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Water quality in the municipalities of Sincerín and Gambote, Bolívar, Colombia (2017-2018)

Calidad del agua de los corregimientos de Sincerín y Gambote, Bolívar, Colombia (2017-2018)

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ABSTRACT: This study evaluates the water quality for human consumption in the municipalities of Sincerín and Gambote. It was measured through physico-chemical (color, turbidity, conductivity, pH, dissolved oxygen, hardness, and heavy metals) and microbiological (total coliforms, *Escherichia coli*) parameters before and after a partial form of water treatment was used (alum and chlorine addition in Gambote and Sincerín municipalities, respectively). This investigation was done in accordance with the maximum permissible values established by the Resolution 2115 of 2007 of the Ministry of Environment, Housing, and Territorial Development of Colombia (MAVD in Spanish). Additionally, the IRCA (Water Quality Risk Index) was calculated to determine the degree of risk of disease occurrence. The results indicated concentrations higher than the recommended values for: (a) hardness (in Sincerín); (b) iron (Fe), turbidity (only before being treated), *E. coli* (in Gambote); and (c) mercury (Hg), and total coliforms. The water supplies of the municipalities presented unsafe IRCA. Therefore, it is expected that the results of this study could be used for proposing strategies for improving these conditions by means of the design and implementation of an adequate treatment system.

RESUMEN: Este estudio evaluó la calidad del agua para consumo humano en los corregimientos de Sincerín y Gambote. Algunos parámetros fisicoquímicos (color, turbidez, conductividad, pH, oxígeno disuelto, dureza y metales pesados) y microbiológicos (coliformes totales, *Escherichia coli*) fueron medidos durante las etapas de pre y post tratamiento parcial usado (alumbre y tabletas de cloro en Gambote y Sincerín, respectivamente). Esta investigación fue hecha de acuerdo con los valores máximos permisibles establecidos por la Resolución 2115 de 2007 del Ministerio de Ambiente, Vivienda y Desarrollo Territorial de Colombia. Adicionalmente, se calculó el IRCA (Índice de Riesgo de la Calidad del Agua) con el fin de determinar el grado de riesgo a la ocurrencia de enfermedades. Los resultados indicaron concentraciones por encima de las recomendables para: (a) la dureza (en Sincerín), (b) hierro (Fe), turbiedad (únicamente antes de ser tratada) y *E. coli* (en Gambote) y (c) mercurio (Hg) y los coliformes totales (en Sincerín y Gambote). Los suministros de agua de los corregimientos presentaron un IRCA inseguro. Por tanto, se espera que los resultados de este estudio puedan contribuir al mejoramiento de estas condiciones a través del diseño e implementación de un sistema de tratamiento.

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1. Introduction

Water is the essence of life; international legislation includes specific obligations to States regarding safe water supply for personal and domestic use. Nevertheless, 884 million people lack adequate sources, and 2.5 billion do not have improved sanitation services [1]. Only until the end of the 18*th* century did basic processes for water treatment begin to be developed [2].

Water for human consumption refers to that used for direct drinking, food manufacturing or preparation, personal hygiene, and cleaning of utensils [3]. Water used for this purpose can be either from surface or underground sources. When it is contaminated with pathogenic microorganisms, it can cause various pathologies such as hepatitis A, cholera, Typhoid, and paratyphoid fever, and, in a large percentage of cases, acute diarrheal diseases [4]. The pollution of the anthropic and natural origin of water sources limits their use mainly for human consumption; quick diagnostic tools and representative as water quality indices (ICA, for its acronym in Spanish) guarantee a comprehensive evaluation of the resource, essential in taking actions to manage and control the sanitary risk through the different purification processes [5, 6].

Water pollution can be found in the form of dissolved or dispersed compounds that come from different activities, such as domestic, agricultural, industrial, and soil erosion wastes. These compounds can be either inorganic (chlorides, sulfates, nitrates, among others) or organic (human, animal, slaughterhouse waste, food, and product processing natural chemicals, etc.) that consume dissolved oxygen and affect aquatic life [2]. The World Health Organization (WHO) developed a water safety plan (WSP); this relates the risk assessment and management to provide water quality from basin to consumer. It has five stages: assembling a WSP team, describing the existing DWSS, identifying hazards and dangerous events, evaluating risks, and planning risk management [7]. Cities in developing countries often suffer from poor water quality. Therefore, it is necessary to have the capacity to make decisions about the current state of urban water quality, as well as the implementation of new infrastructure [8].

In Colombia, the risk associated with the water characteristics for human consumption is evaluated through the Risk Index for Water Quality for Human Consumption (IRCA, for its acronym in Spanish), calculated as a weighted linear combination of various parameters, including total coliforms and *E. coli* [9]. This index is interpreted as the evaluation of the chemical, physical and biological nature of the water in relation to the natural quality, human effects, and possible uses. The IRCA assigns a score to the variables that do not comply with the acceptable values determined by resolution 2115 of 2007 (Colombian standard for the quality of water for human consumption) [10], which establishes the acceptable values for the quality of the water for human consumption that do not represent known health risks. This resolution also presents the characteristics, basic instruments, and frequencies of the system control and surveillance. The IRCA is one of these instruments designed to evaluate the degree of risk of the occurrence of diseases related to non-compliance with the physical, chemical, and microbiological characteristics of water for human consumption as follows: 80.1–100 % (sanitary infeasible), 35.1–80 % (high), 14.1–35 % (medium), 5.1–14 (low), and 0–5 (no risk) [7, 10–12]. Concerning the IRCA, the calculation, and reporting mechanism are constantly flawed due to the lack of stricter regulation on updating information, notifications, and improvement actions. Also influencing the non-existence of the aqueduct service in municipalities with low economic level, failure in the regular municipal conduits, and the lack of trained personnel to take samples [13]. According to the Comptroller General of the Nation's reports, the majority of Colombian municipalities do not comply with the established water quality parameters [12]. The spoilage of the water resources in Colombia is mostly attributed to industrial, domestic, and agricultural wastewater discharges and activities such as fluvial, terrestrial, and maritime transport of hazardous substances, mining extraction, and solid residue disposed of in sanitary landfills [5].

On the other hand, the Colombian Ministry of Health and Social Protection has been carrying out for several periods the national report on the quality of water for human consumption (INCA, for its acronym in Spanish); the results indicate a medium risk level (country average) for the year 2016. It is also observed that this deterioration increases as the degree of rurality is greater, in such a way that the Water Quality Risk Index (IRCA) in these areas is predominantly high and, in some cases, sanitary unfeasible [11]. For the rural area of the Department of Bolívar (political and administrative unit of the study area), an average Water Quality Risk Index of 47.4 (high-risk level) has been reported [11].

The Municipalities of Sincerín and Gambote are part of the Town of Arjona (Department of Bolívar) [14–17]. The source of supply for the town of Gambote is surface water from the *Canal del Dique*; this is a human-made canal connected to the Magdalena River, the most important in Colombia (the largest). This river presents a growing deterioration in its basin due to the socio-economic activities developed along its route. It also has a significant environmental impact on the adjacent ecosystems [18]. In the case of Sincerín town, the water source comes from a 50-m deep well. These two municipalities are mostly composed of low-income families with no access to drinking water and basic sanitation services. In these communities, a partial treatment for the purification of water has been implemented, consisting of adding (a) sodium hypochlorite (groundwater source in Sincerín) and (b) alum (surface water source in Gambote).

This study aims to assess the water quality in these two municipalities by analyzing various physical-chemical (turbidity, apparent color, electrical conductivity pH, dissolved oxygen, and total hardness) and microbiological (total coliforms, Escherichia coli) parameters: Moreover, some heavy metals (Cr, Fe, Ni, Cu, Pb, Hg) and other inorganic ions (chlorides, fluorides, sulfates, nitrates, and bromides). Samples were collected before and after the current partial form of treatment implemented to evaluate its efficacy to improve the drinking water quality delivered to these communities. In addition, the values of the water quality parameters were: (a) compared with the maximum acceptable values established by Resolution 2115 of 2007 and (b) used to calculate the IRCA to determine the level of health risk.

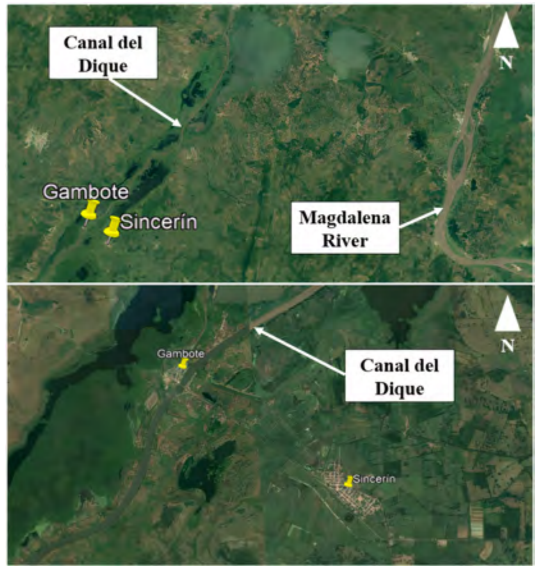

Figure 1 Geographical location of Sincerín and Gambote (*Source:* adapted from Google Earth)

2. Materials and methods

2.1 Study area

Gambote and Sincerín are located in the north of the Department of Bolívar, Colombia; they have a population of approximately 4030 (census of 2019) and 2100 (current population based on the average growth rate of the census carried out by DANE in 2005), respectively [15–17].

Figure 1 depicts the geographical location of Sincerín (geographic coordinates of 10° 8’38.89”N; 75°16’34.64”W) and Gambote (geographical coordinates 10° 9’47.63”N; 75°17’54.99”W).

Neither Sincerín nor Gambote has access to safe drinking water, despite the fact that *Aguas de Cartagena* (the company that provides drinking water to the City of Cartagena, located at nearly 36 km) has a water pumping station in Gambote. It is an important fluvial artery of the Magdalena River (that flows from south to north of Colombia), providing fresh water to Cartagena [18]. In Gambote, raw water from the *Canal del Dique* is pumped to a water storage tank and then distributed via gravity pipe without any treatment. Each family adds a random amount of alum to remove turbidity. As for Sincerín, raw groundwater is pumped to a 50-m^3 water storage tank where sodium hypochlorite (NaClO) is added (1.5 kg of NaClO at 70% is diluted into 60 L of water), and then distributed via gravity pipe.

2.2 Sampling and sample preparation

Six samples were collected for each of the municipalities: three (3) before and three (3) after the partial treatment provided at each municipality. The samples were collected in plastic bottles, glass bottles, and Ziploc® bags for physical-chemical, heavy metals, and microbiological analysis, respectively. Table 1 summarizes the information on parameters measured, preservation, and analytical methods used in this study, and Table 2 describes the type of sample, frequency, date, type of sample, and time of taking.

The raw water samples of Gambote (GAMB) were collected directly from the *Canal del Dique* (Figure 2a) before the residents added alum to it. The so-called treated water (after alum addition, GAMBT) samples were collected at a house near the *Canal del Dique* (Figure 2b). For Sincerín, the raw water samples (SINC) were collected directly from the underground water well (Figure 2c and Figure 2d) through a tube (Figure 2e). The treated water samples –after the addition of NaOCl– (SINCT) were collected from one of the taps at the aqueduct offices (Figure 2f).

2.3 Determination of IRCA

The IRCA is a drinking water quality index that ranges from zero to 100 (0–100) (Table 3). It reduces a total of 22 physical-chemical and microbiological parameters of water quality into a simple expression that can be easily interpreted and understood. Each parameter is allocated a risk score (Table 4) to those parameters that do not have the maximum permissible values established in Resolution 2115 of 2007. Suppose the chemical

Table 1 Parameters measured, methods used, and preservation of samples

Group		Parameter	Preservation	Process	Method
Physical-Chemical		Turbidity	Not required	ISO 7027	Nephelometric
		Color	Not required	GTC2-1994	Photometric
		pH	Immediate analysis	IDEAM TP 0080–2	Potenciometric
		Hardness	Not required	IDEAM TP 0341-2	Complexometric
	Heavy Metals	Mercury (Hg)	Refrigeration	ASTM D3223-12	Atomic absorption
		Cadmium (Cd)	Refrigeration	ASTM D3557-12A	Atomic absorption
		Copper (Cu)	Refrigeration	TP0096-02	Atomic absorption
		Lead (Pb)	Refrigeration	TP0096-02	Atomic absorption
		Chromium (Cr)	Refrigeration	TP0096-02	Atomic absorption
		Iron (Fe)	Refrigeration	TP0096-02	Atomic absorption
		Nickel (Ni)	Refrigeration	TP0096-02	Atomic absorption
		Electrical conductivity	Not required	TP0082	Electrochemical
		Dissolved oxygen	Immediate analysis	TP0083	Electrochemical
	Ions	Chloride (Cl^-)	Freeze	ASTM D4327	Ion chromatography
		Fluoride (F^-)	Freeze	ASTM D4327	Ion chromatography
		Sulfate (SO_4^-)	Freeze	ASTM D4327	Ion chromatography
		Nitrate (NO_3^-)	Freeze	ASTM D4327	Ion chromatography
		Bromide (Br^-)	Freeze	ASTM D4327	Ion chromatography
Microbiological		Total Coliforms	Refrigeration	TP0314–03	Membrane filtration
		E. coli	Refrigeration	TP0314–03	Membrane filtration

Table 2 Description of the samples taken in the study

Sample	Type of sample	Date	Time	Weather season
1	Punctual	August 18, 2017	9:15 am	Rainy
2	Punctual	February 14, 2018	9:15 am	Dry
3	Punctual	April 26, 2018	9:15 am	Rainy

characteristics of the substances that have a recognized adverse effect on human health exceed the maximum acceptable (articles 5 to 8); in that case, the IRCA value will be assigned the score maximum of 100 points, regardless of the other results. Likewise, if Giardia and Cryptosporidium are present [10, 19], the IRCA is calculated by Equation 1.

$$IRCA\,(\%) = \frac{\sum \text{Risk score for unacceptable parameters}}{\sum \text{Risk score for all parameters}} \times 100 \quad (1)$$

Figure 2 Sampling locations **(a)** Gambote's raw water sampling point (GAMB); **(b)** House near the Canal del Dique after alum addition (GAMBT); **(c)** Sincerín's well location; **(d)** Closeup of Sincerín's Well; **(e)** Pipeline connected to Sincerín's well where raw groundwater samples were collected (SINC); **(f)** Aqueduct offices (SINCT). Own photo

Table 3 Classification of the level of health risk according to the IRCA per sample, and actions to be taken **Source:** Resolution 2115 of 2007 [10]

Classification IRCA (%)	Level of Risk	Assessment
80.1 – 100	Sanitary Infeasible	Water not suitable for human consumption
35.1 – 80	High	Water not suitable for human consumption
14.1 – 35	Medium	Water not suitable for human consumption
5.1 – 14	Low	Water not suitable for human consumption. Susceptible to improvement
0 – 5	No-Risk	Water fit for human consumption

Table 4 IRCA's risk scores **Source:** Resolution 2115 of 2007 [10].

Parameter	Associated risk score
Apparent color	6
Turbidity	15
pH	1.5
Free residual chlorine	15
Total alkalinity	1
Calcium	1
Phosphate	1
Manganese	1
Molybdenum	1
Magnesium	1
Zinc	1
Total hardness	1
Sulphate	1
Total iron	1.5
Chloride	1
Nitrate	1
Nitrite	3
Aluminum (Al^{+3})	3
Chromium* (Cr)	100
Nickel* (Ni)	100
Copper* (Cu)	100
Cadmium* (Cd)	100
Lead* (Fe)	100
Mercury* (Hg)	100
Fluoride	1
Bromide*	100
TOC (Total Organic Content)	3
Total coliforms	15
Escherichia coli	25
Total assigned score	**100**

*These parameters do not have a risk score assigned by Resolution 2115 of 2007; for this reason, they are not taken into account in the sum of the total assigned score. The resolution determines that physical, chemical, and biological characteristics with the maximum acceptable values, the IRCA value is zero (0), and when none of them is found, the value will be one hundred points (100) [7].

3. Results and discussion

The values of the three samples of each parameter for both raw water and after the partial treatment (GAMBT and SINCT) were averaged and compared with the maximum acceptable values (MAV) established by the Resolution 2115 of 2007. This resolution does not provide specific risk level for some compounds, such as lead, chromium, mercury, and cadmium; if these exceed the MAV, the resolution establishes that they will be assigned the maximum score of 100 points, regardless of the results obtained [10]. Table 5 shows the water quality evaluation and calculation of the IRCA from Gambote and Sincerin, and Table 6 exhibits the compliance with Resolution 2115 of 2007; underlined cells in the tables indicate concentrations above the established MAV.

The measured values of electrical conductivity and dissolved oxygen were not presented in Table 5 since they are not necessary to calculate the IRCA. The results obtained for the municipality of Gambote (GAMB and GAMBT) oscillated approximately between 180 and 230

Table 5 Water quality evaluation and calculation of the IRCA

Parameter	MAV	Score level of risk	Gambote's samples						Sincerín's samples					
			GAMB			GAMBT			SINC			SINCT		
			1	2	3	1	2	3	1	2	3	1	2	3
Color (PCU)	15	6	125	100	75	NM	10	15	10	10	20	10	5	10
Turbidity (NTU)	2	15	82.9	195	49.87	NM	2.16	1.79	0.08	1.18	7.14	0.35	0.57	3.92
pH (pH units)	6.5-9.0	1.5	8.03	7.42	6.74	NM	7.58	6.55	7.96	7.31	6.84	7.99	7.43	6.83
Hardness (mg $CaCO^3$/L)	300	1	120.11	100.09	99.49	NM	110.1	99.49	360.33	220.20	316.49	360.33	310.28	298.22
Cr (mg/L)	0.050	100	0.030	0.022	0.002	NM	0.021	0.006	0.027	0.025	0.021	0.021	0.020	0.011
Fe (mg/L)	0.300	1,5	1.048	1.019	1.006	NM	0.981	0.977	0.264	0.250	0.245	0.074	0.063	0.062
Ni (mg/L)	0.020	100	ND	ND	ND	NM	ND	ND	ND	ND	ND	ND	ND	ND
Cu (mg/L)	1.000	100	0.017	0.017	0.014	NM	0.011	0.011	0.024	0.024	0.018	0.017	0.017	0.011
Cd (mg/L)	0.003	100	ND	0.001	ND	NM	0.001	ND	ND	0.002	ND	ND	ND	ND
Pb (mg/L)	0.010	100	ND	ND	ND	NM	ND	ND	ND	ND	ND	ND	ND	ND
Hg (μg/L)	0.001	100	0.035	0.030	0.032	NM	0.027	0.023	0.039	0.043	0.029	0.042	0.037	0.022
Chloride (mg/L)	250	1	2.71	2.71	2.71	N/A	3.169	3.169	29.30	29.30	29.30	16.10	16.10	16.10
Fluoride (mg/L)	1.000	1	0.08	0.08	0.08	N/A	0.06	0.06	0.29	0.29	0.29	0.44	0.44	0.44
Sulphate (mg/L)	250	1	4.15	4.15	4.15	N/A	22.52	22.52	15.69	15.69	15.69	9.82	9.82	9.82
Nitrate (mg/L)	10	1	0.62	0.62	0.62	N/A	1.09	1.09	ND	ND	ND	0.07	0.07	0.07
Bromide* (mg/L)	1.000	100	ND	ND	ND	N/A	0.166	0.166	0.085	0.085	0.085	0.054	0.054	0.054
T. Col. (CFU/100 mL)	0	15	100	26	100	NM	100	100	33	100	52	3	100	100
E. coli (CFU/100 mL)	0	25	51	3	100	NM	6	0	100	0	0	0	0	0
IRCA (%)		**$\sum$ 769**	**100**	**100**	**100**	**N/A**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
IRCA's Classification			S.I	S.I	S.I	N/A	S.I	S.I	S.I	S.I	S.I	S.I	S.I	S.I

T.Col.: Total Coliforms; ND: Not Detected; NM: Not Measured; N/A: Not applicable; S.I: Sanitary Infeasible. (*) In the legislation, there is no maximum allowable value for bromide. However, since it is a monoatomic ion and belongs to the halogens group, like fluoride, the value of 1 mg/L will be taken as a reference. Gray cells indicate values above those established by Res. 2115 of 2007.

Table 6 Compliance with Resolution 2115 of 2007

Parameter	Sample			
	GAMB	GAMBT	SINC	SINCT
	Does the parameter comply with the MAV?			
Turbidity	NO	YES	NO	YES
Color	NO	YES	YES	YES
Elec. Cond.	YES	YES	YES	YES
pH	YES	YES	YES	YES
Dissolved oxygen	YES	YES	YES	YES
Hardness	YES	YES	NO	NO
Cr	YES	YES	YES	YES
Fe	NO	NO	YES	YES
Ni	YES	YES	YES	YES
Cu	YES	YES	YES	YES
Cd	YES	YES	YES	YES
Pb	YES	YES	YES	YES
Hg	NO	NO	NO	NO
Chloride	YES	YES	YES	YES
Fluoride	YES	YES	YES	YES
Sulphate	YES	YES	YES	YES
Nitrate	YES	YES	YES	YES
Bromide	YES	YES	YES	YES
Total coliforms	NO	NO	NO	NO
E. coli	NO	NO	NO	YES

Elec. Cond.: electrical conductivity. Gray cells indicate non-compliance with Res. 2115 of 2007

μS/cm, which are below the limits established by the legislation (1000 μS/cm. As for Sincerín (SINC and SINCT), electrical conductivity values ranged between 450 and 1100 μS/cm. The value of 1100 μS/cm, which exceeded the MAV, was observed in one sample. The considerable difference in reported values of electrical conductivity from Gambote and Sincerín is attributed to the fact that groundwater typically has more dissolved ions than surface water, which can also be seen in the higher concentrations of hardness reported in groundwater (Sincerín) when compared to surface water in Gambote.

The range for hardness in Gambote and Sincerín were 99.5-120.1 and 220.2–360.3 mg/L respectively, (Table 5). In fact, five of the six samples (the value of 298.2 was assumed to be 300 mg/L) collected in Sincerín reported values of hardness above MAV (300 mg/L), which indicates that softening must be part of any treatment system to be implemented in Sincerín. Regarding reported concentrations of dissolved oxygen, the water sources of both municipalities were within the range of 6.9 and 8.3 mg/L, which classifies both sources as acceptable ($\geq$ 4 mg/L), according to MinVivienda [20, p. 64].

The GAMB (raw water) reported turbidity values, color, iron, mercury, total coliforms, and *E. coli* did not comply with their corresponding MAV (Table 5). The high values of turbidity and color are typical of surface water, such as the "*Canal del Dique*" since they are generally in contact with organic material (tannins from leaves, wood, roots, etc.), humic acids, and some industrial waste. Water quality studies carried out in some rivers in Colombia, such as Magdalena, Cauca, and Córdoba, where most of the turbidity values were above Colombian regulations, indicate that many rivers present suspended particles that reduce the transparency of the water, generated by dragging processes such as soil removal, and in other cases, by industrial and/or urban dumping [21, 22]. In addition, a climatological influence could not be detected for the turbidity parameter; however, the highest value was obtained in sampling 2 (195 NTU), which was carried out in the dry season. For this reason, the precipitation records were reviewed of the IDEAM on the sampling days: August 18, 2017, February 14, 2018 and April 26, 2018, which were 0 mm, 0 mm and 4 mm respectively, which in hydrological terms is a negligible value. Therefore, it was determined that for the samples taken in this study, there was no incidence of the climatological seasons since no rains were recorded on the sampling days or previous days.

The values reported above the limit for total coliforms and, especially, *E. coli* indicate fecal contamination, which is a danger to the inhabitants' health since they can generate diseases such as gastroenteritis, which is especially harmful to children under five years old [2, 23]. In this context, the risk is even higher given that the *Canal del*

Dique is not only used as a source of drinking water and food (fishing, irrigation, and livestock watering), but also for recreational purposes (both primary and secondary contact) by some of the locals. Similarly, high concentrations of Fe and Hg were found, which are also harmful to human health. Although iron is one of the most abundant metals on earth and is found in freshwater in concentrations of 0.5 to 50 mg/L, the intake of large amounts of iron can cause poisoning, leading to vomit and liver failure, among others [24].

In the case of mercury, the ingestion of high concentrations leads to higher risks since it tends to bioaccumulate through the food chain and can cause mutations (teratogenicity) [25]. It has been reported that up to 90% of the bioaccumulated mercury is incorporated into the digestive system through food [26]. These results are in agreement with the ones reported in several studies performed in the *Canal del Dique*, Cartagena bay, and the Magdalena river basin, where high mercury concentrations have been found not only in the water but also in the river's own fish species, such as bocachico, herring, and catfish. The origin of these metals goes from artisanal mining to tannery industries and industrial dumping [26–33]. As for the other heavy metals assessed, the values obtained did not exceed the MAV. In Table 5, it can be seen that there was no significant decrease in the concentration values, which is not surprising given that coagulation is not efficient at eliminating dissolved substances. Regarding hardness concentration, as previously discussed, reported values indicated that Gambote's water is moderately hard (between 76–100 mg $CaCO_3$/L); therefore, softening is not required [34].

In the case of GAMBT samples, as expected, the addition of a random concentration of alum decreased the measured values of turbidity and color [35]. The turbidity changed from a range of 48.9–95.0 NTU (before addition, GAMB) to 1.79–2.16 NTU and for color from 75–125 PCU to 10–15 PCU. Despite the improvement, it can be observed that a value of 2.16 NTU is not only above the established MAV of 2.0 NTU, but also higher than the typical turbidity values of 1.0 NTU (or less) reached at conventional water treatment plants [36]. Furthermore, an increase of sulfate concentrations was detected (from 4.15 mg/L to 22.52 mg/L), perhaps, due to the formation of calcium sulfate ($CaSO_4$) from the reaction of alum with the natural alkalinity [37] of the water in the *Canal del Dique*, which, in turn, implies that the dose of alum is not optimal. It was also noticed that pH values did not decrease much even though coagulants tend to lower pH as they consume alkalinity. This indicates a high buffer capacity of this water. With respect to the microbiological parameters, total coliform and *E. coli*, levels higher than those allowed by the current regulations were found, except in SINCT samples for *E. coli*.

The assessment of Gambote's water by means of the IRCA revealed that they are not suitable for human consumption, which is mainly due to the concentrations of mercury exceeding the MAV [7]. These results are in line with the IRCA value of a 100 obtained in the municipality of Mahates [38], which also uses the *Canal del Dique* as a source of drinking water. Mercury is accumulated through the Magdalena River basin upstream due to gold mining within the watershed [27, 39].

The water supplies of Sincerín, as expected, showed lower values of color and turbidity when compared to Gambote's, with ranges of 10–100 PCU (SINC) and 5–10 PCU (SINCT) for color, and 0.08–7.14 NTU (SINC) and 0.35–3.92 NTU (SINCT) for turbidity. As to the concentration of hardness and previously discussed, five of the six samples analyzed reported values near or above 300 mg/L, which classifies Sincerín's water as within the category of hard and very hard, implying the need for softening [34].

Regarding the microbiological parameters, the total coliforms reported values for both SINC (33–100 CFU/100 mL) and SINCT (3-100 CFU/100 mL) exceeded the MAV (Table 5). The addition of sodium hypochlorite seemed to be not completely efficient in reducing total coliforms. This might be due to the presence of both substances/particles that caused color and turbidity and the high concentrations of hardness, which are known to reduce the biocidal effect of sodium hypochlorite [40]. The values of *E. coli* exceeded the MAV once (raw water first sample at a value of 100 CFU/100 mL). This result is indicative of (a) the aquifer susceptibility for fecal contamination, which is not surprising given that the basic sanitation services of the municipality are deficient, and (b) the chlorine dosage is not optimal as it is a random concentration, not the result of a dosage obtained, for instance, via chlorination breakpoint curve. In general, and according to the IRCA, Sincerín's water is also classified as sanitary infeasible (a value of 100) chiefly due to the above-the-limit concentrations of mercury reported in the samples analyzed. This result is also in agreement with other groundwater sources used in various municipalities located within the Department of Bolívar, namely San Joaquín, Malagana, and San Basilio de Palenque [38].

The results obtained in this study showed that the water sources of both municipalities (Sincerín and Gambote) are sanitarily infeasible for human consumption, which poses a high risk to human health. These findings coincide with a study carried out in seven municipalities of the Caribbean region between 2005 and 2008, including some belonging to the department of Bolívar (study site) such as Puerto Badel, Bocachica, San Jacinto, among others; the samples indicated that the water for human consumption evaluated is not in ideal conditions for consumption. The risk factors associated with this contamination are associated with the lack of an aqueduct, limited availability of water, prolonged periods in the storage and conservation of water, and the lack of physical or chemical treatment for purification [41]. In general, it can be seen that for populations located in rural areas the level of risk of IRCA increases, which happens in many parts of the country where different geographical and weather conditions are present. This is the case of the Amazon and Orinoquia region, where many municipalities do not have an optimal drinking water supply system, as well as sanitary networks, causing the inhabitants to live in precarious conditions [42]. The implementation and intensification of surveillance actions in environmental health carried out by the competent authorities, such as sanitary inspection visits and acceptable hygienic practices, can reduce the risk level of the water quality risk index [43].

On the other hand, the values notified in the national report [11] for the town of Arjona were classified as drinking water with no risk. This information reveals that drinking water quality in rural areas is not accurately assessed, which confirms these communities' vulnerability problems. In Colombia, the average urban IRCA nationwide in 2008 was 16.7%; in 2009, 13.8 %; in 2010, 11.9%; in 2011, 11.5%, and in 2012, of 13.2%, classifying the country, in these years, at medium and low risk [13]. In general, the IRCAs reported by some departments in the period 2007 to 2013 were, in Nariño, 39.20%; Huila, 33.07%; Casanare, 29.86%; Boyacá, 15.26%; Santander, 15.09%, and Cundinamarca, 7.16% [44].

Some studies have shown that in rural regions, access to improved water sources is predominantly scarce, so the inhabitants of these areas have developed their own collecting systems (self-sufficiency) [45], taking water from springs and streams, as is the case of Gambote where they collect the water directly from the *Canal del Dique*. The other main problem in our study sites is coliform contamination; to face this issue, it is necessary to implement alternatives for biological treatment that show the best economic, functional, and operational profitability. The most widely used in Colombian territory are usually stabilization lagoons, wetlands, and activated sludge, which when used together reflect optimal results greater than 90% in the treatment of domestic wastewater, in case of water shortage (a common situation in rural regions) an alternative water resource may be to reuse the latter [45, 46]. Quality control through physicochemical and microbiological analyzes is essential; however, it is not enough to guarantee the final quality of drinking water; it is just as important to have comprehensive management in drinking water distribution systems (WDS) [47, 48].

4. Conclusions

The Risk Index of Water Quality for Human Consumption (IRCA) calculated for the water supplies of Sincerin and Gambote classified the waters as unfit for human consumption; most of the parameters measured in raw water exceeded the maximum acceptable values established by the corresponding Colombian legislation. Furthermore, the partial treatment used in both municipalities did not improve the water quality.

The high incidence of pathogenic microorganisms on the final value of IRCAs highlights the need to apply efficient strategies for the management of discharges of domestic and livestock origin in order to improve the water quality from Sincerin and Gambote.

5. Declaration of competing interest

We declare that we have no significant competing interests including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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