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Human hair to assess exposure to arsenic in users of contaminated water from La Fuente community in La Paz Centro, León.

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ABSTRACT

The presence of Arsenic in the surface and groundwater of Nicaragua is related to the geoenvironments present in the country. The study area is located NE of the Momotombo volcano, located in the volcanic arc in front of the Nicaraguan Depression, where the predominant geological material is rocks and sediments of the alluvial and volcanic Quaternary. The community of La Fuente is made up of 112 families (1300 inhabitants) that are mostly supplied with water by artisanal sources (90 dug wells and three drilled wells, one of them is communal). In a previous study, total arsenic in water was determined in a range

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Footnote
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of 2.0 to 103.0 μg/L, with the highest value being reported in a thermal spring; where 70% of the sites monitored (24 wells) reports values not suitable for human consumption (greater than or equal to 10 μg/L). The arsenic present in the water is absorbed by the tissues to be subsequently eliminated in the urine; but when the intake is greater than excretion it tends to be accumulated in hair and nails, as in urine and blood; these are excellent biomarkers to determine acute and chronic exposure to this metalloid. Considering the time of ingestion of water contaminated with arsenic by residents of La Fuente, it was decided to determine whether there is arsenic in the residents of La Fuente, using human hair as a biological indicator. A focus group was identified for this study considering the highest concentrations of arsenic present in water, as well as the longest intake time, resulting in a population group of 43 women and 9 men. Approximately 5 grams of hair was collected from each individual to be evaluated, totaling 52 hair samples. Arsenic concentrations detected in hair ranged from 0.014 to 0.925 $\mu g \cdot g^{-1}$; being these values less than 1.00 $\mu g \cdot g^{-1}$, standard established as a toxicity criterion by the Quebec Toxicological Center (CTQ). The highest concentrations of arsenic are associated with the oldest person (woman 90 years old) probably due to the longer exposure time; and the youngest (child 7 years), probably because this pollutant is transmitted from mother to children through the umbilical cord, the newborn presenting a concentration similar to her mother at birth. The community members were informed of their results as part of the social commitment to the population subject to the study.

1. INTRODUCTION

There are numerous populations affected by the intake of arsenic in water throughout the world, without Nicaragua being the exception. Globally, it is considered a public health problem that has various carcinogenic, neurotoxic and mutagenic effects (Rodríguez Barranco, M., Lacasaña, M., Aguilar Garduño, C., Alguacil, J., Gil, F., González Alzaga , B., et al. 2013). According to the Agency for Toxic Substances and Disease Registry (ATSDR, 2011), the International Agency for Research on Cancer (IARC), the National Toxicology Program and the Agency for Environmental Conservation (EPA) declared arsenic as a risk factor for health considering it as a known human carcinogen.

The World Health Organization established in 1993 the maximum admissible value in water for human consumption, the concentration of 50 $\mu g \cdot l^{-1}$ for arsenic; however, due to the toxicity of this metalloid, this value has been reduced worldwide to 10 $\mu g \cdot l^{-1}$ (WHO, 2011).

The use of biomarkers to assess the toxicity of chemical agents present in the environment is increasingly widespread. This way of evaluating the risk for exposed populations has disadvantages such as not considering individual variability against a toxic agent, the existence of a long latency period between exposure and the development of a disease, for example, cancer.

Whereas the use of molecular data makes the period between exposure and detection of markers of genotoxic effects shorter (Smith, Hopenhayn-Rich, Warner, Biggs, Moore, & Smith, 1993).

Studies show that the risk of cancer drinking 1.6 liters of water per day with 2.5 $\mu g \cdot l^{-1}$ is 1/1000; and with levels of 50 $\mu g \cdot l^{-1}$ it is 21/1000; where the population groups most vulnerable to the exposure of metals in the environment are infants, the elderly, and pregnant women (Licata, Trombetta, Cristani, Naccari, Martino, & Calo, 2005).

In Nicaragua, few studies have been carried out evaluating human exposure to arsenic [(Reyes Salgado & Provedor Fonseca, 1998), (Gómez C., 2002), (Gómez Cuevas, 2007), (Genie Zepeda & González Zambrana, 2017)], due to the intake of water and / or food contaminated with this toxic; or by dermal contact with soils and rocks that naturally possess it (Wickre, Folt, Sturup, & Karagas, 2004); as well as using biomarkers [(Wickre, Folt, Sturup, & Karagas, 2004), (PAHO / WHO, Nuevas Esperanzas, 2011)].

Biomarkers are parameters that are quantified in a biological medium from urine, hair, blood, and others, including the presence of a contaminant in a biological medium against the aggression of a xenobiotic as a result of a relatively recent exposure (acute or subacute), long-term (chronic) [(Gil & Hernández, 2009), (Hernández, Gil, & Tsatsakis, 2014)].

Human hair has been used as a biomarker to assess environmental and occupational exposure to certain toxics for more than 50 years (Pereira, Ribeiro, & Goncalves, 2004). (Chojnacka, Góreaka, & Gorecki, 2006)] mention that this preference of hair over other biomarkers is associated with:

- It is a stable matrix.
- The sample is easy to obtain, transport, and store.
- It has proven to be one of the vehicles for the excretion of metals, enormously useful in the evaluation of chronic poisoning.
- The concentrations of arsenic found in the hair are 10 times higher than those in the blood and urine.
- The concentrations of arsenic in blood and urine reflect recent contamination; while in the hair it is indicative of chronic exposure.

At the same time, (Repetto, 1995) mentions that human hair reveals the consumption of water contaminated with inorganic arsenic, as well as the consumption of food contaminated retrospectively; so the hair is a true calendar of the use and consumption of contaminated water, drugs, and food.

The concentration of arsenic in the hair depends on the exposure time and its growth rate; the longer it is, the longer the exposure time. Growth varies between 0.75 and 1.35cm per month, although variables such as age, gender, and pregnancy can significantly alter this speed (Harker, 1993).

ATSDR considers that values greater than 1.00 mg/kg of total arsenic in human hair are harmful to health due to their toxic and carcinogenic effects (ATSDR, 2011); likewise, the Quebec Toxicological Center (CTQ) establishes the same toxicity criteria (CTQ, 1980).

It was not until 2004 that the first study was carried out in Nicaragua using biomarkers. In this investigation, the degree of exposure to arsenic and mercury in children and adults of the mining community in Siuna was determined, using nails as a biomarker (Wickre, Folt, Sturup, & Karagas, 2004). Seven years later, the second study was carried out using biomarkers, in this case, human hair; to determine the impact of the consumption of water contaminated with arsenic on the health of the population of five communities in the municipality of Telica (PAHO / WHO, Nuevas Esperanzas, 2011).

1.1. Study area

The rural community of La Fuente is located in the Municipality of La Paz Centro, with a population of 1,300 inhabitants distributed in 120 families. The study area has an approximate extension of 15 km^2 (Figure 1). It is located northeast of the northern slopes of the Momotombo-El Hoyo volcanic complex and the Monte Galán caldera building (OLADE, 1982).

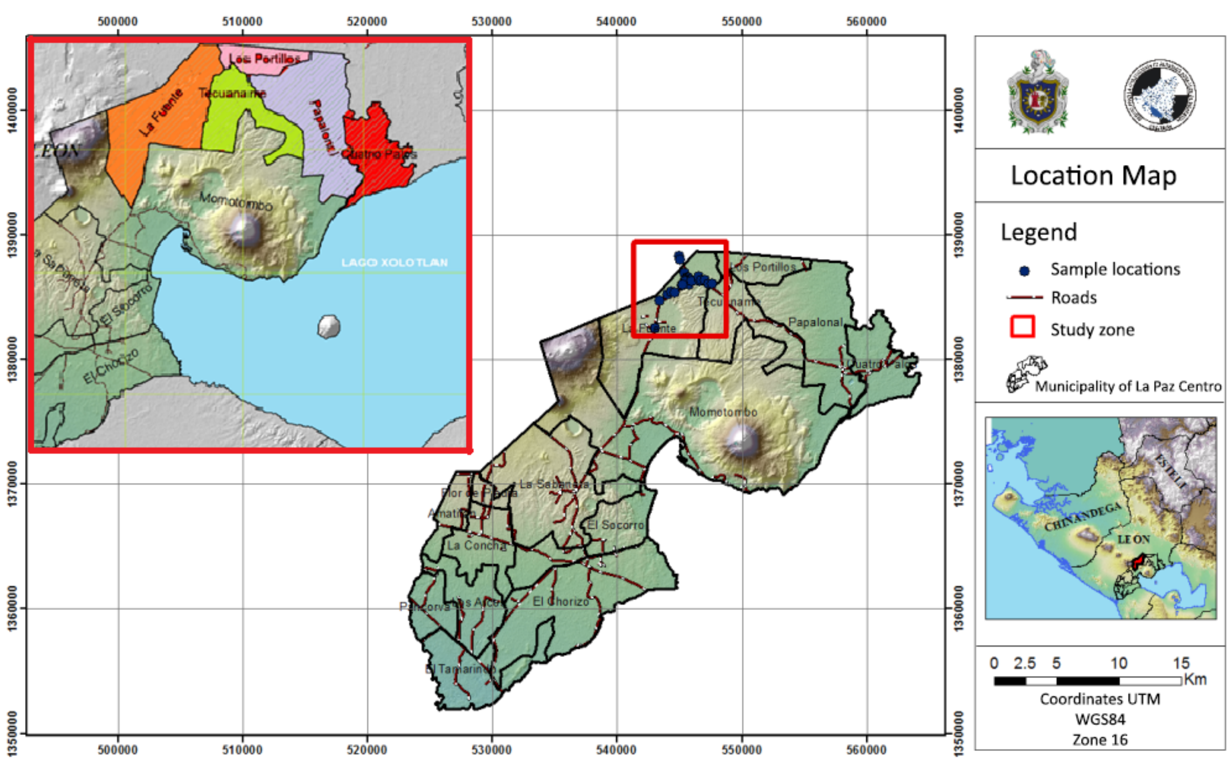

Figure 1. Macro and micro-location of the La Fuente Rural Community, La Paz Centro. Taken from (Altamirano., 2017 in the process).

2. METHODOLOGY

2.1. Materials and methods

The present study is the result of a previous investigation carried out with UNAN-Managua Research Project Funds (FPI #12201504), (Altamirano E, 2017); carried out in the same community where the concentrations of arsenic in water from 34 wells out of the 93 existing were determined; resulting in a concentration range of 2 to 103 $\mu g \cdot l^{-1}$, which corresponds to 70% of the wells having arsenic levels above the 10 $\mu g \cdot l^{-1}$ established by the WHO for human consumption (WHO, 2011). This information was used as a baseline for the execution of this research work.

The first component of this stage consisted of conducting individual interviews with the residents of La Fuente, focusing on the different pathologies suffered by the inhabitants of this community.

An informal conversation was held with community leaders, where the main manifestations expressed during these dialogues are:

1. Kidney diseases.
2. Hypertension, diabetes, and cancer; these three conditions appear on a smaller scale than kidney diseases, and they affect women more than men.
3. Dermatitis: residents express allergies and verrucous lesions on the skin which they associate with water quality problems.

Once the information from the community members was obtained, the selection of the population group that would be submitted to the analysis of arsenic in hair was carried out. For this, it was considered:

1. The content of arsenic in drinking water.
2. The consumption time of that water (exposure time).
3. The age and gender of the person.

In the procedure for taking hair samples (Figure 2), the following should be considered:

- Make it easy to collect.
- Comply with the sampling protocol:

a. Before proceeding to take the sample, the informed consent is read if it is an adult; if they are children, permission is requested from the parents of the child to take the sample.

b. Cut the hair close to the lower part of the neck (at the origin of the hair), since it should not be exposed to the sun, wind, or dust (Figures 2a, 2b, 2c, and 2d). Sterile gloves and scissors are used in this procedure.

c. Capture approximately 5 grams of hair, and store it individually in ziploc bags; which will be labeled with the data of each monitored individual:

d. Date and time of sampling,

e. Name of the person sampled.

f. Sex, age, and time to live in the community.

g. The samples do not need to be preserved.

h. Finally, the hair samples were packed in appropriate containers.

The operating procedure for sample collection (PON-CM-06) established at the CIRA / UNAN-Managua Metal Contaminants Laboratory was followed.

Figure 2 (a, b, c, and d). Hair sampling in La Fuente population group.

3. RESULTS

For the interpretation of the results, only the initials of the population group sampled for this purpose will be used; this to respect their identity and physical integrity; guaranteeing in this way the confidentiality commitment expressed in the informed consent.

Table 1 shows the concentrations of arsenic in human hair from La Fuente population sample; with a concentration range that oscillated from 0.011 to 0.925 $\mu g \cdot g^{-1}$. The age range evaluated was from 7 to 90 years, with an arsenic intake value of 2 to 103 $\mu g \cdot l^{-1}$; and a range of consumption of water contaminated with arsenic from 7 months to 90 years.

Table 1. Arsenic concentrations in human hair ($\mu g \cdot g^{-1}$) of the population group evaluated in La Fuente.

User	Arsenic ($\mu g \cdot g^{-1}$)	Age (years)	Sex	Range of consump-tion (years)	User	Arsenic ($\mu g \cdot g^{-1}$)	Age (years)	Sex	Range of consump-tion (years)
REC	0,464	49	F	30	YH	0,186	61	F	61
NEA	0,640	30	F	30	FCR	0,156	26	F	26
MDL	0,011	27	F	8	LC	0,266	9	F	9
MPV	0,011	40	M	7 meses	PRM	0,106	30	F	30
MBC	0,011	40	F	7 meses	ERH	0,076	50	F	50
AEP	0,011	82	F	70	CA	0,114	60	M	60
GG	0,054	58	F	40	AA	0,227	20	M	20
ARC	0,011	79	F	75	MMR	0,029	14	F	14
MAM	0,138	22	F	20	ADV	0,194	5	F	5
FRO	0,073	70	F	33	KVA	0,162	6	F	6
JAE	0,011	89	F	88	DVR	0,199	5	F	5
RJA	0,029	64	M	45	NCH	0,124	50	M	50
ANH	0,154	42	F	38	EPR	0,416	60	F	60
JRR	0,209	70	F	68	SA	0,281	8	F	8
LA	0,040	69	F	66	DPA	0,120	5	F	5
LSH	0,014	54	F	20	OP	0,057	12	M	12
NSD	0,194	50	F	20	SEP	0,393	54	F	54

User	Arsenic ($\mu g \cdot g^{-1}$)	Age (years)	Sex	Range of consumption (years)	User	Arsenic ($\mu g \cdot g^{-1}$)	Age (years)	Sex	Range of consumption (years)
MIRR	0,167	56	F	42	JLE	0,493	6	F	6
MRV	0,215	80	F	20	JEP	0,248	52	F	52
FRO	0,011	60	F	20	KLM	0,133	23	F	23
MHS	0,011	76	F	52	LEM	0,158	18	F	18
EV	0,044	72	F	67	ASEP	0,129	23	F	23
JVM	0,644	80	F	80	MLM	0,194	24	F	24
DR	0,314	73	F	72	ARS	0,254	25	M	25
MSG	0,125	43	F	43	AYJ	0,319	18	M	18
EIM	0,925	90	F	90	AVR	0,824	7	M	7

Out of the 52 inhabitants who were analyzed for total arsenic in human hair, 44 (84.62%) reported arsenic values above the detection limit; from 0.014 to 0.925 $\mu g \cdot g^{-1}$. The highest concentrations of arsenic were found in four users: EIM with 90 years (0.925 $\mu g \cdot g^{-1}$); AVR with 7 years (0.824 $\mu g \cdot g^{-1}$); JVM with 83 years (0.644 $\mu g \cdot g^{-1}$); and NEA with 30 years (0.640 $\mu g \cdot g^{-1}$) who live in this community from birth (Table 1; Figure 3). None of them is still exposed to concentrations considered toxic in people [established criterion of 1 $\mu g \cdot g^{-1}$ (CTQ, 1980)]. However, the EIM population, who reports the highest concentration detected in this study, is very close to the toxicity criterion.

It is worth mentioning that eight people reported concentrations of arsenic in their hair below the detection limit of the method (Table 1). Of these: AEP, ARC, and JAE drink Fuente Pura wáter (purified wáter), so they are not exposed to the water intake of the community; FRO and MHS were born Tecuaname community, where this toxin is absent and they have little time to reside in La Fuente; MBC practically lives in Momotombo and visits La Fuente once a month, for which reason it has occasionally ingested water with a concentration of 50.90 $\mu g \cdot l^{-1}$. Finally, CDM and MPV have seven months to reside in the community.

When analyzing the peculiarities of EIM, it is observed that he is the oldest person in the population group, who has the longest prevalence time in the community, so it is considered that since birth he has consumed water with a concentration of arsenic of 12, 75 $\mu g \cdot l^{-1}$. AVR is the one who reports the second-highest value of arsenic in the hair (0.824 $\mu g \cdot g^{-1}$), and at the same time, is in the youngest group of those evaluated. Since birth, he has consumed water with 23.27 $\mu g \cdot l^{-1}$ arsenic. JVM and NEA have similar concentrations of arsenic in the hair (0.644 $\mu g \cdot g^{-1}$ and 0.640 $\mu g \cdot g^{-1}$, respectively); however, there is a great difference in age between the two inhabitants: JVM is 83 years old, while NEA is 30 years old. Although, both (JVM and NEA) have ingested arsenic-contaminated water since birth, the concentrations of arsenic in the water sources they consumed differ from 14.8 $\mu g \cdot l^{-1}$ to 34.84 $\mu g \cdot l^{-1}$, respectively.

As can be seen, the higher the concentration of arsenic in the drinking water, the greater the exposure of the person, even though the intake time of water contaminated with this metalloid is shorter; This is reflected in a higher concentration of arsenic detected in hair.

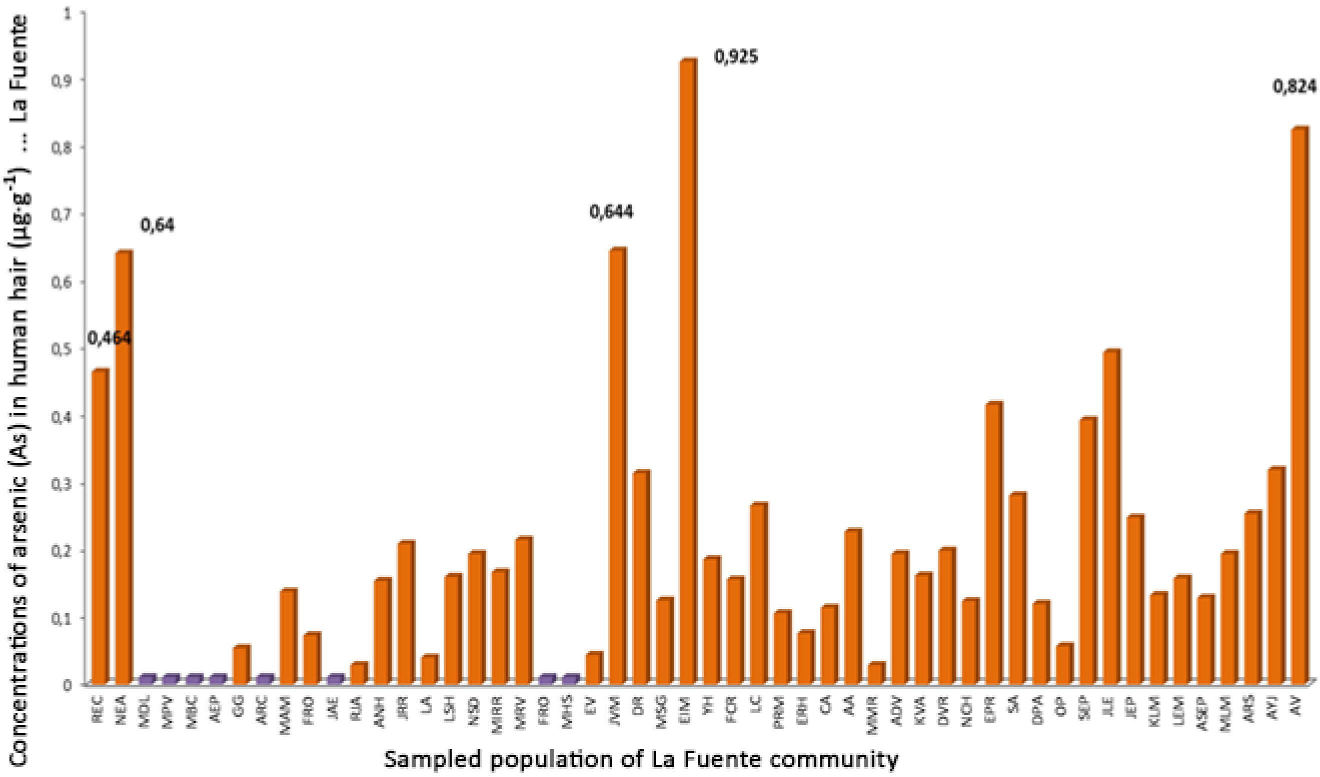

Figure 3. Concentrations of arsenic (As) in human hair ($\mu g \cdot g^{-1}$) in the community of La Fuente.

A finding in this study is the case of two 7-year-old twin girls (ADVR and DVR), who were evaluated, reporting similar arsenic concentrations in hair: 0.194 and 0.199 $\mu g \cdot g^{-1}$, respectively; both have ingested since birth water with an arsenic concentration of 23.52 $\mu g \cdot l^{-1}$ (PE-IR). At a young age, the bioaccumulation of this toxic in the body is perceived; spreading evenly throughout all organs and tissues except hair and nails, where a longer retention time has been observed, although after exposure it may initially focus more on the liver, kidney, and lungs (Bertolero, Marafante, Edel Rade, & Pietra, 1981). Finally, in this particular case, a close relationship between the age-time of intake-concentration of arsenic in drinking water is evidenced.

In the neighboring community of El Papalonal, AB aged 103 reported a concentration of arsenic in hair <0.011 $\mu g \cdot g^{-1}$, consuming water with <0.99 $\mu g \cdot l^{-1}$ arsenic since birth [(Herrera, In progress), (Stynze Ramírez, In Execution)]. When comparing these concentrations of arsenic in hair with the EIM concentrations (0.925 $\mu g \cdot g^{-1}$; 90 years; consuming water with 12.75 $\mu g \cdot l^{-1}$ from birth), it is observed that the use of this biomarker (hair) provides a long-term record of exposure to arsenic from water intake with high concentrations of this carcinogen (Chowdhury, et al., 2000).

In general, the results show that the highest concentrations of arsenic in hair occur in children and the elderly. (Licata, Trombetta, Cristani, Naccari, Martino, & Calo, 2005) mention that this is because children have less weight than adults and are more active, which leads them to drink more water, generating greater intake and exposure; The same happens with the elderly, they eat less food causing some malnutrition; and they are less active, favoring the greater accumulation of this carcinogen. For all the above, hair analysis is perhaps a unique tool due to its special characteristic of extrapolating results over time, being of great importance to be used in pre and post-mortem toxicology, as was the case with Napoleon Bonaparte.

It was determined that 15.4% of the evaluated users (Figure 4) do not have arsenic in their organism since they report values lower than the detection limit of the method (0.011 $\mu g \cdot g^{-1}$); the reason why they are considered without exposure to this toxic. In a second group, where the majority of the evaluated population is located and those who report arsenic concentrations of 0.012 to 0.499 $\mu g \cdot g^{-1}$ in their system, a total of 77% of people exposed to this contaminant in their daily intake (Figure 4). Finally, there are two population sub-groups, each corresponding to 3.84% of the total population evaluated; but whose total range of arsenic concentration detected in the hair is between 0.5 to 0.925 $\mu g \cdot g^{-1}$, these being the most exposed people and with the greatest risk to their health (Figure 4). These results show an average of 0.1550 $\mu g \cdot g^{-1}$, with a mode of 0.011 $\mu g \cdot g^{-1}$, for an average of 0.1998 $\mu g \cdot g^{-1}$; with a minimum of 0.011 and a maximum of 0.925 $\mu g \cdot g^{-1}$ arsenic in human hair.

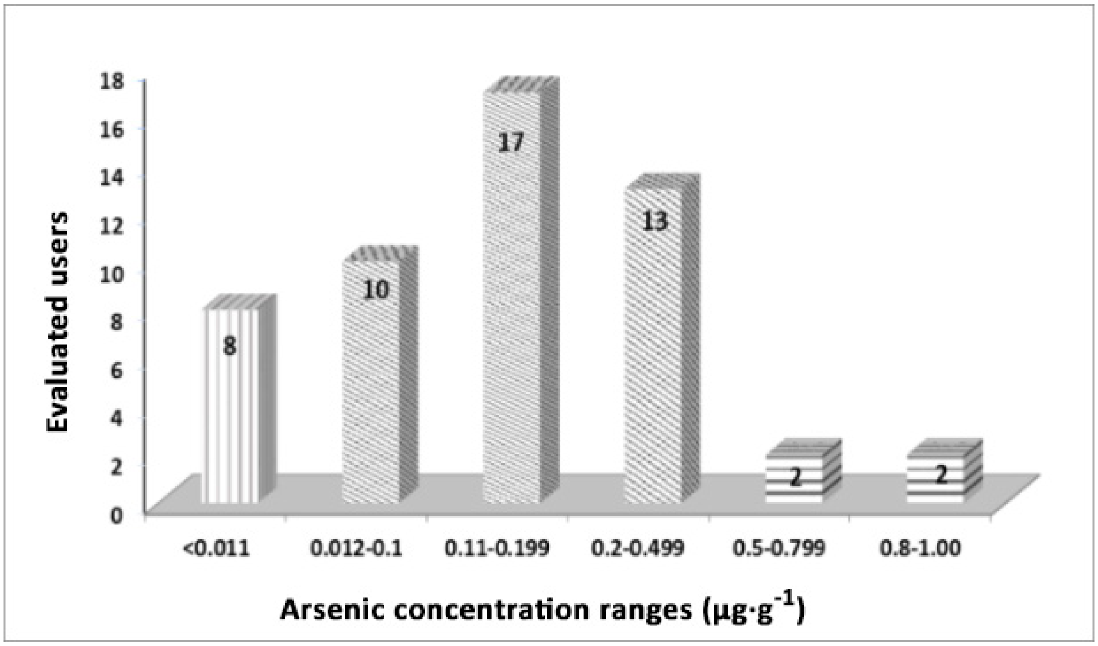

Figure 4. Ranges of total arsenic concentrations in human hair (µg·g^{-1}) in users of contaminated water sources in the rural community of La Fuente.

As part of the social component of this research and the commitment made with the community of La Fuente, a presentation was made on May 25, 2017, at the Santa Ana School in this community. The following were invited to this presentation: 1) the community in general of La Fuente; 2) to the local authorities of the CAPs of El Terrero, Tecuaname, El Papalonal, and La Fuente; 3) to fellow. César Torres Salgado, in charge of Risk Management for the Mayor of La Paz Centro; 4) to the members of the Samaritan´s Purse Canada group, who installed filters for the removal of bacteria in this community; 5) to the principal of the Santa Ana School; and 6) CIRA / UNAN-Managua staff (the Head of the Research and Development Area, the person in charge of the University Projection and Extension Function, and the staff of the Laboratory for Metal Contaminants). In total, approximately 100 community members participated, between adults and children. The presentation was given by the MSc. Maximina Altamirano, executor of this project and Head of the Laboratory of Metal Contaminants of CIRA/UNAN-Managua.

After presenting the results and findings reported in this study, the residents were interested in having the reasons for these values explained to them, which for some of them were worrisome; since as they stated, they did not consider that their water was contaminated, since physically and organoleptically nothing abnormal is observed; much less that they were carriers of this pollutant. The residents consulted what measures they should take to guarantee safe water intake while expressing their willingness to make the necessary changes to avoid continuing to consume this toxic substance that affects their health. CIRA/UNAN-Managua staff advised making use of water sources that present values less than 10 µg·l^{-1} of arsenic, which, according to the WHO, are recommended for human consumption. Finally, the results were delivered in a physical copy to each of the evaluated users (Figure 5).

Figure 5. Presentation and delivery of the results of arsenic (As) in human hair to the evaluated population group of the La Fuente community.

4. CONCLUSIONS

1. Due to the geological characteristics of the study area, arsenic is naturally present, contaminating surface and ground waters; generating a public health problem due to the ingestion of water with high concentrations of this genotoxic.
2. The evaluation of arsenic exposure using human hair as a biomarker indicated that the people evaluated did not exceed the toxicity values established by the CTQ; even in prolonged periods of intake.

3. In the community of La Fuente, the prevailing factor in the prevalence of concentrations of total arsenic in human hair is the arsenic content of its groundwater sources of geogenic origin, where 70% of the sources exceed the regulations assumed by the country.

4. The results indicate the current conditions on the presence of total arsenic in the hair samples to the evaluated users and the risk of exposure by continuing to consume water contaminated with this metalloid.

5. Because of the prevalence of this toxic in the population with the longest time and concentration of exposure to arsenic, sources of safe water supply for human consumption were targeted.

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