwater, the total arsenic concentration in water from 30 dug wells, three drilled wells and a spring was determined. Arsenic concentrations ranged from 2 $\mu g \cdot l^{-1}$ (Houses of Rafaela Rojas and Porfirio Reyes) to 103 $\mu g \cdot l^{-1}$ in the Aguas Calientes spring (La Chistatosa), where 70% of the analyzed samples (24 water sources) exceed the national limit adopted, 10 $\mu g\ As \cdot l^{-1}$ for water for human consumption. The places with the highest temperatures (35.6 to 45.8 °C) are the ones with the highest concentrations of arsenic (38 to 103 $\mu g \cdot l^{-1}$), higher values of electrical conductivity (983 - 1140 $\mu S \cdot cm^{-1}$) and lower pH values (5.80 - 7.08 units). Community members were informed about the risk to which they are exposed by ingesting contaminated water with high values of this toxic; at the same time, safe sources of water for human consumption were identified, which were recommended to users. This research[1], in addition to generating scientific information, becomes a tool to support decision-making for the authorities and for local people, by using alternative water sources for human consumption and for food preparation.

INTRODUCTION

Arsenic is the metaloid with the highest potential for toxicity to human health in nature, usually found in trace concentrations and whose mobility and per-toxicity depend on biotic and abiotic processes (WHO, 2011). Arsenic pollution is one of the major global environmental problems in countries such as Argentina, Chile, Brazil, Peru, Bolivia, Mexico, Thailand, Bangladesh, China, India and the United States, including Nicaragua (Anawar,et al., 2003)

In Nicaragua, cases of arsenicosis (arsenic poisoning) have been reported, such was the case of the community of El Zapote, Sébaco Valley (Gómez C., 2002) where more than 70 people consumed water with 1320 μg/L of arsenic for a year and a half; presenting acute and chronic toxicity [(Gómez C., 2002), (Gómez Cuevas, 2007)]; Therefore, in Nicaragua there is an environmental and public health concern when high levels of arsenic are detected in groundwater. Arsenic has been found in groundwater in the northwest and southwest regions of the country, close to mineralized areas along the most important active tectonic structure, the Depression or Graben of Nicaragua and in the Central Platform (Altamirano, 2005), as well as also in areas near the volcanic mountain range of Los Maribios [(New Hope & Longley, 2010), (PAN AMERICAN HEALTH ORGANIZATION, PAHO / WHO Nicaragua, & New Hope, 2011), (New Hope, 2013)] and what are the only source of water available for the rural population in many communities in the country, such as those located north of the municipality of La Paz Centro, which is this case study. The presence of arsenic in these communities is attributed to intense tectonic stress and the presence of different systems of active and non-active faults, fractures and hydrothermal alteration along faults.

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The study area is located in an active tectonic environment and has a complex geology with igneous and sedimentary rocks of the alluvial and volcanic Quaternary; factors that predispose to pollution of the natural environment and groundwater, such as arsenic; This is one of the main pollutants present naturally in environmental matrices and that is the cause of adverse health effects due to the ingestion of water contaminated with this metalloid (Armienta & Segovia, 2008).

Water is the main route of entry into the human food chain through the intake and consumption of foods of plant origin (rice, vegetables, cereals) and animals (meat, fish, milk) that have been produced with water contaminated with this genotoxic (ATSDR, 2007). The clinical manifestations of acute and chronic arsenic poisoning are associated with various forms of skin diseases and damage to internal organs, cardiovascular, renal, circulatory and respiratory disorders and finally cancer (Hossain, 2006).

Due to this high potential as a carcinogen, it is that norms or guide values have been established that regulate the presence of arsenic in groundwater which vary by country. Nicaragua, through the Nicaraguan Institute of Water and Sewage (INAA, 2001), adopted the guideline values established by the World Health Organization (WHO), which establishes as a quality standard for human water consumption 10 $\mu g \cdot l^{-1}$ of arsenic (WHO, 2011).

Study Area

The study area is the rural community of La Fuente, located at the base of the northern slopes of the Momotombo-El Hoyo volcanic complex and the Monte Galán caldera building; within the geomorphological province of the Nicaraguan Depression. It has an approximate extension of 15 km^2 and is located in the northeast part of the municipality of La Paz Centro, Department of León (figure 1). The community is made up of 1,300 inhabitants distributed in 121 families, who have a distribution network of drinking water through a community perforated well; the rest of the families are supplied through excavated wells (86) and two familiar perforated wells. The community does not have a sewer system, so each house has a latrine or septic tank.

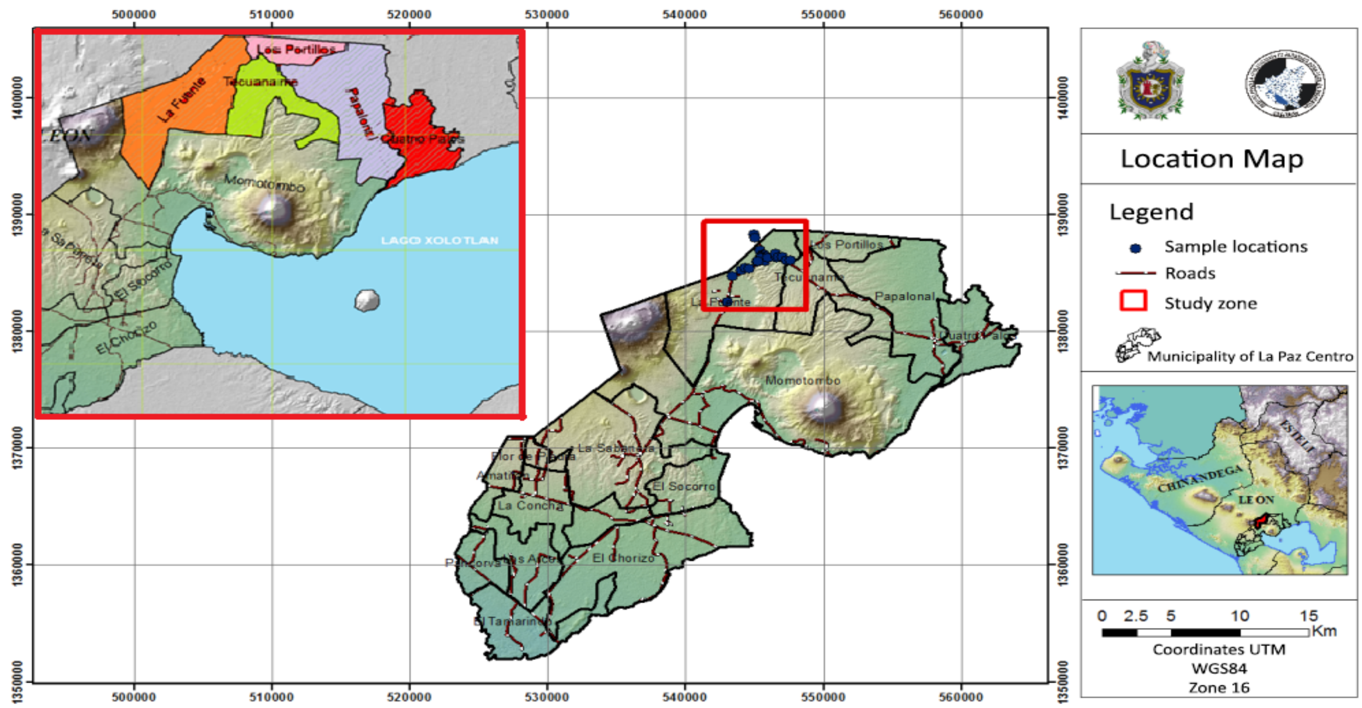

Figure 1. Macro and micro location of the rural community La Fuente, La Paz Centro.

METODOLOGY

Materials y methods

In order to carry out the present study, a tour of recognition was initially carried out by the communities established on the slopes of the Momotombo-El Hoyo volcanic complex, meeting the project executing staff with the community leaders of the communities of Cuatro Palos, El Papalonal, Tecuaname, Los Portillos and La Fuente; in order to know the problem related to the water of human consumption and the possible effects on health through this resource.

Once the information of the community members was obtained, a detailed compilation of geological, chemical and hydrogeological studies available in the area was carried out in order to have a general characterization of the physical and geological environment of the area, as well as the chemistry of groundwater in the region and also on previous studies related to population health in that sector, since the highest prevalence of diseases presented by the residents of La Fuente is chronic kidney failure.

Ninety hydrogeological objects were identified (excavated wells, drilled wells and springs) of which 34 sites were sampled to determine the total arsenic concentrations, considering those wells in which a greater population number made use of them, as well as in those families that have kidney problems. These locations were distributed as follows: 30 excavated wells (PE), 3 drilled wells (PP) and a spring (Mn).

Figure 2. Sampled locations: excavated well Juana Altamirano´s house (A) and Aguas Calientes spring known as La Chistatosa (B), from the rural community La Fuente.

All sampled locations were geo-referenced using a Global Positioning System (GPS); at the same time that at each sampling location measurements were made of physical and chemical parameters *in situ*, such as pH, redox potential (Eh), temperature (T) and electrical conductivity (EC); Using portable measuring equipment. The sampling methodology used was that established in the procedures manual of the Laboratory of Metal Pollutants of CIRA/UNAN-Managua (PROC-CM-02), for the collection of water samples for heavy metal analysis.

The total arsenic in the water samples was determined using the hydride generation technique by means of a Varian SpectrAA-240FS Atomic Absorption spectrophotometer coupled to a VGA 77. The digestion and analysis methodology is established in the Standard Methods for the examination of Water and Wastewater (SMWW, 2012; 22nd edition), following the recommendations and procedures of methods 3114B (3114B, Atomic absorption spectroscopy), continuous hydride generation method (VGA) and 3030F (Hydrochloric Acid Digestion); respectively. The detection limit of the method is 0.99 $\mu g \cdot l^{-1}$ total arsenic in water. Each sample was analyzed in duplicate, and with each batch of samples, control samples, certified samples were analyzed, as well as the recovery percentages of the samples, which were in the range of 94 and 96%.

RESULTS

Table 1 shows the values obtained for the field parameters and the concentration of total As found in the sites monitored in the community of La Fuente.

Table 1. Physical-chemical field parameters and total arsenic content in groundwater of the rural community La Fuente, La Paz Centro, León - June 2016.

Sampled Points	pH (Und)	Temp (°C)	CE (µS·cm-1)	Pot. Redox (mV)	As total (µg·l-1)
1-Aguas Calientes spring (La Chistatosa)	5,80	45.8	1140	168,5	103,00
2-PE Porfirio Altamirano	6,88	35,1	1119	295,8	34,84
3- El Tránsito well	7,08	35,6	983	314,5	55,70
4-PE -Santa Rosa	7,01	36,6	1132	194,5	50,90
5-PE Manuel Araúz	6,69	32,9	995	298,5	22,74
6-PE Adelaida del Socorro	6,76	30,6	914	325,2	21,05
7-PE Narciso Araúz	6,77	31,0	916	320,8	20,94
8-PE Franklin Araúz P	6,51	30,0	910	391,6	19,44
9-Finca Reyes Altamirano	6,70	31,4	945	366,9	23,32
10-PE Juana Altamirano	6,86	34,6	945	350,2	15,99
11-PE Arturo Altamirano	6,94	32,5	961	368,6	20,38
12-PE Rubén Hernández	6,77	31,5	915	347,6	11,32
13-PP La Fuente Comunity	7,06	35,7	925	330,7	12,86
14-PE Arsenio Guido	6,84	32,7	914	351,3	12,26
15-PE Dora Ramírez	7,48	35,1	905	278,5	10,9
16-PE Pedro Castillo	6,65	31,1	791	165,1	23,17
17-PE Isabel Rojas	6,54	31,0	532	200,8	23,52
18-PE Socorro Marenco	6,43	31,8	761	209,2	21,58
19-PE Concepción Vargas	6,59	29,3	799	226,0	15,41
20-PE Esperanza Vargas	6,52	31,6	741	245,6	14,8
21-PE Dominga Rojas	6,74	31,9	818	215,4	10,41
22-PE Zelma Reyes	6,51	30,9	784	221,4	12,75

Sampled Points	pH (Und)	Temp (°C)	CE (µS·cm-1)	Pot. Redox (mV)	As total (µg·l-1)
23-PE Yelba Hernández	7,61	32,3	594	161,3	10,19
24-PP Gertrudis Treminio	6,82	32,7	963	291,2	17,37
25-PE Gertrudis Treminio	6,70	31,2	844	241,5	9,09
26-PE Wilber Espinoza	6,36	31,6	512	227,3	9,20
27-PE Marvin Moya	6,70	33,4	813	243,1	5,86
28-PE Pedro Vill Mejía	6,68	31,7	547	246,9	4,42
29-PE Hermógenes A	7,02	31,9	745	238,2	6,91
30-PE Martin Espinoza Rojas	7,43	32,0	525	232,4	7,04
31-PE Lucía Castillo	6,98	31,0	476	263,6	5,30
32-PE Rafaela Rojas	6,11	30,7	211	433,1	2,19
33-PE Porfirio Mayorga	6,70	31,0	514	374,7	2,21
34-PE Leonila Altamirano E	6,63	32,4	256	341,1	< 0,99
Minimum	5,80	29,3	211	161,3	<0,99
Maximum	7,61	36,6	1140	433,1	103,00
PE: Dug well PP: well	CE: electric conductivity				

Field parameters (pH, Temperature, Electrical Conductivity and REDOX Potential)

The measurement of these parameters *in situ*, provides relevant information on the conditions of an aquifer at a particular time and moment with respect to the acidity or basicity of the water, the temperature conditions (possible sources of thermalism), oxidizing environments or reducers that lead to the release of more toxic species such as arsenic, to name a few.

The electrical conductivity in 94% of the sampled locations exceeds the value recommended by the standards (CAPRE, 1994) for human consumption which is 400 $\mu S \cdot cm^{-1}$. However, the reported values of electrical conductivity in the monitored wells affect the organoleptic quality of the water, specifically in the taste of the water, decreasing its acceptance by consumers (WHO, 2006).

Temperature is one of the most important parameters of water quality and affects its chemistry as it regulates parameters such as pH, dissolved oxygen, REDOX potential and ionic concentrations present in the water. The temperature of the groundwater at a given point and time represents a state of equilibrium between the "contributions" and the "extractions". It was determined that the wells with the highest temperature (table 1) also reported the highest concentrations of arsenic; such is the case of the Aguas Calientes spring with the highest temperature (45.8 °C).

The pH measurements are executed on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7 pH units are considered acidic; while those with a pH higher than 8 pH units are considered alkaline. Of the wells sampled, 76.5% (27 wells) obtained values with a pH lower than 7, being considered slightly acidic to acidic, while 20.5% (7 wells) present values that slightly exceed the neutral pH, being considered slightly alkaline. The lowest pH value (5.80 units) was found in the Aguas Caliente (La Chistatosa) spring, which in turn reported the highest total arsenic temperature and concentration. The oxidation state of arsenic, and therefore its mobility, is mainly controlled by REDOX conditions (REDOX potential, Eh) and pH.

The REDOX potential values in the study area range between 168.5 and 433.10 mV. When the REDOX potential was related to the total arsenic values of the La Fuente rural community, no significant correlation was found with all the analyzed locations, but with the Aguas Caliente (La Chistatosa) spring. At this point, the highest concentration of arsenic and the lowest Eh values were reported indicating reducing conditions, this is probably due to the fact that this site is being controlled by different oxidation-reduction processes due to the wear of chemical minerals and REDOX conditions changers which increase arsenic mobility and facilitate transfer from the solid to the dissolved form (Smedley and Kinniburgh, 2002).

Total Arsenic in Groundwater.

During the geological and hydrogeological survey, it was observed that it is common to find both sides of the road, hydrothermally altered material (rocks) (figure 3); at the same time that these types of rocks are present both in the excavated wells and in the road cuts.

Figure 3. Altered rocks in rural community La Fuente, in front of Narciso Arauz's house.

The 70% of the sampled locations report total arsenic concentrations that exceed the guideline value of 10 $\mu g \cdot l^{-1}$ of arsenic in water established for human consumption (Figure 4), which is a latent danger to the health of the population from La Fuente.

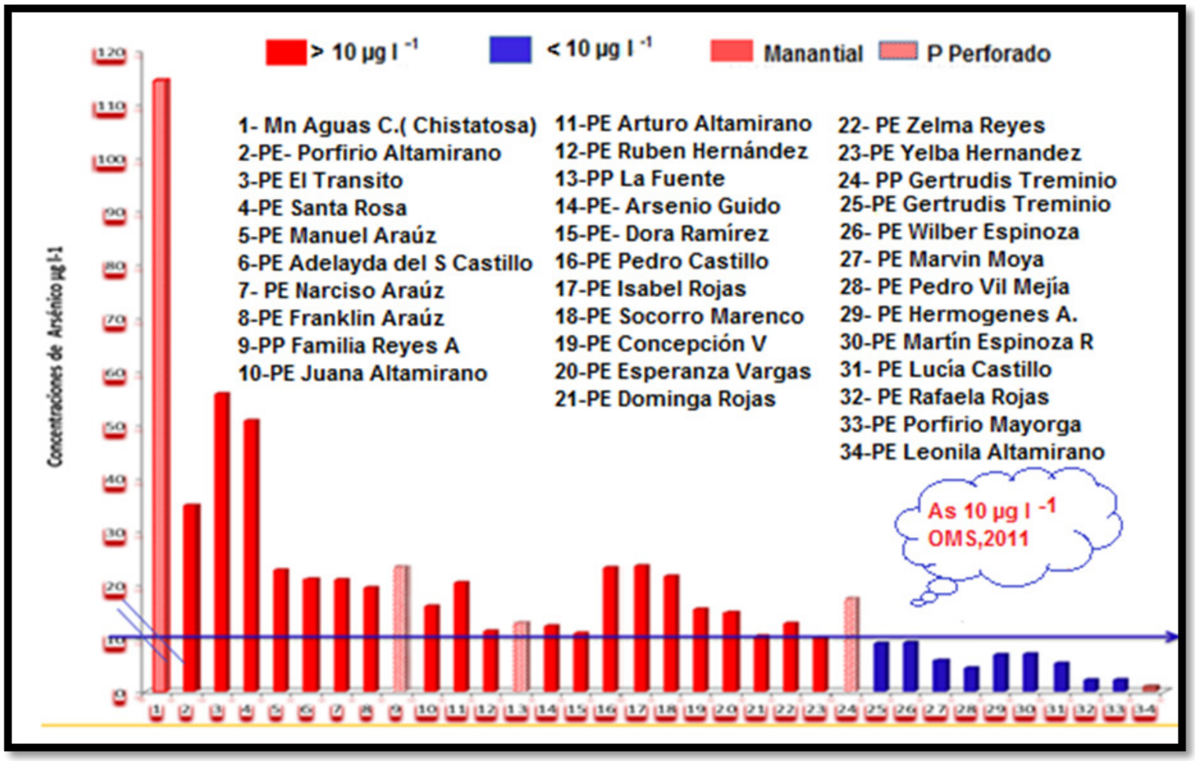

Figure 4. Arsenic concentrations detected in excavated and drilled wells and a spring in the rural community "La Fuente".

It is worth mentioning that the inhabitants deepen the wells annually because they dry up in the summer. These actions generate the risk of increasing the concentrations of the toxic in the drinking water, representing this a conditioning factor for the use of deep groundwater from altered media (Kinniburgh, D G; Smedley, P L; Summary, 2001).

The Aguas Calientes spring is a hot spring that is born from Cerro La Chistatosa (Figure 5); It is located in the northern part of Momotombo port, it is low flow and runs through the municipality from north to south. In this water source, the highest arsenic value (103 $\mu g \cdot l^{-1}$) was detected, a concentration that is similar to that reported in the thermal springs of Tipitapa (102 $\mu g \cdot l^{-1}$; (CIRA/UNAN-Managua & Metal Contaminants Laboratory, 2009) The water from this spring discharges into Lake Xolotlán, presenting a strong smell of sulphide and a temperature close to 50 °C. The area where this spring is located shows an intense hydrothermal alteration which could cause the dissolution of the rocks that are the main source of arsenic in groundwater.

Figure 5. a) La Chistatosa Hill and b) hot spring known as Aguas Calientes that emerges from this hill.

According to (Boyle R, 1979), the intense hydrothermal alteration makes the rock vulnerable because it has no capacity to maintain a constant pH, increasing acidity and decreasing the ability to neutralize chemical reactions, and thus facilitating the incorporation of many metals to the aquifer by percolation of harmful elements such as arsenic to ground and surface waters.

As mentioned earlier, the locations with have the highest temperatures, lowest pH and high electrical conductivities, have the highest concentrations of arsenic (Manantial Aguas Caliente, PE Porfirio Altamirano, PE Santa Rosa, PE El Rosa, PE Manuel Arauz, PE Manuel Arauz, PE Adelaida del Socorro Castillo, PE Narciso Arauz, PE Franklin Arauz P. and PP Finca Reyes Altamirano). These sites are located on an ancient volcanic boiler known as Galán caused by the sinking of a magmatic chamber and which are currently part of extensive plains (OLADE; 1982). These natural concentrations of arsenic could be related to the process of contamination of shallow aquifers by geothermal fluids which also affect the temperature increase in these sites (Electroconsult, 2001).

In the community center area, arsenic concentrations, although lower than those mentioned above, continue to exceed the guideline adopted by the country with concentrations between 20.38 $\mu g \cdot l^{-1}$ and 10.90 $\mu g \cdot l^{-1}$; It should be noted that these wells have a depth between 20 and 25 meters. Before 2013, the PP Community La Fuente, supplied only 7 families, with a concentration of arsenic of 17.00 $\mu g \cdot l^{-1}$; for 2013, INAA selected this well for community use, supplying a total of 112 families. In the present study, this well was monitored reporting a concentration of 12.86 $\mu g \cdot l^{-1}$, so a decrease in the arsenic present in the water is observed; This is probably due to the greater extraction of water in the well, the water table seeks a new equilibrium level to stabilize causing mixtures of water of different qualities where the concentration of the contaminant can be affected (Smedley, Nicolli, Macdonald, & Barros , 2002).

Safe Source Identification

At present there is no effective cure for chronic arsenic poisoning; However, in cases of acute poisoning it is possible to reverse the harmful effects on people's health while they are in the first three stages (pre-clinical, clinical and complication) if the source of drinking water is replaced by a free of arsenic whether it meets the value established by the (WHO, 2011) of 10 $\mu g \cdot l^{-1}$, or with the use of remediation techniques is the only measure to counteract the prevalence of the toxic in humans, and it can be considered that recovery is almost complete.

In the present study, those wells with the lowest arsenic concentrations were identified, these being the sites: PE Rafaela Rojas (2.19 $\mu g \cdot l^{-1}$) and PE Porfirio Mayorga (2.21 $\mu g \cdot l^{-1}$); which were recommended to the residents of La Fuente. As for the community distribution well that currently has PP Comarca La Fuente, it is recommended that it could be used for secondary uses (washing clothes, watering plants, bathing, cattle breeds and crops). However, it should be mentioned that substances that cause cancer (carcinogens), such as arsenic, always represent a risk at any level.

The low concentrations of arsenic in water present in these sites are probably due to the fact that they are located near a groundwater divide, with two micro-basins: one that directs its flows eastward and another southward; so that the water recharge and the interaction of the water-rock present in each microbasin is conferring different chemical characteristics to the waters, hence in some wells there is a higher content of arsenic and in others not; at the same time, it should be considered that the presence of high concentrations of arsenic is associated with the fact that this aquifer is made up of a shallow alluvial aquifer and a volcanic aquifer, so that the ascent of deep groundwater enriched with arsenic is imminent through the faults and fractures, coupled with the fact that this area is volcanic and highly seismic.

The 30% of the sites analyzed are located east of the community of La Fuente looking towards the communities of Tecuaname, El Papalonal and Cuatro Palos (Figure 5), and discharge to the Sinecapa River. (Longley A., 2005); while the highest concentrations of arsenic in water are reported towards the Galán boiler. Given the low concentrations found towards the eastern sector of the study area, it is suggested to promote the use of these waters as safe sources of drinking water supply for human consumption, washing food, brushing teeth and cooking.

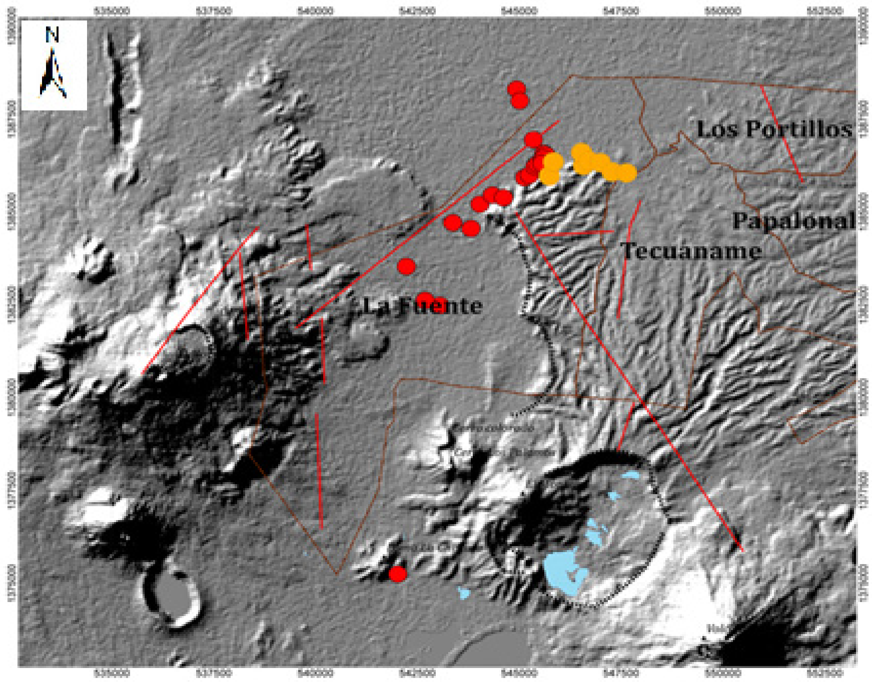

Figure 5. Map of arsenic concentrations, faults and volcanic boilers.

Presentation of results to the community and local actors

On May 25, 2017, a visit was made to the rural community of La Fuente, and the study was presented at the Santa Ana school in this community. The exhibition was held before: 1) the community of La Fuente in general; 2) the local authorities of the CAPs del Terrero, Tecuaname, El Papalonal and La Fuente; 3) the person in charge of Risk Management of the mayor's office of La Paz Centro, the Comrade. César Torres Salgado; 4) members of the Samaritan´s Purse Canada group; and 5) the director of the La Fuente school. The presentation reported on the quality of groundwater according to the concentration of arsenic present in each of them, as well as the irreversible damage that this metalloid causes in human health; Finally, the population and authorities present were oriented on the change in the use of current water sources for alternative sources and safe water for the population, which are equivalent to 30% of the wells analyzed and that meet the values guidelines established for water for human consumption (10 $\mu g \cdot l^{-1}$; WHO, 2011).

This research, in addition to generating unpublished scientific information in this study area, becomes a tool to: 1) support decision-making by the authorities, in terms of safe sources of safe drinking water for the population; 2) that local residents make a change in the use of alternative water sources for human consumption and food preparation; 3) so that government entities such as the mayor's office of La Paz Centro, the Ministry of Health (MINSA) and the National Water Authority (ANA) have a background for the execution of future water projects in relation to the quality of it, and that serves as antecedent for the decision making in the planning and territorial planning of the municipality; and 4) for government authorities and MINSA to carry out health studies on the population, focusing on the prevalence of this toxic in groundwater.

CONCLUSION

Most of the wells monitored in the community of La Fuente exceed the total permissible arsenic concentration value (10 $\mu g \cdot l^{-1}$) in water for human intake established by the World Health Organization and adopted by the Nicaraguan Institute of Water and Sewage as a quality standard for national use.

In the study area, arsenic is of geogenic origin because it is located at the base of the northern slopes of El Hoyo volcano and the Galán´s boiler building.

The intense hydrothermal alteration in this area, product of the recent Quaternary volcanism that promotes the release of arsenic from mineralized structures, as well as the rise of groundwater enriched with arsenic through faults and fractures that serve as a conduit for the contaminant.

Water sources that meet the maximum permissible limits for human water consumption (10 $\mu g \cdot l^{-1}$ arsenic) in the community of La Fuente, are recommended as sources of safe water for population consumption.

It is presumed that the eastern sector of the study area, looking towards the Tecuaname community, may be the recommended sites to drill new wells for safe water supply for the population, prior geological, hydrogeological and water quality studies.

The dissemination of the results generated the empowerment of the population of La Fuente community by changing the culture of water use, using good quality water sources, using alternative methods of arsenic removal (reverse osmosis filters), which will result in the decrease of the pathologies related to this carcinogen.

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