ISUB ARTÍCULO DE INVESTIGACIÓN

REVISTA DE INVESTIGACIÓN EN SALUD. UNIVERSIDAD DE BOYACÁ
2022;9 (2):44-61. doi: https://doi.org/10.24267/23897325.825

Physical-Chemical and Microbiological Characterization of the Water in a Municipality of the Department of Boyacá-Colombia

Liliana Dorado-González[1], Mery Dueñas-Celis[1], Sandra Helena Suescún-Carrero[1]

ABSTRACT

Introduction: Having easy access to water that is safe to drink is fundamental for public health, whether it is used for drinking, domestic use, food production, or recreational purposes. Contaminated water and poor sanitation are linked to disease transmission.

Objective: To evaluate the physical-chemical and microbiological characteristics of the distribution network of the urban aqueduct of a municipality of Boyacá.

Materials and methods: Cross-sectional descriptive quantitative study. Water samples were taken at thirteen points; seven points agreed and materialized from the distribution network, one from the water intake of the plant, two from wells, and three from springs, which supply the population. Physical-chemical and microbiological analyzes were conducted.

Results: The untreated samples showed high levels of cobalt and platinum units and turbidity. The free residual chlorine in two treated water samples was below the established limits. Heterotrophic and Coliform microorganisms were detected in water samples obtained from supply sources. *Giardia* cysts and *Cryptosporidium* oocysts were found in two of the points. Of the thirteen samples studied, three showed a Risk Index due to unsanitary water quality.

Conclusions: It is clear that the water is at a risk level that is unfeasibly sanitary, which proves that the treatment system is not sufficient to ensure a water supply that is suitable for human consumption.

Keywords: water quality; water quality control; coliforms; *Giardia*; *Cryptosporidium*.

[1] Grupo de Investigación del Laboratorio de Salud Pública de Boyacá, Secretaría de Salud de Boyacá (Tunja, Colombia).

Correspondence Author: Sandra Helena Suescún Carrero. E-mail: sandrahsc@yahoo.com

Cite the article as follows:

Dorado-González L, Dueñas-Celis M, Suescún-Carrero SH. Physical-Chemical and Microbiological Characterization of the Water in a Municipality of the Department of Boyacá-Colombia. Rev Investig Salud Univ Boyacá. 2022;9(2): 44-61. https://doi.org/10.24267/23897325.825

Fecha de recibido: 26/05/2022 **Fecha de aceptación:** 04/11/2022

Caracterización físico-química y microbiológica del agua de un municipio del departamento de Boyacá (Colombia)

RESUMEN

Introducción: El agua salubre y fácilmente accesible es importante para la salud pública, si se utiliza para beber, uso doméstico, producir alimentos o fines recreativos. El agua contaminada y el saneamiento deficiente están relacionados con la transmisión de enfermedades.

Objetivo: Evaluar las características físico-químicas y microbiológicas de la red de distribución del acueducto urbano de un municipio de Boyacá.

Materiales y métodos: Estudio cuantitativo descriptivo transversal. Se tomaron muestras de agua en 13 puntos, 7 concertados y materializados de la red de distribución, uno en la bocatoma de entrada de la planta, dos pozos y tres nacimientos, de donde se abastece la población. Se realizaron análisis físicos, químicos y microbiológicos de cada una de las muestras.

Resultados: En las muestras sin tratamiento hubo concentraciones altas de unidades platino, cobalto y turbiedad. El cloro residual libre en dos muestras de agua tratada estaba por debajo de los límites establecidos. Se detectaron microorganismos heterótrofos y coliformes en las muestras de agua obtenidas de fuentes de abastecimiento. En dos puntos se encontraron quistes de *Giardia* y ooquistes de *Cryptosporidium*. De las 13 muestras estudiadas, tres arrojaron un índice de riesgo por calidad del agua inviable sanitariamente.

Conclusiones: Se evidenció que el agua se encuentra en un nivel de riesgo inviable sanitariamente, lo cual demuestra que el sistema de tratamiento es insuficiente para garantizar el suministro de agua apta para el consumo humano.

Palabras clave: calidad del agua; control de calidad del agua; coliformes; *Giardia*; *Cryptosporidium.*

Caracterização físico-química e microbiológica da água de um município do departamento de Boyacá (Colômbia)

RESUMO

Introdução: Água segura e de fácil acesso é importante para a saúde pública, seja ela usada para beber, uso doméstico, produção de alimentos ou para fins recreativos. A água contaminada e o saneamento precário estão ligados à transmissão de doenças.

Objetivos: Avaliar as características físico-químicas e microbiológicas da rede de distribuição do aqueduto urbano de um município de Boyacá.

Materiais e métodos: Estudo quantitativo descritivo transversal. Foram coletadas amostras de água em 13 pontos, 7 concertados e materializados da rede de distribuição, um na entrada da planta, dois poços e três nascentes, dos quais a população é abastecida. Foram realizadas analises físicas, químicas e microbiológicas em cada uma das amostras.

Resultados: Nas amostras não tratadas havia concentrações altas de unidades platina, cobalto e turbidez. O cloro residual livre em duas amostras de água tratada estava abaixo dos limites estabelecidos. Microrganismos heterótrofos e coliformes foram detectados em amostras de água obtidas de fontes de abastecimento. Os cistos de *Giardia* e os oocistos de *Cryptosporidium* foram encontrados em dois pontos. Das 13 amostras estudadas, três apresentaram um índice de risco para a qualidade não higiénica da água.

Conclusões: Ficou evidente que a água está em um nível de risco sanitário inviável, o que mostra que o sistema de tratamento é insuficiente para garantir o abastecimento da água adequada para o consumo humano.

Palavras-chave: Qualidade da água; controle de qualidade da água; coliformes; *Giardia; Cryptosporidium.*

INTRODUCTION

Having easy access to water that is safe to drink is fundamental for public health, whether it is used for drinking, domestic use, food production, or recreational purposes. Improving the water supply, sanitation, and water resource management is an important factor for the economic growth of countries, and it contributes significantly to reducing poverty. Contaminated water and poor sanitation are related to the transmission of diseases such as cholera, other diarrheal diseases, dysentery, hepatitis A, typhoid fever, and poliomyelitis. If there are no water and sanitation services, or if they are insufficient or poorly managed, the population will be exposed to preventable health risks. The World Health Organization estimates that about 829,000 people die each year from diarrhea caused by unsafe water, inadequate sanitation, or poor hygiene (1).

Water is an essential natural element for the development of life and human activities. The assessment of water quality can be understood as the evaluation of its chemical, physical, and biological nature in relation to its natural quality, human effects, and possible use (2).

The total demand for water in Colombia has grown rapidly in recent decades while the extraction of water for human use and consumption has increased considerably. In Colombia, 16 billion cubic meters of water are used annually by the agricultural sector; more than 20% of the water in the country's departments is used for agricultural purposes; and other fields with high demand for water are: electricity, livestock, and domestic use (3).

Some studies in different municipalities of Colombia have assessed their water quality, such as in Bogotá and Soacha, where conductivity, color, and nitrates had permissible values; pH and turbidity had a slight trend towards high concentrations, and there were low amounts of residual chlorine. In addition, the risk level was medium in 11.5% of the households, low in 61.5% of them, and there was no risk in 27% (4).

Another study carried out in two municipalities of the department of Cesar analyzed the microbiological and physical-chemical properties of the water. *Pseudomonas aeruginosa* was found in 84.94%, *Giardia spp*. in 46.1%, and *Cryptosporidium spp*. in 22.18%. As for the physical-chemical results, they showed that only 4.3% of the sampled tanks contained water that was suitable for irrigation without posing any health risks (5). In the municipality of Puente Nacional (department of Santander), water quality was determined through a physical-chemical analysis that reported high quantity of iron and inadequate turbidity levels, which could affect the taste and appearance of the water. The total coliform count was higher than 300 colony-forming units per 100 ml, with the identification of *Escherichia coli, Klebsiella oxytoca, Pseudomonas aeruginosa,* and *Enterococcus,* which indicates that the water is not suitable for human consumption (6).

In Colombia, health authorities monitored water quality in 29 departments and in Bogotá city. However, there were no reports on water quality in the departments of Amazonas, Guaviare, and Chocó due to political-administrative and telecommunications difficulties in these regions.

Based on the Water Quality Risk Index (*IRCA in Spanish*), the result of the water quality monitoring in 2015 showed that 10%, which corresponds to three departments (Quindío, Arauca, and San Andrés and Providencia), is classified as having no risk, with a range of 0.0-5.0.

26.6% of Colombia's regions, including seven departments and Bogotá D.C. (Antioquia, Atlántico, Cesar, Córdoba, Cundinamarca, Risaralda, and Santander), is classified as low-risk, which corresponds to a range of 5.1 to 14.0.

46.7% of the country's regions, which corresponds to 14 departments (Bolívar, Boyacá, Caquetá, Cauca, Casanare, Guainía, Guajira, Magdalena, Meta, Norte de Santander, Sucre, Vaupés, Valle del Cauca, and Vichada), fall under the medium-risk category (14.1-35.0).

Lastly, 16.7%, which corresponds to five departments (Caldas, Huila, Nariño, Tolima, and Putumayo), is classified as high-risk (35.1-80.0) (7).

The Ministry of Health and Social Protection, the Ministry of Housing, and the Ministry of Environment and Sustainable Development have issued regulations that define the responsibilities of different actors to carry out water quality monitoring activities through systematic and permanent processes of data collection, organization, analysis, interpretation, updating, and dissemination of specific health-related data and its determinants in order to use them in planning, implementing, and evaluating public health practices. In Boyacá, the government has implemented inspection, surveillance, and monitoring actions based on the competencies granted by Law 715 of 2001 (8) to ensure the quality of water for human consumption.

According to the different municipal categories, health authorities are assigned responsibilities by surveillance levels, as described in Decree 1575 of 2007 (9) and Resolution 2115 of that same year (10), which regulate the permissible levels of organoleptic, physical, chemical, and microbiological characteristics of water for human consumption.

The Public Health Laboratory of the Department of Boyacá (*Laboratorio Departamental de Salud Pública de Boyacá - LDSP*) supports surveillance by conducting organoleptic, physical, chemical, and microbiological analyses of water samples taken from the distribution networks of water service providers (EPSA), complying with Resolution 811 of 2008 (11), to ensure the quality and reliability of the results. These analyses are carried out according to the standards and guidelines established by the Colombian National Institute of Health, which serves as a reference for the laboratory network for water quality control and surveillance. Health authorities must ensure compliance with the regulatory requirements. Therefore, it is important to join efforts and establish strategies to implement actions that allow the population to have good quality water. In light of the above, the purpose of this study was to evaluate the physical-chemical and microbiological characteristics of the urban water distribution network in a municipality of Boyacá.

MATERIALS & METHODS

Type and Field of Study

This was a cross-sectional quantitative-descriptive study. Water samples were taken from thirteen points in a municipality of Boyacá. Seven of the points corresponded to eight of the representative points of the entire distribution network agreed upon and materialized by the EPSA network, and they comply with what was established for routine surveillance of water quality. According to Resolution 811 of 2008 (11), it was not possible to take a sample at one of the points. Supply sources were included: the water inlet of the treatment plant, three springs, and two wells (a deep well of the southern treatment plant and its outlet), which supply the population due to the scarcity of water sources in the municipality. (Table 1).

Table 1. Samplings points and analyses with their corresponding coordinates

Sample	Sampling Site	Coordinates
1.	Water inlet at the entrance of the water treatment plant of the municipality being studied. Untreated water	N 5º37'26,5" W 73º47'60,9"
2.	Final point (code 0001 located at calle 7 # 12-43). Treated water	N 5º36'87" W 73º49'44"
3.	Mid-point (code 0002 located at calle 2 # 9-39 in front of house B27). Treated water	N 5º36'54" W 73º49'52"
4.	Final point (code 0003 located at carrera 9 # 4-65). Treated water	N 5º36'28" W 73º49'80"
5.	Initial point (code 0005 located at calle 21 # 4-48). Treated water	N 5º36'93" W 73º48'66"
6.	Final point (code 0006 located at carrera 7 # 30-39). Treated water	N 5º36'47" W 73º48'44"
7.	Mid-point (code 0007 located at carrera 13 # 18-60). Treated water	N 5º37'03" W 73º49'30"
8.	Final point (code 0008 located at carrera 21 # 30-39). Treated water	N 5º36'54" W 73º49'52"

Sample	Sampling Site	Coordinates
9.	Spring Pilitas. Untreated water	N 5º37'22,3" W 73º48'44,8"
10.	Spring Veranitas. Untreated water	N 5º36'23,2" W 73º48'19,7"
11.	Deep well # 3 sur. Untreated water	N 5º36'16,4" W 73º49'55,1"
12.	Outlet of Deep well # 3 sur. Untreated water	N 5º36'16,4" W 73º49'55,1"
13.	Carrera 10 vía Caldas. Untreated water	N 5º36'29,6" W 73º50'06,9"

Sample Collection

Sample collection was carried out by environmental sanitation technicians, in accordance with the technical guidelines of the LDSP (12).

Sample processing

Residual free chlorine, pH, and conductivity parameters were determined on the field. The samples were transported to the LDSP for the corresponding analysis, and the custody chain was guaranteed. Physical (color, turbidity, pH, and conductivity) and chemical (total alkalinity, aluminum, calcium, chlorides, residual free chlorine, copper, total hardness, fluorides, phosphates, total iron, magnesium, nitrites, and sulfates) analyses were performed using nephelometric, spectrophotometric, potentiometric, and gravimetric techniques. Bacteriological analyses (heterotrophs, total coliforms, and *Escherichia coli*) were also made using the defined substrate technique described in the *Standard Methods for the Examination of Water and Wastewater*; heterotrophic microorganism counts were made using the 9215B technique of the *Standard Methods* (13) in all the sites analyzed, and parasitological analyses (*Giardia* and *Cryptosporidium*) were made in two points using method 1623.1 of the Environmental Protection Agency: one at the water inlet and one in the distribution network (14).

Statistical analysis

The data obtained from the analytical tests of each of the samples were tabulated in the Microsoft Excel® software, recorded in the Information System of Water Quality Surveillance for Human Consumption, and Water Quality Risk Index calculation was made to determine the risk at each of the points studied.

Ethical considerations

According to Resolution 8430 of 1993 issued by the Colombian Ministry of Health and Social Protection, this research is classified as minimal risk. Samples and data collection complied with the ethical standards to guarantee confidentiality.

Table 2. Microbiological analysis of the samples studied

Parameters	Heterotrophs (CFU/ml)	Total coliforms (MPN/100 ml)	Escherichia coli (NMP/100 ml)	Giardia (cysts/l)	Cryptosporidium (oocysts/l)
1	11300	2420	66	12,4	8,7
2	<10	0	0	ND	ND
3	<10	0	0	ND	ND
4	<10	0	0	ND	ND
5	<10	0	0	ND	ND
6	<10	0	0	ND	ND
7	<10	0	0	196,4	25,2
8	<10	0	0	ND	ND
9	350	27	0	ND	ND
10	4290	2420	435	ND	ND
11	4380	2420	0	ND	ND
12	<10	0	0	ND	ND
13	<10	2420	1414	ND	ND
Accepted values	<100	0	0	0	0

CFU: Colony Forming Units; MPN: most probable number; ND: no data.

RESULTS

According to Table 2, no heterotrophic microorganisms, total coliforms, or *E. coli* were found in the microbiological analysis of samples from the agreed and materialized points that correspond to the distribution network and the outlet of deep well 3. Heterotrophic microorganisms and total coliforms were detected in samples taken from supply sources. *E. coli* was found in three of the five sampled sources, indicating fecal contamination.

Parasites were found at the two points where *Giardia* cysts and *Cryptosporidium* oocysts were detected. Lower counts were found at the water inlet than in point 3 of the distribution network (Table 2).

The physical parameters analyzed showed that, for apparent color, untreated samples presented high platinum-cobalt units (PCU), as well as for the turbidity parameter considering the permissible limits in the regulation. As for the pH parameter, the sample from the intake was the only one that had units below the standard established. The conductivity parameter was within the permissible limits in all the samples, (Table 3).

Table 3. Physical analysis of the samples studied

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	Accepted values
Apparent color (PCU)	500,0	45	40,0	40,0	30,0	30,0	30,0	15,0	5,0	5,0	200,0	10,0	30,0	≤15
Turbidity (NTU)	102,6	6,08	0,02	0,03	0,02	0,02	0,02	1,87	0,02	0,02	357,8	0,40	13,72	≤2,0
pH (units)	5,21	8,2	7,34	7,67	6,57	6,55	6,60	7,0	7,63	6,66	7,62	7,99	7,4	≥6,5 and ≤9,0
Conductivity (µS/cm)	419	772	771	750	731	726	728	759	640	99,1	541	554	381	≤ 1000

1: Water inlet; 2: final point (code 0001); 3: mid-point (code 0002); 4: final point (code 0003); 5: initial point (code 0005); 6: final point (code 0006); 7: mid-point (code 0007); 8: final point (code 0008); 9: spring pila 3 de Julio; 10: spring Veranitas; 11: deep well 3 south; 12: outlet of deep well 3 south; 13: carrera 10 vía Caldas.

PCU: platinum-cobalt units; NTU: nephelometrics turbidity units

Table 4. Chemical analysis of the samples studied

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	Accepted values
Residual free chlorine (mg of Cl_2/l)	0,0	0,2	1,0	0,2	1,5	1,2	1,0	0,6	0,0	0,0	0,0	0,2	0,0	≥0,3 and ≤2,0
Total alkalinity (mg of $CaCO_3$/l)	4,27	218,7	54,17	44,18	237,04	236,59	241,49	19,73	247,61	4,86	257,39	213,38	ND	≤200
Calcium (mg OF Ca/l)	58,4	44,9	36,6	40,2	34,6	34,3	37,0	61,4	112,5	12,2	67,8	45,1	88,6	≤60
Phosphates(mg of PO_4/l)	0,31	0,016	0,003	0,012	0,007	0,012	0,013	0,006	0,292	0,084	1,155	0,038	0,179	≤0,5
Magnesium (mg of Mg/l)	7,4	20,4	13,6	7,3	11,4	11,7	13,2	1,0	3,5	10,8	13,7	11,5	ND	≤36
Total hardness (mg of $CaCO_3$/l)	176,4	196,0	147,0	130,6	133,4	133,6	146,6	157,4	295,0	75,0	225,4	160	ND	≤300

Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	Accepted values
Sulphates(mg of SO_4/l)	5,0	SD	192,8	57,1	176,3	186,5	178,7	192,5	190,5	103,2	46,8	41	ND	≤250
Total iron (mg of Fe/l)	0,717	0,024	0,019	0,022	0,008	0,015	0,010	0,013	0,02	0,020	0,750	0,275	1,335	≤0,3
Chlorides (mg of Cl^-/l)	36,8	75,4	64,7	13,7	71,2	70,9	71,4	58,1	65,6	44,3	24,5	64,3	15,2	≤250
Nitrites (mg of NO_3/l)	0,542	0,202	0,077	0,05	0,037	0,038	0,041	0,032	0,027	0,034	0,531	0,112	ND	≤0,1
Aluminum (mg of Al^3/L)	0,200	2,02	0,088	0,07	0,116	0,086	0,194	0,198	0,003	0,116	0,006	0,039	ND	≤0,2
Fluorides (mg of F^-/l)	0,36	0,51	0,17	0,11	0,33	0,37	0,35	0,45	0,27	0,31	0,34	0,21	0,07	≤1
Copper (mg/l Cu)	0,92	0,04	0,03	0,20	0,07	0,04	0,05	0,05	0,55	0,04	3,2	0,03	0,03	≤1,0

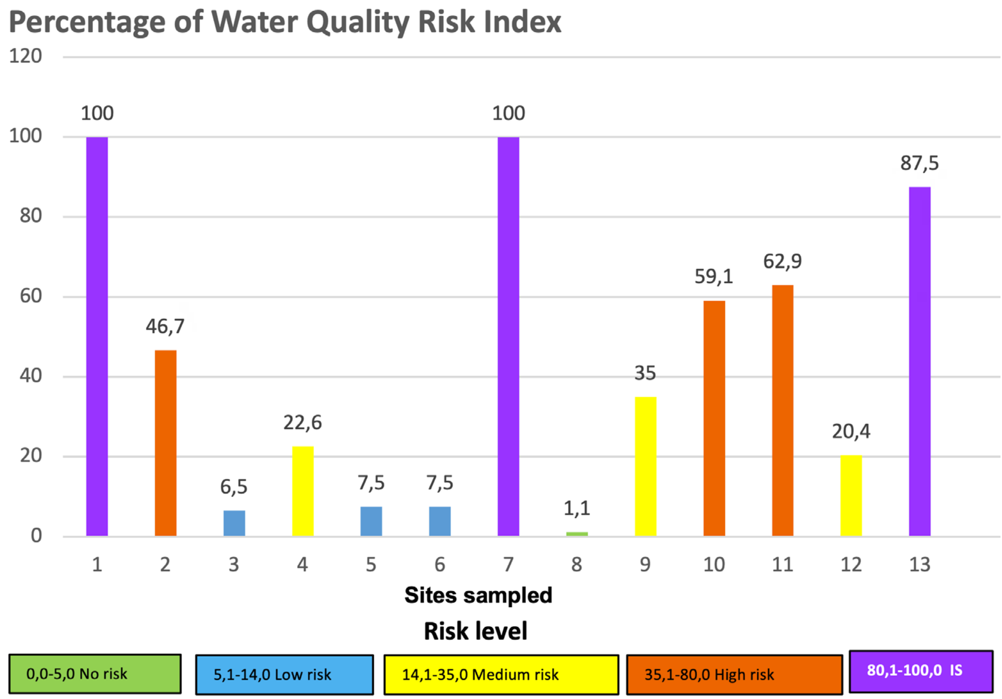
1: Water inlet; 2: final point (code 0001); 3: mid-point (code 0002); 4: final point (code 0003); 5: initial point (code 0005); 6: final point (code 0006); 7: mid-point (code 0007); 8: final point (code 0008); 9: spring pila 3 de Julio; 10: spring Veranitas; 11: deep well 3 south; 12: outlet of deep well 3 south; 13: carrera 10 vía Caldas.

ND: no data.

Table 4 shows that of the 13 chemical parameters analyzed, 5 (aluminum, chlorides, fluorides, magnesium, and sulfates) are within the permitted limits of the regulation, both in treated and untreated samples. The residual free chlorine in two treated water samples was below the established limits.

Of the 13 samples studied, 3 had an unviable sanitary Water Quality Risk Index; 2 due to evidence of contamination with *Giardia* cysts and *Cryptosporidium* oocysts, and the other due to several physical-chemical parameters that exceeded the permissible limits in the regulation. Of the samples, 12 represent some risk to health by showing physical, chemical, or bacteriological parameters that do not comply with the allowed values for human consumption water, and one sample did not show any risk (Figure 1).

Figure 1. Distribution of the Water Quality Risk Index values (IRCA) of the samples studied



DISCUSSION

According to the results obtained, concentrations of free residual chlorine that comply with permissible limits as per the standard (0.3 to 2 mg/l) were found in treated water samples. This correlates with the results obtained in the analysis for the detection of heterotrophic microorganisms, total coliforms, and *E. coli*, where none were detected due to the effective disinfection action of chlorine during the treatment process.

However, the *Giardia* and *Cryptosporidium* analysis showed counts of cysts and oocysts of these parasites in treated waters, as they are resistant to the disinfection process with chlorine. This coincides with studies conducted in Venezuela, where the presence of *Cryptosporidium* and *Giardia* was identified in human consumption waters before and after treatment (15). In Sao Paulo (Brazil), *Giardia* was reported in 46% of samples of water for human consumption, and *Cryptosporidium* in 7% (16). The above is consistent with what is reported in the literature regarding the viability of *Cryptosporidium spp*. oocysts in water for 140 days and their resistance to most common disinfectants, which makes their destruction difficult, or even impossible, by normal water chlorination (17).

Water for human consumption has a very special connotation, especially considering that it is the basis of life itself. Therefore, some related factors, such as the presence of calcium, magnesium, pH, and conductivity, indicate the water quality parameters (18). Within the physical parameters analyzed in this study, samples from Rio Suárez and deep wells, which supply the community, had high color quantities (500 PCU) and turbidity (357.8 UNT). These results reveal the organic load, which significantly influences water treatment efficiency, mainly in chlorination (19). On the other hand, the suspended solids parameter was very high, indicating the high impact of economic activities in the region, such as mining, dairy farms, tanneries, among others (20), on water quality.

The leachates that arrive through runoff to Rio Suárez raise the iron concentrations and affect the water source's color, causing a brick-red color at a glance. Therefore, large amounts of coagulant (such as sulfate or aluminum polymers) are necessary in water treatment, as well as an alkalinizing agent (such as sodium hydroxide), to produce the oxidation reaction that allows iron precipitation and its removal from the water. For this reason, iron concentrations in the network are within acceptable values according to the standard; and even though the color in most network samples is outside the norm (greater than 15 PCU), there is effectiveness in removing the organic matter, going from concentrations of 500 PCU to 40 and 30 PCU. However, the use of aluminum salts increases aluminum concentrations, as evidenced at the final point, with a value of 2.02 mg/l. Therefore, it is essential to consider that the ingestion of significant concentrations of aluminum can produce neurotoxic effects and it has been proposed as a risk factor for developing of Alzheimer's disease (21,22).

In this study, variations in total alkalinity values were found throughout the distribution network, which are related to the discharge of waste materials from tanneries. This activity is evidenced in the risk map of the municipality, which indicates discharges of diluted solutions of acids and bases. These results are similar to those reported in a previous study, in which variations in alkalinity values were found at different points located upstream and downstream and in the tannery zone of the Bogotá River in the municipality of Villapinzón (23).

The high amounts of calcium and magnesium in water causes the *hard water* phenomenon, as is the case with the source that supplies the aqueduct of the municipality studied. This finding has financial and indirect consequences on human health (24). For this study, all the points characterized show a concentration of calcium carbonate ($CaCO_3$) hardness within the maximum values allowed in Colombia, which are ≤300 mg/l of $CaCO_3$, and this coincides with what was reported in a study in Bogotá (25). In contrast, a study conducted in Costa Rica obtained lower hardness values, such as 95.26 mg/l of $CaCO_3$, which cite a reference value of up to 180 mg/l of $CaCO_3$ according to the country's regulations (24,26).

The concentrations of the points monitored in this study are between 75 and 295 mg/l of $CaCO_3$, which, according to the values established by the World Health Organization, classifies them as moderately hard and very hard waters (24). This can be a risk factor for the production of kidney, urethral and lower urinary tract stones (18).

A value of 3.2 mg/l of copper was found in the deep well sample, which is a chemical characteristic that has a recognized adverse effect on human health. Some of the factors that influence the presence of copper in water are hardness, water alkalinity, ionic strength, pH, and *redox* potential, due to processes such as complex formation with inorganic and organic ligands; absorption in metallic oxides, clays, and particulate organic material; and bioaccumulation and interaction between sediment and water. There are precedents reported in the literature about the possible causes of the presence of copper in drinking water, derived from corrosion/leaching reactions of pipe materials (27).

Based on the chemical analyses made to the samples from the sources that supply the municipality, it was determined that the fluorides concentrations were within the permissible limits established by current regulations (Resolution 2115 of 2007), lower than what was published in a Mexican study, where values between 0.44 and 1.28 mg/l were found - some of which exceeded the maximum permissible concentrations. Such results indicate that the population is exposed to excessive fluoride intake through drinking water, and this represents a risk to public health since the consumption of fluoride from different sources could promote the increase and appearance of new cases of dental fluorosis in the young population and skeletal fluorosis in the adult population (28).

Six samples taken from the urban distribution network points, of which bacteriological and physicochemical parameters were analyzed, presented a Water Quality Risk Index of 15.3%, placing it at medium risk. This coincides with what was reported in a study in the department of Boyacá, where the studied municipality is classified at the same risk (29). The two samples that showed the presence of *Giardia* and *Cryptosporidium* were classified as inviable risk level, considering the provisions of

Resolution 2115 of 2007. This aspect favors the appearing of acute and chronic diseases, such as parasitological pathologies, intoxications, alterations in digestive transit, among others (30). A study limitation was that it was not possible to collect the sample at one of the agreed and materialized points of the EPSA distribution network due to the lack of water at that point on the day of the site visit.

CONCLUSIONS

The evaluation of the physical-chemical and microbiological characteristics of the water in the municipality studied showed that untreated samples presented high PCU and turbidity concentrations. Free residual chlorine in two treated water samples was below established limits. Heterotrophic and coliform microorganisms were detected in the water samples obtained from supply sources. Two points analyzed showed *Giardia* cysts and *Cryptosporidium* oocysts. Out of the 13 samples studied, 3 yielded a sanitary non-viable Water Quality Risk Index, resulting in water unfit for human consumption according to Decree 1575 of 2007 and Resolution 2115 of 2007. We recommend evaluating the physical-chemical and microbiological characteristics of the water in different municipalities to determine the Water Quality Risk Index of the department.

Based on the study results, it is important to note that the current regulations imply routine surveillance with basic analyses, as well as results that demonstrate the effectiveness of the implemented system and evidence of water with a risk-free quality index. However, when evaluating this with special tests that are complementary to the routine surveillance, such as metals (copper), *Giardia*, and *Cryptosporidium*, the water is at a non-viable sanitary risk level, indicating that the treatment system is insufficient to guarantee the supply of water that is suitable for human consumption.

ACKNOWLEDGMENTS

To the environmental sanitation technicians of the Boyacá Health Secretariat for the sampling, storage, and transportation of water samples.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

FUNDING

Departmental Public Health Laboratory and Departmental Health Secretariat, Boyacá Governor´s Office.

REFERENCES

1. Organización Mundial de la Salud. Agua para consumo humano [internet]. 2022 [citado 2022 jul 23]. Disponible en: https://www.who.int/es/news-room/fact-sheets/detail/drinking-water

2. Fernández-Rodríguez M, Guardado-Lacaba RM. Evaluación del Índice de Calidad del Agua (ICAsup) en el río Cabaña, Moa-Cuba. Min Geol. 2021;37(1):105-19.

3. Ministerio de Ambiente y Desarrollo Sostenible de Colombia. Conozca cómo podría disminuir la demanda de agua en el sector agrícola [internet]. 2022 mar 14. Disponible en: https://www.minambiente.gov.co/gestion-integral-del-recurso-hidrico/conozca-como-podria-disminuir-la-demanda-de-agua-en-el-sector-agricola/

4. Silva E, Villarreal ME, Cárdenas O, Cristancho CA, Murillo C, Salgado MA, et al. Inspección preliminar de algunas características de toxicidad en el agua potable domiciliaria, Bogotá y Soacha. Biomédica 2015;35(Supl 2):152-66. https://doi.org/10.7705/biomedica.v35i0.2538

5. Vence Márquez L, Rivera González M, Osorio Bayter Y, Castillo Sarabia AB. Caracterización microbiológica y fisicoquímica de aguas subterráneas de los municipios de La Paz y San Diego, Cesar, Colombia. Rev Investig Agrar Ambient. 2012;3(2):27-35. https://doi.org/10.22490/21456453.953

6. Correales-Ramírez LC, Santamaría-Moaquera YN, Luccioli-Peña DA, Castañeda-Casas MA. Evaluación de la calidad del agua de la vereda río Suárez de Puente Nacional, Santander. NOVA. 2021;19(37):79-98. https://doi.org/10.22490/24629448.5497

7. Ministerio de Salud y Protección Social, Subdirección de Salud Ambiental. Informe nacional de calidad del agua para consumo humano (INCA) 2016 [internet]. Bogotá; 2018 may. Disponible en: https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/SNA/ssa-inca-2016.pdf

8. Ministerio de Ambiente Vivienda y Desarrollo Territorial. Ley 715. In: Congreso de Colombia. 2001. Fecha de consulta: 15 de octubre de 2021. Disponible en: http://apolo.creg.gov.co/Publicac.nsf/5a684731419aae4305256eee006e1fc8/79b997abce53413c0525785a007a72e3?OpenDocument

9. Decreto 1575/2007 del 9 de mayo, por el cual se establece el Sistema para la Protección y Control de la Calidad del Agua para Consumo

Humano [internet]. Ministerio de Ambiente Vivienda y Desarrollo Territorial. Disponible en: https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=30007

10. Resolución 2115/2007 de 22 de junio, por medio de la cual se señalan características, instrumentos básicos y frecuencias del sistema de control y vigilancia para la calidad del agua para consumo humano [internet]. Ministerio de Ambiente Vivienda y Desarrollo Territorial. Disponible en: https://scj.gov.co/sites/default/files/marco-legal/Res_2115_de_2007.pdf

11. Resolución 811/2008 de 5 de marzo, por medio de la cual se definen los lineamientos a partir de los cuales la autoridad sanitaria y las personas prestadoras, concertadamente definirán en su área de influencia los lugares y puntos de muestreo para el control y la vigilancia de la calidad del agua para consumo humano en la red de distribución [internet]. Ministerio de Ambiente Vivienda y Desarrollo Territorial. Disponible en: https://www.minvivienda.gov.co/normativa/resolucion-0811-2008

12. Instituto Nacional de Salud. Manual de instrucciones para la toma, preservación y transporte de muestras de agua de consumo humano para análisis de laboratorio [internet]; 2011. Disponible en: https://www.ins.gov.co/sivicap/Documentacin%20SIVICAP/2011%20Manual%20toma%20de%20muestras%20agua.pdf

13. Clesceri LS, Greenberg AE, Eaton AD, editores. Standard methods for the examination of water and wastewater. 20.ª ed. Washington: American Public Health Association; 2012.

14. Environmental Protection Agency (EPA). Method 1623.1: *Cryptosporidium* and *Giardia* in water filtration/IMS/FA [internet]. 2012. Disponible en: https://www.epa.gov/sites/default/files/2015-07/documents/epa-1623.pdf

15. Cermeño J, Arenas J, Yori N, Hernández I. *Cryptosporidium parvum* y *Giardia lamblia* en aguas crudas y tratadas del estado Bolívar, Venezuela. Univ Cienc Tecnol [internet]. 2008;12(46):39-42. Disponible en: http://www.scielo.org.ve/scielo.php?script=sci_arttext&pid=S1316-48212008000100006&lng=es&tlng=es

16. De Almeida Mastropaulo A, Pepe Razzolin MT. Qualidade da água de sistema alternativo coletivo de abastecimento para consumo humano: ocorrência de cistos de *Giardiae* oocistos de *Cryptosporidiumem* poços de São Paulo-SP. Rev Bras Cienc Saúde. 2018;22(3):237-46. https://doi.org/10.4034/RBCS.2018.22.03.07

17. Ríos-Tobón S, Agudelo-Cadavid RM, Gutiérrez-Builes LA. Patógenos e indicadores microbiológicos de calidad del agua para consumo humano. Rev Fac Nac Salud Pública. 2017;35(2):236-47. https://doi.org/10.17533/udea.rfnsp.v35n2a08

18. Rodríguez Zamora J. Parámetors fisicoquímicos de dureza total en calcio y magnesio, pH, conductividad y temperatura del agua potable analizados en conjunto con las Asociaciones Administradoras del Acueducto (ASADAS), de cada distrito de Grecia, cantón de Alajuela, noviembre del 2008. Rev Pensamient Actual. 2009;9(12-13):125-34.

19. Guzmán BL, Nava G, Díaz P. La calidad del agua para consumo humano y su asociación con la morbimortalidad en Colombia, 2008-2012. Biomédica. 2015;35 (supl. 2):177-90. https://doi.org/10.7705/biomedica.v35i0.2511

20. Gobernación de Boyacá, Secretaría de Salud. Mapa de riesgo de la calidad del agua para consumo humano del centro urbano del municipio de Chiquinquirá-Boyacá [internet]. 2014. Disponible en: chrome- https://www.boyaca.gov.co/secretariasalud/wp-content/uploads/sites/67/2014/07/images_Documentos_Salud_Publica_Ano_2014_MAPA-DE-RIESGO-DE-CHIQUINQUIRA.pdf

21. Rondeau V, Commenges D, Jacqmin-Gadda H, Dartigues JF. Relation between aluminium concentrations in drinking water and Alzheimer's disease: an 8-year follow-up study. Am J Epidemiol. 2000;152:59-66. https://doi.org/10.1093/aje/152.1.59

22. Freitas M, Brilhante O, Almeida LM. Importância da análise de água para a saúde pública em duas regiões do Estado do Rio de Janeiro: enfoque para coliformes fecais, nitrato e aluminio. Cad Saúde Pública. 2001;17:651-60. https://doi.org/10.1590/S0102-311X2001000300019

23. Suárez Escobar AF, García Ubaque CA, Vaca Bohórquez ML. Identificación y evaluación de la contaminación del agua por curtiembres en el municipio de Villapinzón. Tecnura. 2012;16:185-94.

24. Reyes Y, Vergara I, Torres O, Díaz M, González E. Contaminación por metales pesados: Implicaciones en salud, ambiente y seguridad alimentaria. Rev Ing Investig Desarr. 2016;16(2):66-77. https://doi.org/10.19053/1900771X.v16.n2.2016.5447

25. Fajardo Zapata A, Gaines Acuña S, Muñoz-Silva V, Otero Jiménez V, Mendoza Montaña VA. Calidad del agua y características habitacionales de un barrio en Bogotá.

NOVA. 2017;15 (27):31-6. https://doi.org/10.22490/24629448.1956

26. Mora Alvarado D, Alfaro Herrera N, Portuquez CF, Peinador Brolatto M. Cálculos en las vías urinarias y su relación con el consumo de calcio en el agua de bebida en Costa Rica. Rev Costarric Salud Pública [internet]. 2000 dic [citado 2022 abr 29];9(17):61-70. Disponible en: http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S1409-14292000000200008&lng=en

27. Sancha AM, Lira L. Presencia de cobre en aguas de consumo humano: causas, efectos y soluciones [internet]. Universidad de Chile; 2014. Disponible en: http://www.ingenieroambiental.com/4014/sancha.pdf

28. Galicia Chaón L, Molina Frechero N, Oropez Oropeza A, Gaona E, Juárez López L. Análisis de la concentración de fluoruro en agua potable de la delegación Tlahuac, Ciudad de México. Rev Int Contam Ambie. 2011;27(4):283-9.

29. Dueñas-Celis MY, Dorado-González LM, Espinosa-Macana P (q. e. p. d.), Suescún-Carrero SH. Índice de riesgo de la calidad del agua para consumo humano en zonas urbanas del departamento de Boyacá, Colombia 2004-2013. Rev Fac Nac Salud Pública. 2018;36(3):101-9. https://doi.org/10.17533/udea.rfnsp.v36n3a10

30. Rojas Rodríguez DL, Colmenares Cruz RA. Análisis de los índices de riesgo de calidad de agua potable (IRCA) en Boyacá entre 2016-2019. Agricolae Habitat. 2021;4(1):30-44. https://doi.org/10.22490/26653176.4315