Assessment of heavy metal presence and concentration metals arsenic, mercury, copper, silver and cadmium in well water in the community of Santa Rosa del Peñón, León, Nicaragua*

Evaluación de la presencia y concentración de metales pesados como arsénico, mercurio, cobre, plata y cadmio en agua de pozo en la comunidad de Santa Rosa del Peñón, León, Nicaragua

Edith Soralia Vásquez[1]

Fecha de recepción: 28 de enero de 2026
Fecha de aprobación: 16 de agosto de 2026

Abstract

In Nicaragua, groundwater supply for human consumption presents significant challenges, particularly in rural communities, due to anthropogenic activities and natural processes. One of the main concerns is contamination by heavy metals, which poses a risk to human health and contributes to the deterioration of water quality. This study evaluated the presence and concentration of heavy metals in well water from the community of Santa Rosa del Peñón, Department of León, Nicaragua, using the CAPRE Standard to determine its suitability for human consumption. Water samples were collected from four drilled wells and two dug wells between April and November 2019, and between June and December 2020. Heavy metals were analyzed by atomic absorption spectrometry, using cold vapor techniques for mercury, hydride generation for arsenic, and graphite furnace for cadmium, copper, and silver. Mercury, copper, cadmium, and silver concentrations remained within the maximum permissible limits established by the CAPRE Standard for water intended for human consumption. In contrast, arsenic concentrations exceeded the established limit of 0.01 mg/L, with the highest values recorded in Delirio Well and Pilón Well, averaging 14.10 and 22.28, respectively, in 2019 and 2020. The evaluated arsenic levels detected in these wells indicate groundwater contamination and place the population in the study area at risk, as

* Artículo de investigación resultado de la tesis de grado de maestría.

[1] Universidad Nacional Autónoma de Nicaragua, Centro de Investigación de Recursos Acuáticos de Nicaragua UNAN- MANAGUA /CIRA. Correo: edith.vasquez@cira.unan.edu.ni. https://orcid.org/0009-0009-4448-3140

the water is unsuitable for human consumption. The concentrations of the metals analyzed in the community of Santa Rosa del Peñón varied and appear to be closely associated with the natural characteristics of the ecosystem, the volcanic geological context of the region, and the influence of human activities, particularly the mining activity historically carried out in the municipality.

Keywords:

groundwater, contamination, heavy metals, water quality CAPRE Standard.

Resumen

En Nicaragua, el abastecimiento de agua subterránea para consumo humano presenta desafíos importantes, particularmente en las comunidades rurales, debido a actividades antropogénicas y a procesos naturales. Una de las principales preocupaciones es la contaminación por metales pesados, la cual representa un riesgo para la salud humana y contribuye al deterioro de la calidad del agua. Este estudio evaluó la presencia y la concentración de metales pesados en agua de pozo de la comunidad de Santa Rosa del Peñón, departamento de León, Nicaragua, utilizando la norma CAPRE para determinar su aptitud para el consumo humano. Se recolectaron muestras de agua de cuatro pozos perforados y dos pozos excavados entre abril y noviembre de 2019, y entre junio y diciembre de 2020. Los metales pesados se analizaron mediante espectrometría de absorción atómica, utilizando vapor frío para el mercurio, generación de hidruros para el arsénico y horno de grafito para el cadmio, el cobre y la plata. Las concentraciones de mercurio, cobre, cadmio y plata se mantuvieron dentro de los límites máximos permisibles establecidos por la Norma CAPRE de calidad del agua para consumo humano. En contraste, las concentraciones de arsénico superaron el límite establecido de 0.01 mg/L, y los valores más altos se registraron en el pozo Delirio y el pozo Pilón, con promedios de 14.10 y 22.28, respectivamente, en 2019 y 2020. Los niveles elevados de arsénico detectados en estos pozos indican contaminación del agua subterránea y ponen en riesgo a la población del área de estudio, ya que el agua no es apta para el consumo humano. Las concentraciones de los metales analizados en la comunidad de Santa Rosa del Peñón variaron y parecen estar estrechamente asociadas con las características naturales del ecosistema, el contexto geológico volcánico de la región y la influencia de las actividades humanas, particularmente las actividades mineras desarrolladas históricamente en el municipio.

Keywords:

agua subterránea, contaminación, metales pesados, Calidad del agua Norma CAPRE.

Introduction

Groundwater contamination, whether of anthropogenic or natural origin, poses a threat to aquatic life and human health and contributes to the gradual deterioration of both water quality and the environmental condition of this resource. For this reason, it is important to assess the presence and concentration of heavy metals in water from wells in order to determine water quality and evaluate its implications for local public health. Such assessment also makes it possible to evaluate the concentrations of these metals and formulate relevant recommendations.

The company Cóndor Gold SA, which is exploring the possibility of gold mining, and the company La Mina India Gold S.A., which has mined this mineral as a concessionaire authorized by the Ministry of Energy and Mines and the General Directorate of Mines of Nicaragua, have highlighted the importance of environmental commitment to local communities through constant monitoring of the quality of water for human consumption from dug and drilled wells in the community of Santa Rosa del Peñón, León, Nicaragua. This situation underscores the need for these companies to operate sustainably and to contribute to the economic, social, and environmental development of the community. Furthermore, these companies are expected to assess environmental risks and social impacts, prevent pollution, and ensure the effective management of the most vital resource for life, namely water intended for human consumption at the local level.

This scientific study addresses the assessment of the presence and concentration of heavy metals in well water from the community of Santa Rosa del Peñón, with the aim of determining its quality and evaluating its implications for local public health. In accordance with this purpose, field sampling procedures were carried out, and results were obtained through the application of advanced analytical methods and techniques, specifically atomic absorption spectrometry, in laboratory physicochemical analyses to detect and quantify heavy metals in water, specifically As, Hg, Cd, Cu, and Ag. The community of Santa Rosa del Peñón is located in Nicaragua's dry corridor, a condition that places this territory at risk and makes this vital resource a constant concern. In recent years, climate change has affected these regions, making water for human consumption increasingly vulnerable in terms of both access and quality.

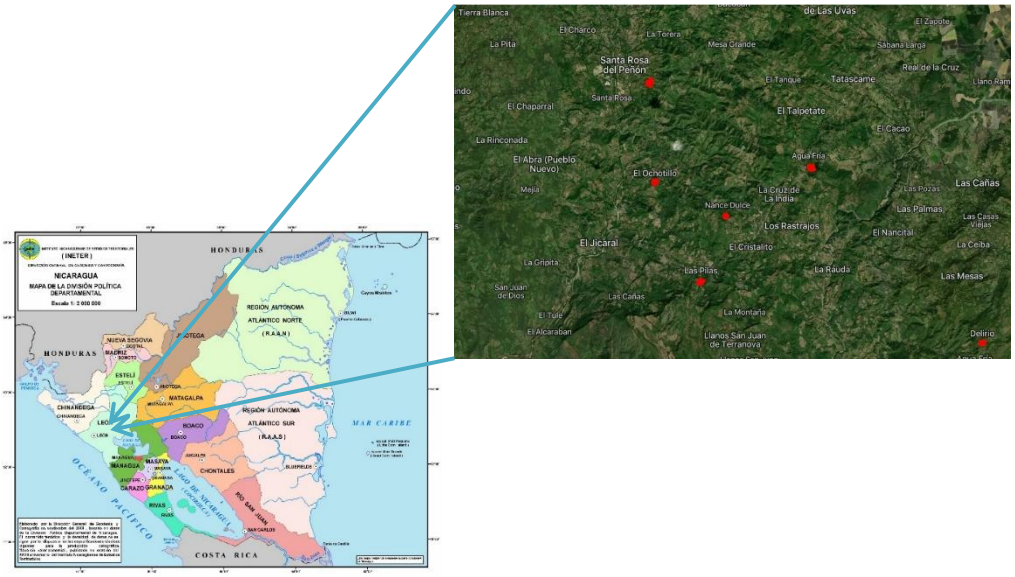
The need to maintain continuous monitoring and evaluation of the quality of water for human consumption in this area, using specialized sampling and analytical methods, is an ongoing task in which the local population, mining companies, and national reference laboratories such as CIRA must participate. Therefore, determining the presence of heavy metals (As, Hg, Cd, Cu, and Ag) in well water from the community the Santa Rosa del Peñón is of great importance. This information is useful for the protection and conservation of water resources and for the populations that use them for human consumption, as well as for institutions, mining companies, educational entities, and other interested organizations. In this context, the present study evaluated the presence and concentration of heavy metals in well water of the community of Santa Rosa del Peñón in order to determine its quality.

Introduction

Description of the sampling site

The study area corresponds to the community of Santa Rosa del Peñón, located at 12°48' N latitude and 86°22' W longitude. It is bordered to the north by the municipality of San Nicolás (Department of Estelí), to the south by the municipality of El Jicaral (Department of León), to the east by the Municipality of San Isidro (Department of Matagalpa), and to the west by the Municipality of El Sauce (Department of León). The community is located in the northern part of the Department of León and covers an approximate area of 227.6 km². Water samples were collected in April and November 2019 and in July and December 2020 at six sampling sites: four drilled wells (El Campo, Escuela Agua Fría, Nance Dulce, and Aguas Arribas) and two dug wells (El Delirio and El Pilón) (figure 1).

Figura 1.
Location of the study area



Source: INETER, Google Maps.

Sample collection and analysis

Four sampling rounds were conducted, two in 2019 and two in 2020, based on the proximity of the wells to populated areas and to sites where future mining exploration and exploitation activities are expected to take place. Water samples were collected in 1 L plastic bottles, preserved with 2 mL of HNO3, and labeled for the identification of each well. Field variables were measured using portable meters for temperature, pH, and electrical conductivity (EC). The samples were stored in a cooler with ice at a temperature of 4 °C and were subsequently transported for analysis in accordance with the Standard Operating Procedures (SOPs) of the Metal Contaminants Laboratory at CIRA, UNAN-Managua, following the Standard Methods for the Examination of Water and Wastewater (22nd ed.).

To determine the concentrations of metals in well water, arsenic, mercury, copper, silver, and cadmium were analyzed. Atomic absorption spectrometry was used for the analysis of each metal, applying different techniques, including hydride generation, cold vapor, and graphite furnace. Standards were prepared for each analysis, and the corresponding solutions were processed according to established analytical techniques. For each batch of analyzed samples, a replicate, a blank, and a duplicate were included, together with the corresponding control according to the calibration curve for each analyte. The procedure also included the preparation of calibration curves, stock solutions, working solutions, and recovery tests.

Tabla 1.
Analytical methods used in water analysis to determine heavy metals

	Arsenic	**Mercury**	**Copper**	**Silver**	**Cadmium**
Method	Hydride generation atomic absorption spectrometry	Cold vapor atomic absorption spectrometry	Graphite furnace atomic absorption spectrometry	Graphite furnace atomic absorption spectrometry	Graphite furnace atomic absorption spectrometry
Solutions	Titrisol As vial, 1 000 000 µg/L 10 000 µg/L stock Solution	Titrisol Hg vial, 1 000 000 µg/L 10 000 µg/L working solution	Titrisol Cu vial, 1 000 000 µg/L 10 000 µg/L working solution	Titrisol Ag vial 1 000 000 µg/L 10 000 µg/L working solution	Titrisol Cd vial, 1 000 000 µg/L 10 000 µg/L working solution
Calibration curve	Standards at 2.5, 5.0, 10.0, and 15 µg/L	Standards at 1.0, 2.5, 5.0, and 10.0 µg/L	50 µg/L standard	20 µg/L standard	5 µg/L standard
Control	10.0 µg/L	5.0 µg/L	25 µg/L	10.0 µg/L	1.0 µg/L
Recovery	5.0 µg/L	5.0 µg/L	25.0 µg/L	10.0 µg/L	1.0 µg/L
Limits detections	0.62 µg/L	0.17 µg/L	0.69 µg/L	0.68 µg/L	0.10 µg/L

Source: own elaboration.

Results

The results obtained in 2019 ranged from 2.54 to 18.68 µg/L (table 1). The El Delirio and El Pilón wells exceeded the maximum allowable values (MAVs) established by the CAPRE standard, set at 0.01 mg/L, equivalent to 10.0 µg/L. These two wells showed similar trends in the three subsequent sampling rounds, with arsenic concentrations ranging from 3.51 to 22.98 µg/L in November 2019, from 4.57 to 23.22 µg/L in July 2020, and from 5.36 to 24.23 µg/L in December 2020. All of these values also exceed the laboratory detection limit of 0.62 µg/L (table 2).

Tabla 2.
Arsenic concentrations from well sampling in 2019 and 2020

Wells	2019		2020		Average
	April (µg/L)	November (µg/L)	July (µg/L)	December (µg/L)	
El Campo	6.43	9.58	9.34	8.73	8.52
Agua Fría	5.65	7.74	8.27	9.66	7.83
Nance Dulce	2.54	3.51	4.57	5.36	4.00
El Delirio	12.17	13.95	15.63	14.63	14.10
Aguas Arriba	5.48	7.74	9.29	9.02	7.88
El Pilón	18.68	22.98	23.22	24.23	22.28

Source: own elaboration.

The results of the 2019 sampling showed that mercury concentrations in all wells were below 0.001 mg/L, which corresponds to the maximum value established by the CAPRE standard, equivalent to 1.00 µg/L. A similar pattern was observed in the 2020 sampling, in which mercury concentrations were also below 0.001 mg/L (1.00 µg/L). In all cases, the recorded values did not exceed the laboratory detection limit of 0.17 µg/L (table 3).

Tabla 3.
Mercury concentrations in samples collected in 2019 and 2020

Wells	2019		2020	
	April (µg/L)	November (µg/L)	July (µg/L)	December (µg/L)
El Campo	-0.55	-0.46	0.07	-0.05
Agua Fría	-0.39	-0.37	-0.20	-0.09
Nance Dulce	-0.58	-0.50	-0.23	0.05
El Delirio	-0.59	-0.55	-0.21	-0.06
Aguas Arriba	-0.49	-0.71	-0.25	-0.05
El Pilón	-0.58	-0.97	-0.06	-0.08

Source: own elaboration.

The results obtained in 2019 ranged from -0.26 to 0.99 µg/L. Copper concentrations in the wells did not exceed the MAVs established by the CAPRE standard. Similar trends were observed in the three subsequent sampling rounds, in which copper concentrations ranged from 0.64 to 4.27 µg/L in November 2019, from 0.57 to 3.02 µg/L in July 2020, and from 0.61 to 6.68 µg/L in December

2020. These values remained below the maximum level established by the CAPRE standard for copper, which is 2.0 mg/L, equivalent to 2000 µg/L. Some values exceeded the laboratory detection limit of 0.69 µg/L (table 4).

Tabla 4.
Copper concentrations in samples collected in 2019 and 2020

Wells	2019		2020	
	April (µg/L)	November (µg/L)	July (µg/L)	December (µg/L)
El Campo	0.27	1.23	3.02	0.61
Agua Fría	0.04	0.64	1.41	1.48
Nance Dulce	-0.26	1.16	1.57	1.42
El Delirio	0.15	3.38	0.73	6.68
Aguas Arriba	0.99	4.27	1.04	1.07
El Pilón	0.25	2.46	0.57	1.15

Source: own elaboration.

The results obtained for silver in 2019 ranged from -0.01 to 0.07 µg/L. A similar trend was observed in the three subsequent sampling rounds, in which silver concentrations ranged from 0.05 to 0.29 µg/L in November 2019, from 0.00 to 0.07 µg/L in July 2020, and from -0.07 to -0.89 µg/L in December 2020 (table 5). Overall, all wells under study showed low silver concentrations. The CAPRE standard does not establish maximum permissible levels for silver in drinking water. In the sampling conducted between July and December 2020, low silver concentrations were observed in all wells. Some values were above the laboratory detection limit of 0.68 µg/L.

Tabla 5.
Silver concentrations in sampling conducted in 2019 and 2020

Wells	2019		2020	
	April (µg/L)	November (µg/L)	July (µg/L)	December (µg/L)
El Campo	0.07	0.15	0.00	-0.89
Agua Fría	0.03	0.28	0.07	-0.89
Nance Dulce	0.07	0.05	0.06	-0.07

El Delirio	0.02	0.09	0.02	-0.14
Aguas Arriba	0.03	0.13	0.02	-0.18
El Pilón	-0.01	0.29	0.06	-0.11

Source: own elaboration.

The results for cadmium obtained in April 2019 ranged from 0.00 to 0.03 µg/L, and none of the wells exceeded the MPVs established by the CAPRE standard. A similar pattern was observed in the three subsequent sampling rounds, in which cadmium concentrations ranged from 0.02 to 0.07 µg/L in November 2019, from 0.01 to 0.06 µg/L in July 2020, and from 0.01 to 0.6 µg/L in December 2020. Overall, all wells under study showed low cadmium concentrations and did not exceed the maximum level established by the CAPRE standard, which is 0.05 mg/L, equivalent to 50.0 µg/L. Likewise, the concentrations did not exceed the method detection limit of 0.10 µg/L (table 6).

Tabla 6. *Cadmium concentrations in samples collected in 2019 and 2020*

Wells	2019		2020	
	April (µg/L)	November (µg/L)	July (µg/L)	December (µg/L)
El Campo	0.02	0.02	0.03	0.03
Agua Fría	0.03	0.07	0.01	0.01
Nance Dulce	0.00	0.03	0.03	0.03
El Delirio	0.01	0.04	0.02	0.02
Aguas Arriba	0.02	0.05	0.06	0.06
El Pilón	0.01	0.05	0.02	0.02

Source: own elaboration.

Consequently, in July 2020, cadmium concentrations in the wells ranged from 0.01 to 0.06 µg/L and did not exceed the MPVs established by the CAPRE standard. A similar pattern was observed in the subsequent sampling round, in which cadmium concentrations ranged from 0.02 to 0.06 µg/L (table 6). Overall, all wells showed low cadmium concentrations and remained below the maximum level established by the CAPRE standard, which is 0.05 mg/L, equivalent to 50.0 µg/L.

Discussion

Although most of the analyzed metals (Hg, Cu, Ag, and Cd) comply with the current regulations for water intended for human consumption, the presence of arsenic at concentrations above the permissible limit in the El Delirio and El Pilón wells represents a critical condition. From a public

health perspective, excess arsenic classifies the water quality of these two wells as poor, since arsenic is a priority contaminant with cumulative effects and high toxicity.

The obtained results were compared with those reported by Ramirez-Cota et al. (2025), who conducted a comprehensive review of research on heavy metals in drinking water in northern Mexico in order to characterize exposure and estimate age-specific hazard quotient (HQ) and carcinogenic risk (CR) values for the region. A total of 316 heavy metal concentrations were reported across 55 studies published between 1975 and 2021, with concentration ranges of 0–11.100, 0–5.250, 0–350, 0–25, and 0–9.470 µg/L for arsenic, cadmium, chromium, mercury, and lead, respectively. The maximum likely concentrations (95th percentile) in drinking water were 244.55, 10, 56, 1.68, and 90.35 µg/L for arsenic, cadmium, chromium, mercury, and lead, respectively. The HQ values for all heavy metals ranged from 0.0011 to 404.62. Children under two years of age showed an extremely high risk (HQ > 40) of adverse health effects associated with arsenic consumption.

On the other hand, Kshipra et al. (2024) reported that arsenic levels in Ropar and Anandpur Sahib (India) were 0.09 and 0.068 mg/L, respectively, whereas cadmium levels were highest in Nurpur Bedi (0.041 mg/L). The risk index for adults was also highest in Nurpur Bedi (2.66). In addition, the lifetime incremental cancer risk (ILCR) values indicated a high risk of cancer associated with arsenic, chromium, and lead in all evaluated blocks.

At the national level, Altamirano and Delgado (2020) reported arsenic concentrations ranging from 2 $\mu g \cdot l^{-1}$ at the homes of Rafaela Rojas and Porfirio Reyes, to 103 $\mu g \cdot l^{-1}$ at the Aguas Calientes spring (La Chistatosa). 70 % of the analyzed samples (24 sources) exceeded the national limit of 10 µg $As \cdot l^{-1}$ established for water intended for human consumption. The sites with the highest temperatures (35.6–45.8 ° C) also showed the highest arsenic concentrations (38–103 µg l^{-1}), higher electrical conductivity values (983–1140 $\mu S \cdot cm^{-1}$), and lower pH values (5.80–7.08).

Consequently, water from El Delirio and El Pilón wells is not suitable for human consumption without specific pretreatment for arsenic removal, since prolonged ingestion may lead to chronic health effects in the population. This finding reinforces the need to implement surveillance measures, continuous monitoring, water treatment strategies, and stricter control of mining and agricultural activities in the area in order to protect both water resources and the health of the inhabitants of Santa Rosa del Peñón.

The primary route of exposure of the population to the identified heavy metals is the direct ingestion of groundwater used for human consumption. In this context, the presence of heavy metals at elevated concentrations, particularly arsenic, represents a significant risk to public health, as chronic exposure has been associated with kidney disease, neurological disorders, skin conditions, cardiovascular disorders, and developmental abnormalities in children.

According to national regulations issued by CAPRE and the Nicaraguan Ministry of Health (MINSA), as well as guidelines established by the World Health Organization, arsenic (As) is classified as a highly toxic and carcinogenic metalloid, with a very low permissible limit due to its

cumulative effects on the human body. Prolonged exposure may cause skin lesions, liver damage, nervous system disorders, cardiovascular diseases, and cancer. For this reason, its concentration in drinking water is strictly regulated in Nicaragua by the National Water Authority (ANA).

The results obtained, which showed elevated arsenic levels in the El Delirio and El Pilón wells, do not allow for the definitive identification of a single contamination source. However, it may be inferred that its presence is associated with both natural and geological processes in the area, where volcanic and mineralized formations predominate, as well as with anthropogenic activities, mainly artisanal and industrial mining, the use of agricultural fertilizers and pesticides, and the inadequate waste disposal. These activities constitute potential sources of heavy metal release into aquifers. In the other wells evaluated, as well as for mercury, copper, silver, and cadmium, no direct risks to human health were identified, since their concentrations remained below the regulatory limits.

Conclusions

The presence of heavy metals such as arsenic (As), mercury (Hg), copper (Cu), silver (Ag), and cadmium (Cd) in the wells of the community Santa Rosa del Peñón was detected at varying concentrations and appears to be closely associated with the natural characteristics of the ecosystem, the volcanic geological context of the region, and the influence of human activities, particularly the mining activities historically carried out in the municipality.

The excess arsenic detected in the El Delirio and El Pilón wells exceeded the permissible limits established by the standard, confirming a critical contamination condition that directly compromises the potability of the water at these sites and indicates a significant environmental and health risk for the exposed population. The spatial and temporal variability of heavy metal concentrations reflects the combined influence of hydrogeological, climatic, and land-use factors. The seasonal dynamics of aquifer recharge, the permeability of volcanic soils, and the geological fractures characteristic of the local ecosystem favor the natural mobilization of trace elements, particularly arsenic, from geological formations into groundwater.

The results suggest that the presence of heavy metals in the wells is not attributable to a single source of contamination, but rather to the interaction between natural geochemical release processes and anthropogenic sources, especially artisanal and industrial mining, the historical use of agrochemicals in agriculture, and the absence of adequate systems to protect the wells from contaminated runoff.

Recommendations

It is recommended that a permanent groundwater quality monitoring program be implemented, including periodic analyses of heavy metals, as well as physicochemical and microbiological parameters, in order to assess trends, identify increases in contamination, and activate early prevention measures, given the high hydrogeological vulnerability of the local ecosystem.

The application of remediation technologies appropriate to the rural context is also recommended, such as activated carbon filtration systems, ion exchange resins, iron oxide adsorption, and biosorbent filters, especially in wells with elevated arsenic levels, in order to reduce the population's direct exposure to heavy metals.

It is essential to strengthen the enforcement of current environmental and health regulations by requiring mining companies to conduct regular hydrochemical monitoring, properly manage environmental liabilities, and strictly comply with environmental management plans, in view of the fragility of the dry corridor ecosystem.

It is recommended that environmental education and community awareness programs be developed and implemented in order to inform the population about the health risks associated with the consumption of water contaminated with heavy metals, proper well management, and safe alternatives for water supply.

It is further recommended that alternative sources of drinking water supply be evaluated, such as rainwater harvesting and storage, the drilling of new wells in hydrogeological safer areas, and the implementation of community water treatment systems, as a response to the ecosystem's limited water availability.

More in-depth hydrogeological studies are also recommended in order to achieve a more precise understanding of aquifer dynamics, recharge zones, groundwater flow, and the mobility of heavy metals in relation to local geology and mining activity.

It is recommended that wells classified as having poor water quality be temporarily closed for human consumption until appropriate treatment systems are implemented and their recovery is confirmed through further testing.

Finally, it is recommended that scientific research on the interaction between mining, the ecosystem, and groundwater resources in Santa Rosa del Peñón continue, as a basis for technical decision-making aimed at ensuring environmental protection, public health, and the sustainable development of the community.

Referencias

Altamirano, M., & Delgado, V. (2020). Contaminación natural por arsénico en las aguas subterráneas de la comunidad rural "La Fuente", para sugerir y promover el uso de fuentes alternativas de agua segura municipio La Paz Centro, León, Nicaragua. León.

CAPRE. (1994). Norma regional de calidad del agua para consumo humano. Comité Coordinador Regional de Instituciones de Agua Potable. San José, Costa Rica.

Kshipra, K., Shakti, K., Shakti, K. V., Obaidullah, A., & Yadav, K. K. (2024). Evaluación del riesgo para la salud de los metales pesados en las aguas subterráneas: evaluación carcinogénica y no carcinogénica. India.

Ramirez-Cota, M., Escobar-Sanchez, O., Betancourt-Lozano, M., Frías-Espericueta, M. G., Zamora Arellano, N. Y., & Osuna Martínez, C. C. (2025). Metales pesados en fuentes de agua potable en el norte de México: una revisión de las concentraciones y evaluación de riesgos para la salud humana. Mexico.

Cómo citar este artículo

Vásquez, E. S. (2026). Assessment of heavy metal presence and concentration metals arsenic, mercury, copper, silver and cadmium in well water in the community of Santa Rosa del Peñón, León, Nicaragua. *Citas 12* (2), 103-114.

https://doi.org/10.15332/24224529.11654