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Relationship Between Microbiological and Physicochemical Parameters in Water Bodies in Urabá, Colombia

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Abstract

The presence of pathogens, toxic substances, and excess nutrients in rivers is due to the combination of industrial, agricultural, and livestock farming activities, as well as the absence of wastewater treatment plants and sewerage networks. River degradation is the result of these factors. The results from four water quality monitoring, carried out between November 2023 and August 2024, in the rivers of northern Urabá are presented in this paper, and the relationships between physicochemical and microbiological parameters are assessed. Water samples from 16 sites, upstream, downstream and within urban centers, as well as at the mouths of the Hobo, Zapata, and Damaquiel rivers, and two water bodies flowing into the coastal lagoon of Bahía El Uno are presented. The results revealed elevated content coliforms exceeding permissible Colombian standards and indicate that urban discharges increase microbial loads and induce degradation of conditions in the study area.

Keywords: water quality; coliforms; physicochemical parameters; wet and dry seasons; wastewater

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1. Introduction

Rivers are dynamic ecosystems whose physicochemical and biological composition is determined by their interaction with the atmosphere, soil and biota. However, the combination of industrial, agricultural and livestock activities, mining and deforestation among many others, exert increasing pressure on these systems, affecting their quality and availability [1–3].

The environmental state of a region is often reflected in its rivers, as they carry, or are depositories of, large amounts of waste generated by anthropogenic activities, which may cause varying degrees of alteration [4]. However, natural events such as hurricanes, volcanic eruptions and earthquakes, floods, and erosion also contribute materials and substances to rivers that, together with runoff, are transported and eventually deposited in the marine environment [5–7]. Globally, about 80% of all industrial and domestic wastewater is discharged with no prior treatment, bringing detrimental effects to the water bodies receiving it [8]. This is due to a lack of adequate wastewater treatment plants and sewage networks, and means pathogens, toxic substances and excess nutrients enter rivers. Wastewater discharges are among the main drivers of impacts associated with aquatic ecosystem degradation, increasing the risk of disease and diminishing the water quality [8–10]. The resulting ecological imbalances, lead to a significant reduction in global biodiversity and negative effects on socio-economic growth [10], as aquatic ecosystems provide a wide variety of goods and services, many of which are irreplaceable [11,12].

When wastewater enters an aquatic environment, biotic and abiotic parameters are affected; the concentration of dissolved oxygen (DO) can be reduced by the presence of organic and microbiological pollutants [13]. This parameter provides information related to biological and biochemical reactions in the aquatic environment and is therefore important in determining the quality of water [14].

Water quality can also be analyzed by assessing the presence of organisms; thermotolerant coliforms being a reference, as they are indicators of faecal contamination, and their presence is associated with risks to aquatic life and human health [15]. A high load of coliforms in a water body can represent a health risk, as it not only alters the balance of the ecosystem, but also affects the uses to which that water can be put, making it unviable for human consumption, recreation and other activities, such as agriculture and domestic use [16]. In the Urabá region, wastewater treatment is often lacking, and microorganisms of faecal origin are commonplace meaning that water quality is compromised.

Studies aimed at assessing water quality in the rivers of this region are practically non-existent, except the one carried out by [17], which did not include the rivers in the northern area. The present study thus examined the relationship between physicochemical and microbiological parameters in water bodies in the municipalities of San Juan de Urabá, Arboletes, Necoclí and Turbo, in the north of Urabá, Antioquia, in order to identify patterns of environmental deterioration associated with urban discharges, and their variation according to meteorological conditions.

2. Materials and Methods

2.1. Study Area

The study area lies close to the Gulf of Urabá, in the state of Antioquia, northern Colombia. It has a tropical climate, with marked seasonal variations, determined by the movements of the Intertropical Convergence Zone, giving two main seasons: a dry season, with lower rainfall and higher temperatures, and a wet season, with higher rainfall and runoff [18]. The dry season typically runs from December to April, while the rainy season lasts from May to November [19].

In the Gulf of Urabá, the temperature ranges from 19 to 40 °C, with a mean annual of 27 °C, while rainfall is between 40 and 100 mm/month [20], and the relative humidity is approximately 85.9 %; climatic characteristics of a tropical rainforest [21]. The seasonal variations of various parameters in surface waters were analyzed.

Four sampling campaigns were carried out: the first in November 2023 (dry season-DS), the others in January (DS), April and August 2024 (wet season-WS).

Sixteen sampling sites were selected, four each on the Zapata, Damaquiel, and Hobo rivers, and in the streams of Bahía el Uno (Figure 1), including sites influenced by the villages of Zapata, Damaquiel, Hobo River, and Bahía el Uno respectively (Table 1).

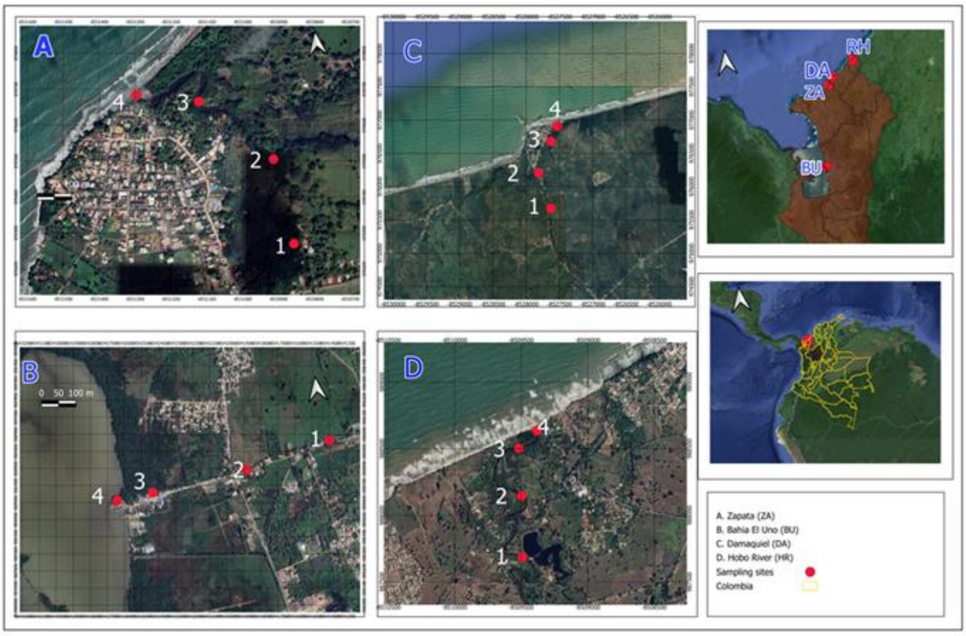


Figure 1. Location of the study area, and sampling sites in the water bodies in Urabá.

Table 1. Location of sampling sites.

Water body		**Site location**	**Coordinates**
Bahia el Uno	B1	Before the entrance to Bahia el Uno	8°06′46″- 76° 43′22″
	B2	New canal—before the entrance to Bahía el Uno	8°06′8.276″- 76°43′38.5″
	B3	Caño el Uno*	8°06′31″- 76° 44′11″
	B4	River mouth	8°06′18″- 76° 44′20″
Zapata River	Z1	Upstream, away from the entrance to Zapata	8°40′328″- 76° 37′59″
	Z2	Before entering to Zapata	8°40′36″- 76° 38′42″
	Z3	Zapata*	8°40′33″- 76° 38′02″
	Z4	River mouth	8°44′10.0″-76°38′15″
Hobo River	H1	Upstream before the entrance to Hobo River	8°49′09.7″-76° 26′30.9″
	H2	Pond	8°59′48.6″- 76° 26′17.8″
	H3	Hobo river*	8°50′44.3″- 76° 26′27.7″
	H4	River mouth	8°50′45.9″- 76° 26′27.3″
Damaquiel River	D1	Last stream flowing into the river—Before Damaquiel.	8°44′10.0″- 76° 36′23.3″
	D2	Entrance to the river	8°44′08.2″- 76° 36′24″
	D3	Damaquiel*	8°44′22.5″- 76° 36′18.1″
	D4	River mouth	8°44′30.8″- 76° 36′14.3″

*Village centre.

These sites were chosen so as to evaluate the possible influence of urban discharges, considering areas before, within and after the settlements on each tributary, as well as at its mouth.

In the case of Bahía el Uno, two streams, running into the lagoon were sampled, uptream and downstream of the village; the Coastal Lagoon registers a change in the location of its natural entrance, currently located in the northern area, with greater influence from the mouth of the Turbo River.

2.2. Sampling

Physicochemical parameters were measured in situ and surface water samples were collected for laboratory analysis, following the methodology of the Standard Methods [22]. Dissolved oxygen (DO), temperature, pH, and total dissolved solids (TDS) were recorded using a multi-parameter probe. Water samples were also taken at each sampling site, using Winkler bottles for laboratory determination of DO (Winkler method), fixing the samples in situ.

For the evaluation of microbiological quality (total coliforms and thermotolerant coliforms), water samples were taken using previously sterilized Schott glass containers of 250 mL capacity, which were submerged and opened under water, filling them partially.

Each sample was properly labelled, sealed and stored for transport to the analytical laboratory at a temperature of approximately 4 °C. The method used for the determination of total coliforms (TC) and thermotolerant coliforms (TTC) was the most probable number (MPN).

2.3. Data Analysis

An analysis of the data was carried out using the Lilliefors test (Kolmogórov-Smirnov, $p < 0.05$), establishing that the data were not distributed normally. Therefore, Spearman's non-parametric correlation tests were used to evaluate the relationship between DO, temperature and coliforms. Correlation analysis determines whether the relationship between two variables is present or absent, and that two variables are associated to a degree, and the significance was based on a p-value of less than 0.05.

Statistical analyses and graphs representing the distribution of the data were performed using IBM SPSS Statistics 26.

The results obtained were compared with the values established in the Colombian environmental and health regulations (Resolutions 2115/2007, 0631/2015 and Decree 1076/2015), in order to determine the extent to which they adhere to the standards, and the possible risks associated with use of this water.

3. Results

Table 2 shows the values recorded in physico-chemical and microbiological variables at the sampling sites, and the reference values given in Colombian regulations.

The highest surface temperature recorded was at the river mouth Bahía el Uno (B4) (33.7 °C), in the last sampling, corresponding to wet season (August), while the lowest record (26.9 °C) was obtained in Hobo River, in the first sampling, in the dry season (November). The temperature variation was lowest in April (29.8–32.8 °C) and highest in August (29.0–33.7 °C), both periods correspond to the wet season

There was greatest variability in the second and fourth sampling, both of which are related to changes in weather conditions between seasons. Sites in Bahía El Uno had the highest temperatures (Figure 2a); in contrast, sites on the Damaquiel River (D1–D4) had low temperatures and less variability.

Table 2. Variation of the physico-chemical parameters assessed at the sampling sites.

Sampling / Month	Season	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Total dissolved solids (mg/L)	Thermotolerant coliforms (MPN/100 mL)	Total coliforms (MPN/100 mL)
1—November	Dry (DS1)	26.9–30.9	0.48–6.53	6.69–8.4	79.7- 15000	780–2200000	54000-24000000
2—January	Dry (DS2)	29.8–32.8	0.25–9.11	6.97–7.8	125.8–12470	360–8400000	35000-11000000
3—April	Wet (WS1)	27.8–31.1	2.27–7.02	7.00–7.99	3.73–699	4000–3300000	40000-17000000
4—August	Wet (WS2)	29.0–33.7	0.26–8.17	7.31–7.87	98.8–>15000	20–6300000	78- 9200000
Range		26.9–33.7	0.25–9.11	6.69–8.4	19.85–>15000	78–8400000	78- 24000000
Mean ± SD		30.0 ± 1.329	5.32 ± 2.05	7.51 ± 0.30	2777 ± 3964	399812 ± 1405339	1542043 ± 4097424
Reference		-—-	>3.0[+] 4.0[++]	4.5–9.0[▫]	-—-	<200[*]	1000[**]

+ Institute of Hydrology, Meteorology and Environmental Studies-IDEAM (2019). ++Criteria for the preservation of Fauna and Flora. (Ministry of Environment and Sustainable Development, Decree 703 of 2018). ▫Water quality criteria for primary contact (Decree 1076 of 2015, Ministry of Environment). *Admissible quality criteria for the end use of the water, for human and domestic consumption (Ministry of Environment and Sustainable Development, Decree 703 of 2018). **Admissible quality criteria for the end use of water, for human and domestic consumption.

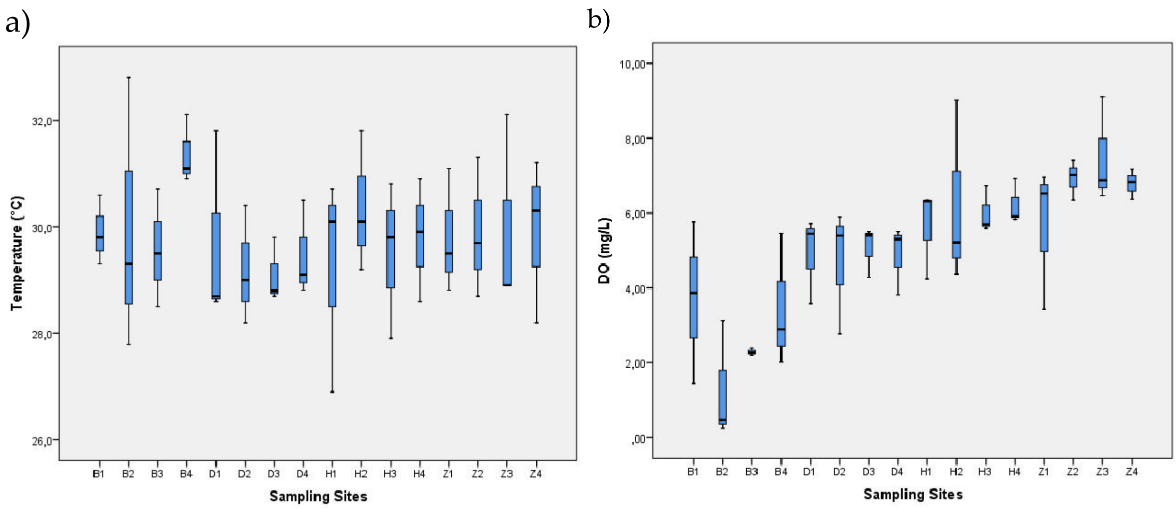
There was significant variability between sampling points in the concentration of dissolved oxygen (DO); 0.25 mg/L to 9.11 mg/L, in Bahía el Uno during the January sampling and in the Zapata River respectively, with both data corresponding to dry season (DS1). In Bahía el Uno, sites B2 and B3 had the lowest values, 3.3 mg/L and 3.11 mg/L respectively. In contrast, sites on the Hobo River (H2) and Zapata River (Z2 and Z3) had the highest concentrations, 9.02 mg/L and 9.11 mg/L (Figure 2b).

Regarding the pH of the water, relatively stable values were seen for all the sampling sites, varying between 6.69 and 8.40 (Figure 2c), values within the acceptable range according to environmental regulations in Colombia (4.0–9.0). The values recorded in November (DS1) were the most extreme, with a minimum and maximum of 6.69 and 8.4 respectively. In the last sampling corresponding to WS2 there was less variation (7.31–7.87) (Figure 2c).

The values for Total dissolved solids (TDS) varied greatly, with a minimum concentration of 3.73 mg/L and a maximum of over 15000 mg/L (Figure 2d). In the first sampling the recorded concentrations were 79.7–15000 mg/L; in the second from 125.8 to 12470 mg/L, in the third 3.73–699 mg/L, and in the fourth sampling values ranged from 98.8 to >15000 mg/L. TDS values were particularly high at sites established at the river mouths and in the village centers. A wide variability was presented in TDS concentration, with levels over 14,000 mg/L at sites B4 and Z4. In contrast, sites such as D1, H1, H2, Z1, Z2, and to a lesser extent B1, had low and stable concentrations (Figure 2d).

The concentrations of thermotolerant coliforms (TEC) ranged from 20 to 8400000 NMP/100 mL (Figure 3a), recorded in the DS1 (H2) and WS1 (B2), respectively. The highest concentrations and most variability were in Bahía el Uno, while in the Hobo River, especially, the concentrations were substantially lower.

With respect to total coliforms (TC) values, expressed in NMP/100 mL, it is seen that the sites in Bahía el Uno (B1, B2 and B4) had highest concentrations, especially the site at the river mouth (B4), the one with greatest variability.



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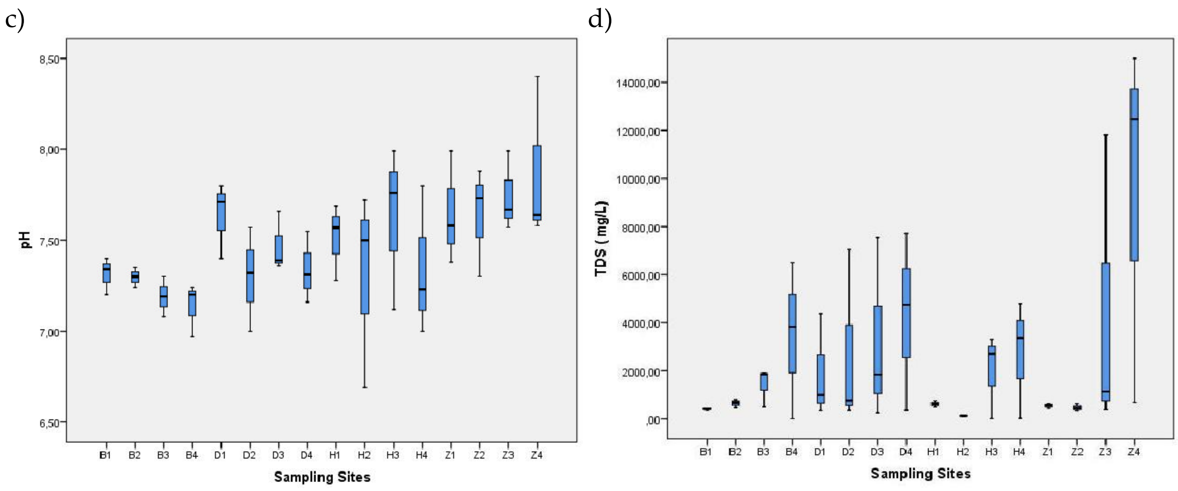

Figure 2. Distribution of physicochemical parameters recorded at the sampling sites. a) temperature (°C), b) dissolved oxygen (mg/L), c) pH, d) total dissolved solids (mg/L).

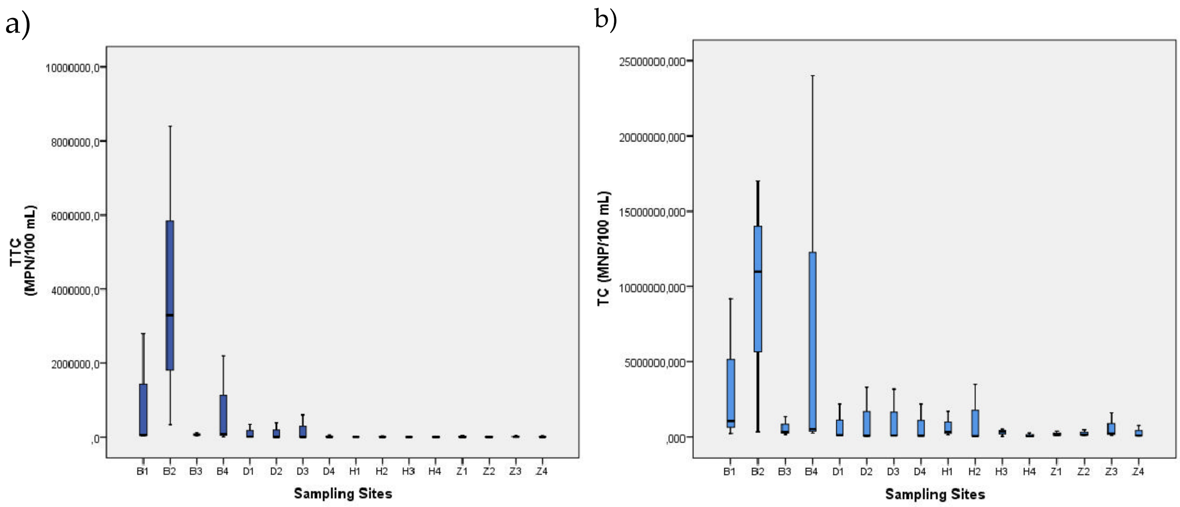

Figure 3. Distribution of coliforms recorded at the sampling sites. a) thermotolerant coliforms (MPN/100 mL), b) total coliforms (MPN/100 mL).

Of the parameters evaluated, only the temperature values had a normal distribution ($p > 0.05$), which is why Spearman's correlation coefficient was used to evaluate the relationships between the variables. The results obtained from this analysis are presented in Table 3.

Table 3. Spearman Correlation Analysis for the parameters evaluated.

Spearman's Rho						
		TTC	**TC**	**OD**	**TDS**	**Water Temperature**
TEC	Correlation coefficient	1.000	.906	-.495	-.307	-.270
	Sig. (bilateral)	.	.000	.000	.014	.031
	N	64	64	64	64	64
TTC	Correlation coefficient	.906	1.000	-.484	-.277	-.294
	Sig. (bilateral)	.000	.	.000	.026	.018
	N	64	64	64	64	64
DO	Correlation coefficient	-.495	-.484	1.000	-.066	.017
	Sig. (bilateral)	.000	.000	.	.607	.892

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	N	64	64	64	64	64
SDT	Correlation coefficient	-.307	-.277	-.066	1.000	.365
	Sig. (bilateral)	.014	.026	.607	.	.003
	N	64	64	64	64	64
Water Temperature	Correlation coefficient	-.270	-.294	.017	.365	1.000
	Sig. (bilateral)	.031	.018	.892	.003	.
	N	64	64	64	64	64

A moderate negative correlation was identified between DO and thermotolerant coliforms (r = -0.495. $p < 0.05$), as well as with total coliforms (r = -0.484. $p < 0.05$). Negative and significant correlations were also identified between coliforms and TDS (r = -0.277; r = -0.307; $p < 0.05$), and with temperature (r = -0.294; r = -0.270; $p < 0.05$); however, no significant correlation was observed between temperature and DO (r = 0.017; p = 0.892).

4. Discussion

The release of raw and improperly treated wastewater onto watercourses has both short- and long-term effects on the environment and human health [23] because the inadequate disposal of human and animal excreta can contaminate water resources, causing high nutrients, decreased oxygen levels, and an increase in the number of pathogens in the water body [24,25].

The discharge of wastewater may have different effects on the microscopic species that comprise the foundation of water ecosystems [26]. These changes are directly reflected in the environment and, consequently, in water quality. This is particularly true in many developing countries, where sewage is often discharged directly into watercourses. due to the total, or partial, lack of sewage networks and treatment plants in many urban centres, as is the case in the coastal municipalities of Urabá, where the discharge of wastewater to natural watercourses deteriorates the water resource quality.

For the water bodies evaluated, the variation of physico-chemical and microbiological parameters showed differences between sites and between climatic periods, with the greatest variations seen in the data from the sampling sites in Bahía el Uno, except for pH, which varied more at sites in the Hobo River, and in the Zapata River mouth.

The pH data were stable within the normative range (4.0–9.0), with values between 6.69 and 8.1; neutral and slightly alkaline, as described for other rivers in Urabá, where values recorded were 7.1 and 8.2 [17]. There was little variability between the sampling sites, suggesting that this variable is not a critical risk factor in the water bodies evaluated.

In rivers, the temperature is largely controlled by incoming solar radiation [27,28]. The temperature data ranged from 26.9 to 33.7 °C, reflecting the climatic conditions of the region, and variations that occur in lotic systems, where this parameter fluctuates on daily, seasonal [29,30] interannual time scales, and along the longitudinal axis of the channel [30], and is also influenced by latitude and tends to correlate with air temperature [29,31,32].

The highest temperatures were recorded in August 2024 (WS2), reaching values from 29.0 to 33.7 °C. Such temperatures generate favorable conditions for microbial proliferation, increasing bacterial activity. According to [33], the environmental conditions of high temperatures and high concentrations of nutrients in tropical aquatic ecosystems could favor the proliferation of *E. coli.*

The lowest variability in temperatures were seen in the DS2 (3.0 °C), followed by the WS1 (3.3 °C).

Temperature behavior was influenced by the El Niño event, starting in the second half of 2023. According to the [34], the phenomenon reached its peak between November 2023 and January 2024 before dissipating and extending its influence until March [35]. In all periods evaluated during the present study, a precipitation deficit was recorded in the Colombian southern Caribbean [36–39] according to the reference values for this region [40].

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Temperature has a direct or indirect effect on various physical and chemical processes, which are determinant in the distribution of organisms [41–43]. Its effect on the saturation constants of dissolved gases means that high temperatures reduce the concentration of these gases, which can intensify the effects of pollution [44]. In this way, DO responds to temperature variations, but also to oxygenation processes that include wind action, interaction with the atmosphere, and the activity of photosynthetic organisms.

Throughout the samplings, the average DO was 5.32 ± 2.05 mg/L, indicating that in general terms the concentrations remained at acceptable levels for aquatic life (≥ 4.0 mg/L). The greatest variations, and the lowest concentrations, were found in the water bodies of Bahía el Uno. However, DO was not significantly correlated with temperature, despite the fact that Bahía el Uno recorded high temperatures and low DO concentrations, contrary to the behavior reported by [45], who reported a significant negative correlation between temperature and dissolved oxygen (DO) in Mexican water bodies.

This difference could be attributed to the high loads of organic matter derived from untreated wastewater in the systems evaluated here, which alter the typical physico-chemical dynamics. In these water bodies, the DO seems to be conditioned by factors such as microbial activity associated with pollution, rather than by thermal variations.

The lowest variability in DO was seen in April (WS), followed by November (DS), with the lowest records equivalent to 0.25 mg/L, determined during January (DS) and August (WS) at various sampling sites. DO results were relatively stable, except for the sampling sites in Bahía el Uno (Figure 3), where the low concentrations recorded could compromise aquatic life, and therefore the equilibrium of these water bodies.

In Bahía el Uno, there is a significant contribution of wastewater, which alters the oxygen balance of the water, with B2 being the most critical site, recording very low DO levels (0.25 mg/L). These conditions also limit the possible use of water due to the presence of bacteria, including coliform groups. These bacteria increase dissolved oxygen consumption, which is also affected by the presence of decomposer microorganisms. Both situations increase anaerobic conditions, leading to increased survival of bacteria, such as coliforms in water contaminated with faecal matter [46].

In a riverbed, oxygen consumption is relevant to biological and chemical processes, and very important in the decomposition of organic matter and with the sediments present in the bottom of a river [47]. Oxygen consumption also varies due to the presence of microorganisms, which influences the availability of oxygen, therefore its study, as it allows understanding the relationship between the physical and microbiological parameters of water.

Microorganisms constitute the fundamental compartments of aquatic ecosystems because of their high concentration and activities [48]. However, pathogenic contamination of water contains significant health risks to aquatic environments and human beings. The microbiological results gave the highest concentrations of thermotolerant coliforms (8400000 NMP/100 mL) and total coliforms (24000000 NMP/100 mL) in January (DS2), and November (DS1) respectively, with an average of 399812 ± 1405339 NMP/100 mL for thermotolerant coliforms and 1542043 ± 4097424 NMP/100 mL for total coliforms. These values far exceed the maximums allowed in Colombian regulations (200 and 1000 NMP/100 mL, respectively), evidencing high faecal contamination in the water bodies evaluated.

The high concentrations of coliforms in Bahía El Uno (especially at B2 and B3) indicate the considerable load of faecal contamination associated with direct discharge of untreated domestic wastewater. The high coliform concentrations in Bahía El Uno (especially in B2 and B3) indicate the considerable burden of faecal contamination associated with the direct discharge of untreated domestic wastewater.

Similar findings were shown in studies by [15,49–51], who identified urban areas as the main sources of microbiological deterioration in tropical rivers. In Colombia, the relationship between water pollution and the proliferation of waterborne diseases mainly affects infants under one year of age and children from 1 to 4 years of age [52], a problem related to the inappropriate use of water resources affected by the discharge of effluents receiving faecal matter, which increase the bacterial load in the water bodies.

Coliforms can grow in natural surface waters due to the large amount of organic matter and high temperatures [53,54]. Bahía el Uno receives a significant amount of wastewater discharges, not only from homes in this area, but also from a sector of the municipality of Turbo, through a natural drain that receives wastewater and was channeled to this sector, causing further deterioration.

For the remaining sites, the highest coliform concentrations occurred in April (WS1). This behavior is related to the carryover of stagnant water in some sectors due to the low rainfall recorded from the second half of 2023 to March 2024. These waters are carried away by rainfall, increasing the concentration of microorganisms in the receiving water bodies.

Wastewater and other waste discharges generate excessive organic matter, and also promote eutrophication processes, that bring an increase in the concentration of nutrients and thereby, of phytoplanktonic organisms. This leads to mortality, and growth of aerobic microorganisms that consume oxygen, and reduce the availability of this gas in the ecosystem [55,56]. In Bahía el Uno, OD concentrations of far less than 2.0 mg/L were recorded, these conditions hinder the survival of many species.

The increase in eutrophication and associated hypoxia/anoxia (hypoxia < 2.0 mg/L, anoxia < 0.5 mg/L), influenced by rising temperatures combined with the acidification of susceptible waterbodies, are detrimental to ecosystem functioning [57,58]. The results indicate that among the study sites, Bahía el Uno was the only sector that recorded anoxic (B2) and hypoxic conditions, except during the sampling carried out in the WS corresponding to April, demonstrating the repercussions of inadequate wastewater management on the trophic state of the water bodies in this sector.

Sampling sites in Bahía el Uno feature shallow waters with low circulation, this causes changes in the trophic status of water bodies, resulting in greater deterioration in this sector compared to sites established on rivers. It is worth noting that the contribution of organic matter is significant after prolonged periods of little or no rainfall since when it occurs, much of the accumulated material is removed and transported to these bodies of water.

This material is primarily composed of domestic waste. The pollutant load is represented by high percentages of organic matter and microorganisms of faecal origin. The ability of faecal bacteria to survive in water indicates that their presence in this environment is associated with recent infections or with the presence of suitable conditions (pH, temperature, humidity, and organic matter) [59].

The organic load generated by household waste contains organic carbon, nitrogen, and pathogens attached to particles such as sand [60]. The entry of this contaminant load requires oxygen for decomposition and respiration processes, which explains the moderate negative correlation determined between DO and coliform concentrations. Faecal contamination favors microbial activity and reduces DO availability, as has been recorded in other water bodies by [13,61].

On the other hand, the differences in TDS concentration among the sampling sites suggest that their sources may respond to specific local conditions, such as the presence of sites with a higher degree of urbanization, the amount of wastewater discharged, and the self-purification capacity of each water body.

TDS data shows a positive, significant correlation with temperature, coinciding with results reported by [62], who attributed this relationship to evaporation processes that increase the concentration of solutes in the water. This suggests that the higher ionic concentration generated during warmer periods could favour eutrophication processes or alter microbial dynamics. This parameter is highly variable (19.85–>15000 mg/L), with an average of 2777 ± 3964 mg/L. The highest levels were recorded in the DS (November) and WS (August), suggesting a significant contribution of organic load and pollutants of anthropogenic origin in both periods.

The high concentrations of TDS determined directly affect the availability of oxygen present in water bodies. This is related to the fact that the highest TDS records were found at sites with the highest incidence of urbanization.

The relationship between the variables evaluated shows a pattern with high temperatures, coliform concentrations and TDS, and a tendency toward low DO levels, favoring bacterial growth processes that accentuate deoxygenation and negatively affect water quality.

The interaction between these variables underlines the need for monitoring that generates information on the ecological status of water bodies, and an integrated approach that simultaneously considers microbiological, physicochemical, pollutant and climatic factors.

Overall, the results seen here reflect deterioration and contamination in most of the water bodies analyzed. Data from few sites meets the criteria established in Colombian regulations, representing risks to the health of the ecosystem and to public health. Unfortunately, this situation is also seen in other water bodies across the country, as reported by [63].

6. Conclusions

This study analyzed the relationship between physicochemical and microbiological water parameters and their impact on resource quality. Fecal contamination was identified in the assessed water bodies due to the discharge of untreated wastewater. The parameters analyzed showed deterioration, particularly dissolved oxygen (DO) concentration. Bahía el Uno was the sector's greatest impact by wastewater influence. The study area suffers from inadequate wastewater management, which compromises the quality of these aquatic environments, alters the system's balance, and limits the ecosystem services associated with the resource. The results highlight the need to implement adequate wastewater management and treatment measures in these sectors.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

TC	Total coliforms
TTC	Thermotolerant coliforms
°C	Centigrade degrees
SD	Standard deviation
GISMAC	Marine and coastal systems research group
IDEAM	Colombian Institute of Hydrology, Meteorology and Environmental Studies (Instituto de hidrología, meteorología y estudios ambientales de Colombia).
mL	Milliliter
mm/month	Millimeters per month
mg/L	Milligrams per liter
MPN	Most Probable Number
MPN/100mL	Most Probable Number per 100 milliliters
DO	Dissolved oxygen
TDS	Total dissolved solids

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