Water Quality Assessment Using the Water Quality Index (WQI – IDEAM) in the Lower Basin of the Cesar River, Colombia

[1]Héctor Antonio Pava Morales, [2]Juan Bautista Pacheco Fernández, [3] Yim James Rodríguez Díaz,

[1]Ingeniera Ambiental y Sanitaria. Maestrante en Ciencias Ambientales. Universidad Popular del Cesar. Valledupar, Colombia.
Correo electrónico: hpava@unicesar.edu.co
ORCID: https://orcid.org/0009-0008-9195-9220
[2]Docente de Física e investiga didáctica de las ciencias naturales en la Universidad Popular del Cesar. Valledupar, Colombia.
Correo electrónico: juanpacheco@unicesar.edu.co
ORCID: http://orcid.org/0000-0002-1333-5040
[3] Profesor Titular. Programa Ingeniería Ambiental y Sanitaria. Universidad Popular del Cesar. Valledupar, Colombia.
Correo electrónico: yimrodriguez@unicesar.edu.co
ORCID: https://orcid.org/0000-0002-4463-0077

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Abstract

Introduction: Water is one of the most important natural resources for life on Earth and constitutes a cross-cutting axis for the sustainable development of societies. Its availability, distribution, and quality directly influence public health, food security, biodiversity, economic productivity, and the overall well-being of human communities. The quality of surface water is a subject of international debate, primarily due to anthropogenic pollution levels, which are often harmful to the natural self-purification processes of water bodies and difficult to address through conventional chemical treatment. The Cesar River plays a key role in the surrounding areas of the Cesar Department and parts of La Guajira Department, serving as a central source for economic activities such as agriculture, fishing, livestock farming, and material extraction. These activities have altered the ecosystems associated with this natural water source.

Methods: This research was conducted using a quantitative approach, with a non-experimental and longitudinal design. The study area corresponds to the lower basin of the Cesar River, near the Zapatosa marsh complex, specifically within the jurisdiction of the municipality of Chimichagua, Cesar Department. Four strategic sampling points were selected along a 6.25-kilometer section of the river. This stretch begins at the river port located in the village of Saloa (Chimichagua), where various physicochemical and microbiological parameters were measured to determine the Water Quality Index (WQI) as proposed by IDEAM (2020). These parameters included: dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), pH, electrical conductivity, nitrates, fecal coliforms, and total phosphorus.

Discussion y Conclusions: The assessment of water quality in the lower basin of the Cesar River using the Water Quality Index (WQI) methodology established by IDEAM (2020) revealed unfavorable conditions for the use of the resource for human consumption. The comprehensive analysis of physicochemical and microbiological parameters showed that high levels of suspended solids, turbidity, BOD, COD, phosphates, nitrates, and fecal coliforms are closely associated with anthropogenic activities such as intensive agriculture, extensive livestock farming, untreated wastewater discharges, and material extraction from the riverbed.

Keywords: WQI, water quality, Cesar River, productive activity, pollution, physicochemical and microbiological parameters, IDEAM.

1. Introduction

Water is one of the most important natural resources for life on Earth and serves as a cross-cutting axis for the sustainable development of societies. Its availability, distribution, and quality directly influence public health, food security, biodiversity, economic productivity, and the overall well-being of human communities. In this regard, water is recognized as a strategic element in both environmental planning and decision-making processes related to territorial management. Therefore, it is considered an essential resource that requires special attention from government entities to preserve life and prevent its deterioration, mainly caused by irresponsible and intensive use of water resources (Betancurt & Galeano, 2020).

Surface water quality has become a matter of global concern due to the levels of anthropogenic pollution that hinder the natural self-purification processes of aquatic ecosystems, making treatment from a chemical standpoint particularly challenging (Ariza et al., 2023). Water quality can be affected by a wide range of natural factors, but it is primarily influenced by anthropogenic activities that introduce pollutants into water bodies, altering their composition and ecological functionality. These activities have been identified as one of the main sources of water contamination, leading to severe consequences for aquatic ecosystems and human health by affecting wildlife and limiting access to safe drinking water (Arismendi et al., 2024). Major causes of surface water quality deterioration include the discharge of untreated wastewater, solid waste disposal, agricultural activities, pig and cattle farming, extraction of riverbed materials, and deforestation in recharge zones (Agudelo et al., 2023).

In Colombia, the need to comprehensively evaluate the state of water resources has led to the development of technical tools that allow for the quantification of water degradation and the formulation of intervention strategies. One of the most important tools in this regard is the Water Quality Index (ICA) proposed by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), which synthesizes the behavior of various physicochemical and microbiological variables to assign a categorical rating to the current state of surface water bodies (IDEAM, 2020). In this context, the Colombian Caribbean region faces significant challenges in managing and conserving its water bodies, including the Cesar River. This river stretches approximately 280 km, originates from the southeastern slopes of the Sierra Nevada de Santa Marta, and flows into the Zapatosa Marsh, where it connects with the Magdalena River basin. Its course runs through the departments of La Guajira and Cesar, crossing eleven municipalities such as San Juan, Valledupar, San Diego, La Paz, El Paso, Astrea, Chimichagua, and Chiriguaná, among others (Guzmán, 2013).

The Cesar River plays a crucial role in the surrounding areas of the department of Cesar and part of La Guajira, as it serves as a central point for economic activities such as agriculture, fishing, livestock farming, and material extraction. These activities have significantly altered the ecosystems associated with this natural water source (Ariza et al., 2023). Moreover, there is a notable lack of water quality analysis specifically in the lower basin, which is home to rural communities with high levels of vulnerability and a direct dependence on the river for their livelihoods. The lower Cesar River basin has historically been a vital axis for the region’s economic development, due to the presence of activities such as agriculture, livestock farming, artisanal fishing, mining, and agroindustry, all of which exert constant pressure on water quality (Guzmán, 2013). Thus, the quality of water resources directly influences the determination of the current condition of a water body and its potential for use or contamination in the study area. In this regard, Gallo et al. (2021) emphasize that the physical, chemical, and biological variables of water quality enable the use of water quality indices that represent the overall condition of surface or groundwater over a specific period. These indices incorporate data from multiple physical, chemical, and biological parameters into a mathematical equation through which the water body’s quality status can be assessed.

Consequently, the objective of this article is to determine the water quality in the lower basin of the Cesar River, Colombia, using IDEAM’s Water Quality Index (ICA), with the aim of generating scientific information that contributes to the sustainable environmental management of water resources in the region, specifically in the municipality of Chimichagua, southern Cesar. This study seeks to provide an overview of the current conditions of the river channel through the application of the ICA methodology established by IDEAM. This article was developed as a research product of the Master's Program in Environmental Sciences of the SUE Caribbean Network, with participation from the Universidad Popular del Cesar.

2. Methodology

This research was conducted using a quantitative approach, with a non-experimental and longitudinal design. This approach allowed for the analysis of changes and behaviors of the physicochemical variables associated with water quality over a defined period, aiming to determine the current condition and environmental impact in the lower basin of the Cesar River (Hernández & Mendoza, 2018).

The study area corresponds to the lower basin of the Cesar River, near the Zapatosa marsh complex, specifically within the jurisdiction of the municipality of Chimichagua, in the department of Cesar (Guzmán, 2013). For data collection, four strategic sampling points were established along a section of the river with an approximate length of 6.25 kilometers. This segment begins at the river port located in the village of Saloa (Chimichagua), with the exact geographic coordinates detailed below:

Table 1. Sampling sites.

Sampling Point	North (Latitude)	West (Longitude)
P1	9°12'0.70"N	73°43'32.97"O
P2	9°12'27.70"N	73°43'56.53"O
P3	9°13'37.12"N	73°44'50.56"O
P4	9°13'47.86"N	73°45'19.40"O

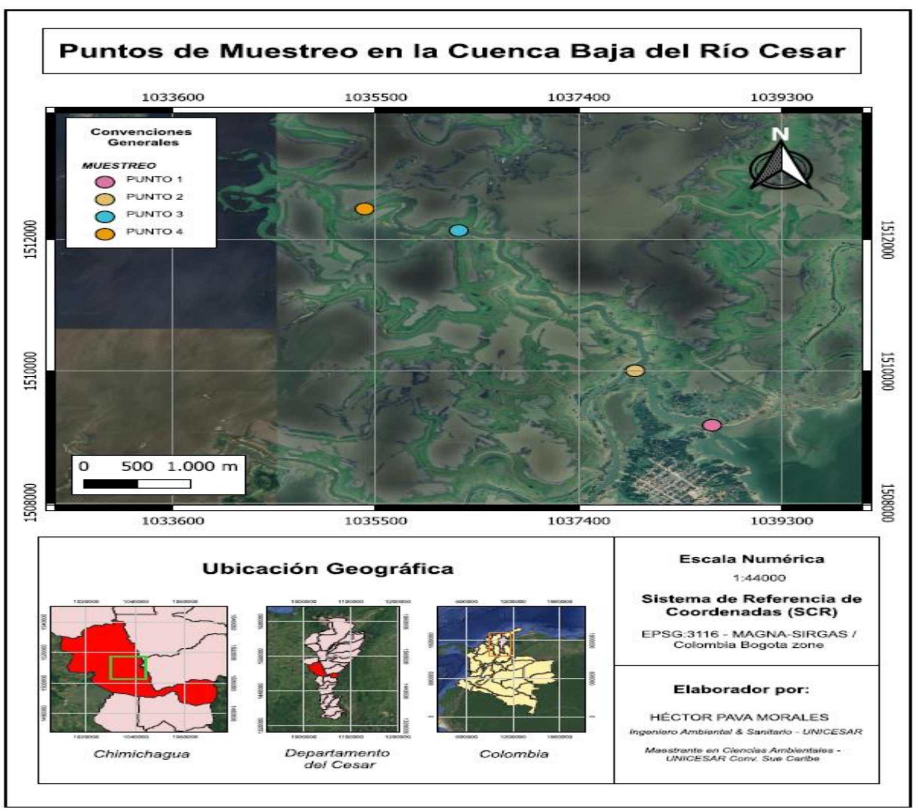

Figure 1. Location of Water Sampling Points for Water Quality Assessment Using the IDEAM Water Quality Index (WQI)

At the beginning of the investigation, systematic sampling campaigns were carried out under stable meteorological conditions to avoid bias in the results. These campaigns took place specifically in April and December of 2024 within the study area. During these campaigns, standardized surface water sampling protocols were applied, following the guidelines of IDEAM (2020) and previous experiences such as those of Benavides (2019). Samples were collected in sterile containers and kept refrigerated during transport to the laboratory, ensuring full traceability through records of date, time, ambient temperature, and exact collection coordinates.

During data collection, field observations were also made regarding human activities near the sampling points, such as domestic discharges, livestock presence, cultivated areas, or drainage infrastructures. These observations were incorporated into the analysis to establish possible correlations between anthropogenic pressure sources and water quality deterioration levels—an approach also used by Galezzo (2020) in the characterization of river ecosystems in rural contexts.

Subsequently, key physicochemical variables were determined for the calculation of the Water Quality Index (WQI), based on the methodology proposed by IDEAM. These variables included dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), pH, electrical conductivity, nitrates, fecal coliforms, and total phosphorus. The samples were analyzed at the laboratories of the Universidad Popular del Cesar, Sabanas campus, in Valledupar, as well as at specialized laboratories, in accordance with standard quality methods. Some physicochemical variables were measured in situ (Dueñas, 2020). Sampling was replicated on the same day to establish temporal behavior patterns and verify the consistency of results (Cruz et al., 2023).

Once the data were obtained, the WQI was calculated following the formula proposed by IDEAM (2020), which assigns a weight to each parameter according to its relative importance in determining the ecological status of the water. The analysis of results allowed for the classification of water quality at each sampling point into categories such as "good," "acceptable," "fair," "poor," or "very poor" (see Table 2), according to the ranges established by the institutional methodology. This classification is based on the variables and weights proposed by the national authority (see Table 3). In addition, graphical representations and descriptive statistical tools were used to compare values between sampling points and dates, allowing for the detection of significant trends or anomalies.

Table 2. Water Quality Index (WQI) Classification According to IDEAM

Category	Water Quality Rating	Alert Level
0 - 0.25	Very Poor	
0.26 - 0.5	Poor	
0.51 - 0.7	Fair	
0.71 - 0.9	Acceptable	
0.91 – 1.0	Good	

Source: IDEAM (2020)

Tabla 3. Variables and Categorization of the Water Quality Index (WQI) According to IDEAM

Variable	Unidades	Peso de importancia (ICA 6 variables
Oxígeno disuelto	%saturación	0.17
Solidos suspendidos totales	mg/l	0.17
Demanda química de oxígeno	mg/l	0.17
Conductividad eléctrica	uS/cm	0.17
Nitrógeno total / Fosforo total (NT/PT)	Adimensional	0.17
pH	Unidades de pH	0.15

Source: IDEAM (2020)

3. Results and Discussion

Characterization of the Sampling Sites

During the characterization of the sampling sites, it was observed that at Point 1—located in Figure 1 and shown in Figure 2—specifically in the area of influence of the village of Saloa, near the port of Las Palmitas, productive activities were mainly focused on cattle ranching on properties adjacent to the sector. Additionally, agricultural activities were evident, including the cultivation of cassava, plantain, squash, and maize. According to Núñez and Reyes (2016), the commonly implemented productive activities in the Cesar River area include agriculture, dual-purpose livestock farming, and riverbed material extraction, all of which negatively affect the quality of the watercourse, particularly when these activities intensify along the riparian zone. In this area, flood-prone plains are predominant during the rainy season.

On the other hand, at Point 2—located 1.5 km downstream from Sampling Point 1—a bifurcation of the Cesar River to the left was observed, leading toward the port of Saloa. Agricultural and livestock activities were also identified in the surrounding properties, which are situated in flood-prone plains. In this regard, Madera et al. (2016) associate such plains with the mobilization of sediments and nutrients into the river, which can trigger eutrophication processes if there is no control over discharges or agricultural runoff (Madera et al., 2016).

Figure 2. Access to the sampling site during the study periods.

On the other hand, Site 3—located 3.5 km from Point 2—is notable for the interconnection of the Cesar River with other watercourses in the area. Once again, livestock and agricultural activities (specifically the cultivation of cassava, plantain, squash, and maize) are prevalent. Similar to the previous site, the area is dominated by floodplains with characteristics akin to those observed at Point 2, including homogeneous slopes and steady current velocities. According to the study by Madera et al. (2016), in similar areas of the Tucuy and Maracas Rivers, a reduction in aquatic species diversity and water self-purification capacity was observed due to habitat alterations caused by agricultural and livestock activities—particularly in the absence of riparian vegetation buffers to mitigate environmental impacts.

Finally, point 4 is located approximately 1.6 km from Point 3 and presents characteristics similar to the previous points. This site features calm water zones where communities of macrophyte species accumulate, with notable presence of aquatic vegetation and the proliferation of odors caused by decomposing plant material. The accumulation of organic matter and proliferation of microorganisms may indicate a system transitioning toward states of ecological stress, which can also alter the structure of aquatic communities and generate eutrophic conditions (Madera et al., 2016).

Analysis of Physicochemical and Microbiological Parameters

The results related to turbidity levels are shown in Figure 3, revealing a variable dynamic between sampling points during the dry season. Turbidity progressively increases from Point 4 to Point 1. However, Point 1 exhibits a sharp rise, reaching turbidity levels similar to those recorded at the final point. This phenomenon is associated with the recirculation of flow in the confluence zone of the Cesar River and other tributaries within the Zapatosa wetland complex. In this area, the merging of water bodies favors sediment resuspension, which, due to low flow velocities, is not effectively transported to other areas. Among the main anthropogenic activities contributing to this behavior is the extraction of riverbed materials, which intensifies during the dry season when low water levels facilitate their removal. According to Ramos (2018), this activity increases the concentration of suspended solids and significantly alters water quality. In contrast, during the rainy season, a gradual decrease in turbidity is observed toward the river's mouth. This trend suggests greater self-purification capacity and assimilation of solids by the fluvial system, influenced by increased flow and riparian vegetation cover (Ramos, 2018).

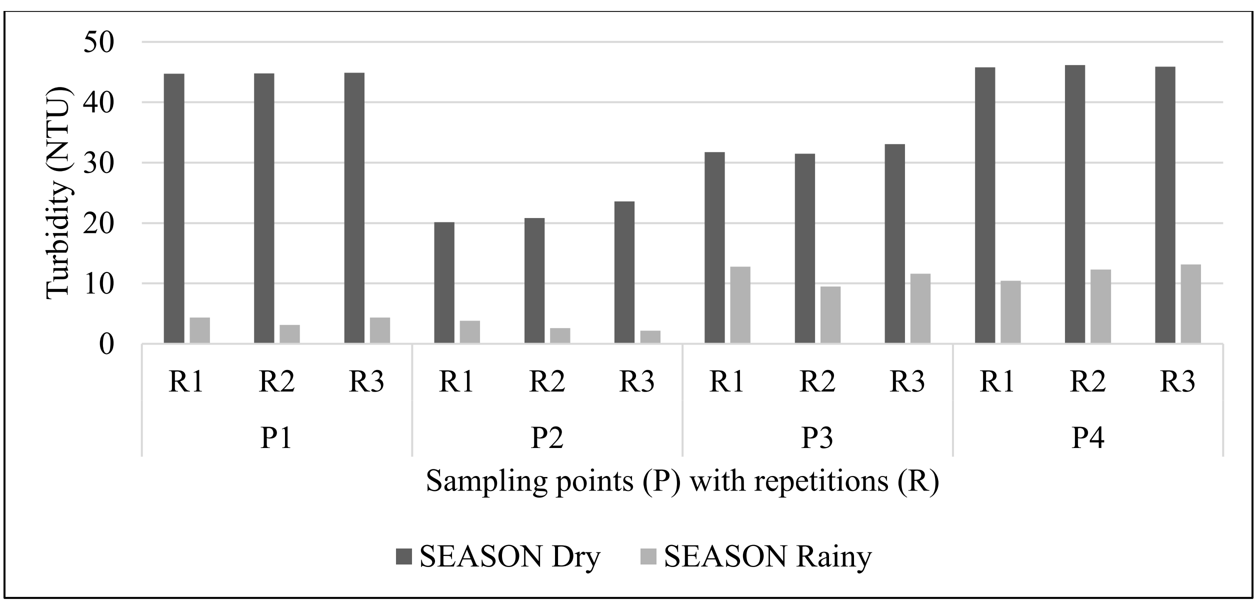

Figure 3. Turbidity results during rainy and dry seasons.

On the other hand, the pH values shown in Figure 4 indicate that during the dry season, pH levels remain relatively stable, ranging between 7 and 8. However, during the rainy season, a slight decrease is observed, with values fluctuating between 6 and 7. According to Rojas and Torres (2022), the pH variations at these sampling sites are not considered significant, as the values fall within acceptable ranges for human consumption, suggesting an adequate water quality based on this parameter. Nevertheless, the current conditions of the Cesar River, as reported by Ariza et al. (2023) and Guzmán (2013), reveal a deterioration in water quality attributed to the region's intensive productive activities, which may be impacting other aquatic zones of the river under study.

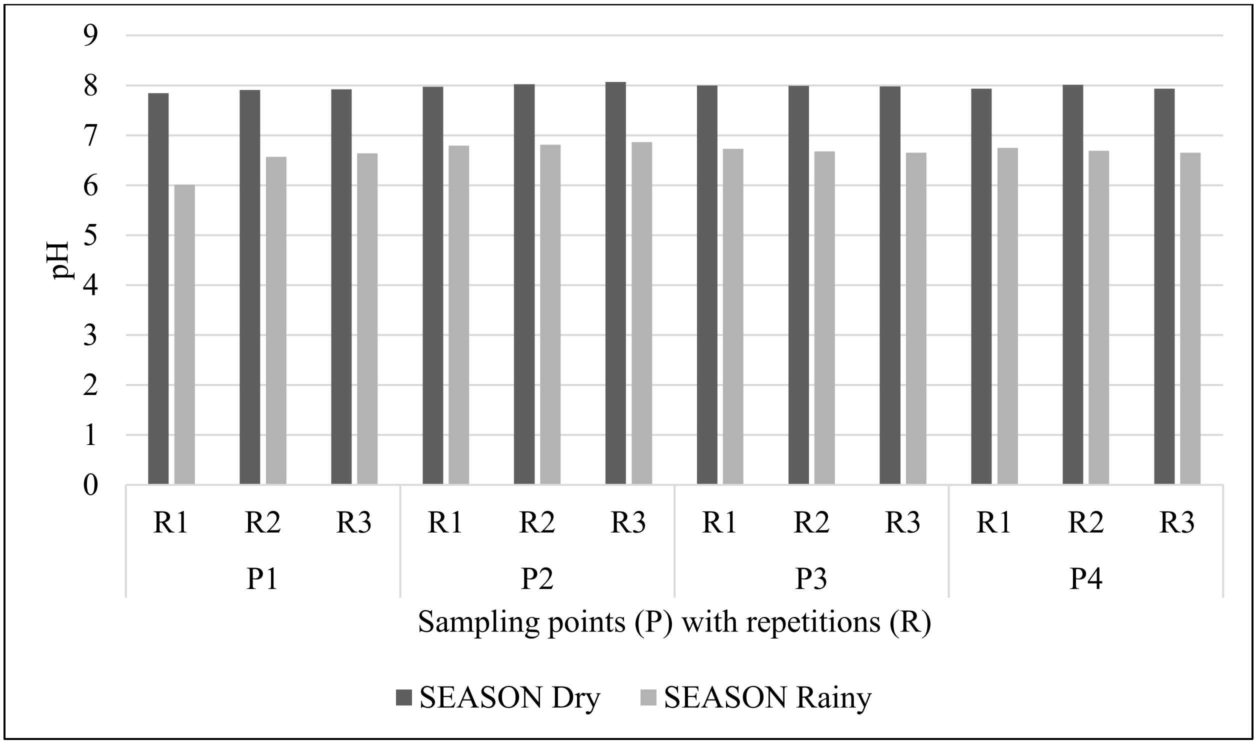

Figure 2. *pH values during rainy and dry seasons.*

The results obtained for conductivity (see Figure 5) showed that during the dry season, this value was high at all sampling sites, with the highest value recorded at point four, exceeding 500 µS/cm². However, in the other study areas, values fluctuated between 300–360 µS/cm², indicating higher ionic concentrations at sampling point four. This suggests a significant concentration of ions in the water, available in the form of dissolved salts and inorganic materials such as alkalis, chlorides, sulfides, and carbonate compounds. These are directly related to turbidity levels caused by suspended solids (Caicedo & Pérez, 2021). In contrast, during the rainy season, conductivity values decreased to a range between 120–150 µS/cm² and remained stable across all sampling points. This may be associated with the reduction in turbidity levels at the same sampling sites during the rainy season. According to Calvo (2020), lower levels of conductive inorganic compounds were present during this period, along with organic molecules that do not dissociate in water, resulting in lower conductivity. Additionally, Núñez and Reyes (2016) emphasize that the higher volume of water promotes the dilution of these conductive particles, thus reducing their concentration.

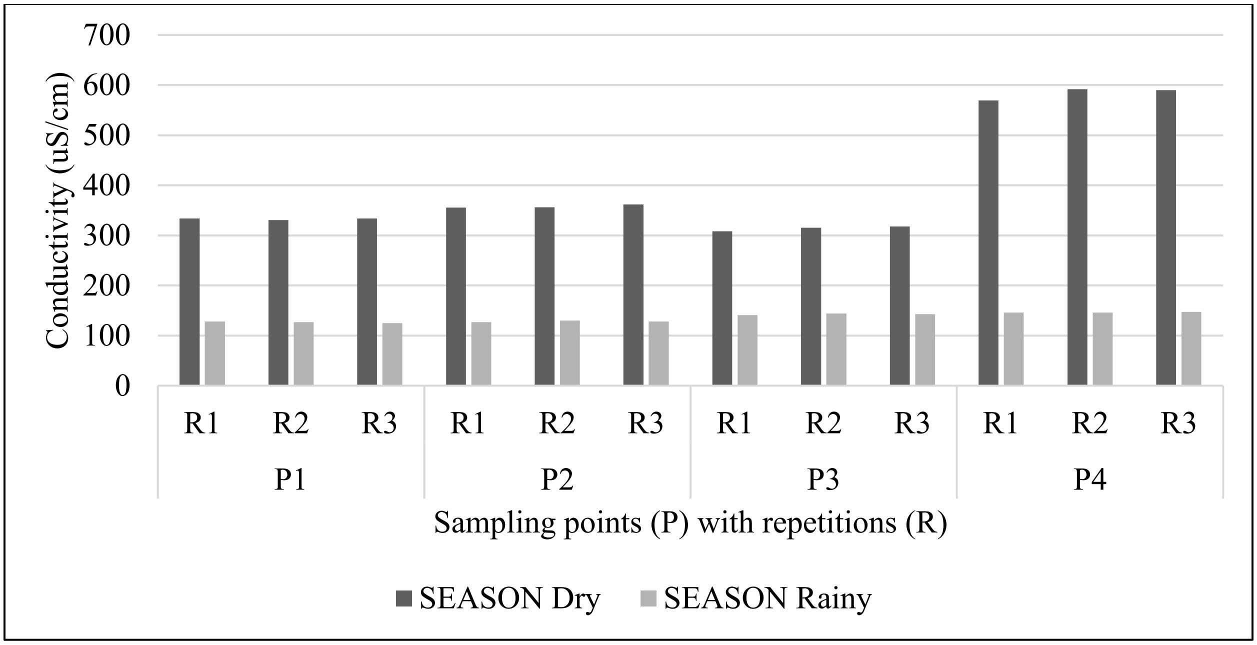

Figure 3. Conductivity results during the rainy and dry seasons.

Based on the results presented in Figure 6a regarding total suspended solids (TSS) and Figure 6b regarding volatile solids, a significant increase in the concentration of these particles was observed during the dry season, particularly at sampling point one, where concentrations exceeded 400 mg/L. This rise is attributable to the influence of fluvial activities in the La Zapatosa marsh area, where flow agitation promotes sediment resuspension, resulting in increased turbidity and suspended solids. Additionally, the confluence of the Cesar River with the marsh further contributes to this phenomenon. As the flow moved downstream, values decreased to 70 mg/L at point 2, following a pattern similar to that observed in turbidity levels. This trend suggests that the channel morphology and low flow velocity favored a laminar regime, facilitating the deposition of sediments and organic matter on the riverbed. However, at point four, maximum values of 373 mg/L were recorded, coinciding with sediment extraction activities from nearby tributaries and the mouth of smaller lotic sources. This behavior aligns with the findings of Hernández et al. (2022), who noted that high TSS levels may be associated with erosion processes, domestic discharges, material extraction, and improper disposal of solid waste, all of which are directly linked to increased turbidity. Furthermore, the predominant agricultural and livestock activities in the area contribute to the degradation of water resources due to the constant use of pesticides, fertilizers, and agrochemicals, which are washed into rivers and streams through surface runoff.

In contrast, during the rainy season, a significant reduction in suspended solids concentrations was evident, with values ranging between 10 and 40 mg/L. This decrease is explained by the dilution effect generated by the increased flow, which promotes sediment transport along the riverbed and hinders sedimentation. Although rivers mobilize large volumes of particles during the rainy season, the higher current velocity prevents their effective deposition as occurs in dry periods. Jaramillo and Salcedo (2023) indicate that when transport and resuspension levels are low, it can be inferred that flow velocities have decreased, thereby reducing suspended solids concentrations in the fluvial system.

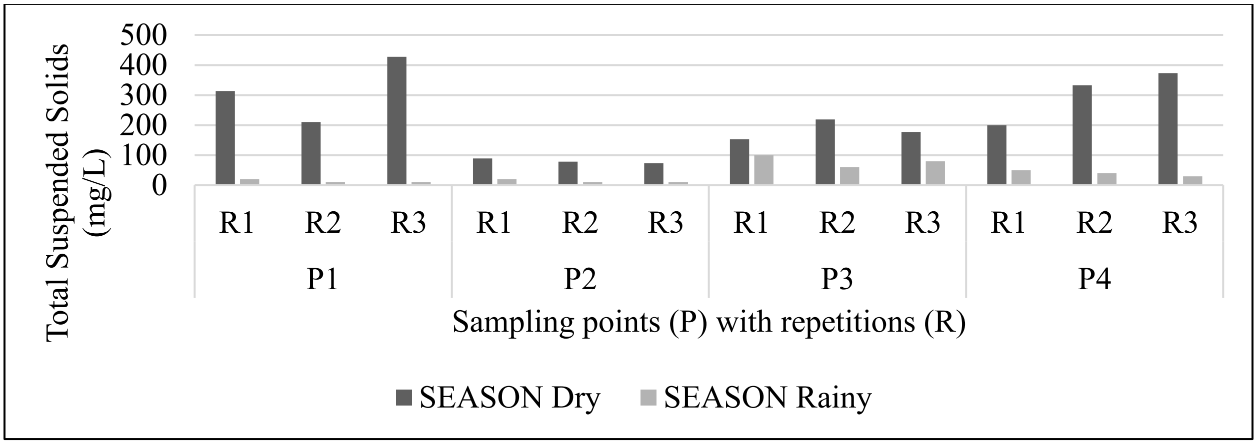

Figure 4a. Results of total suspended solids during the rainy and dry seasons.

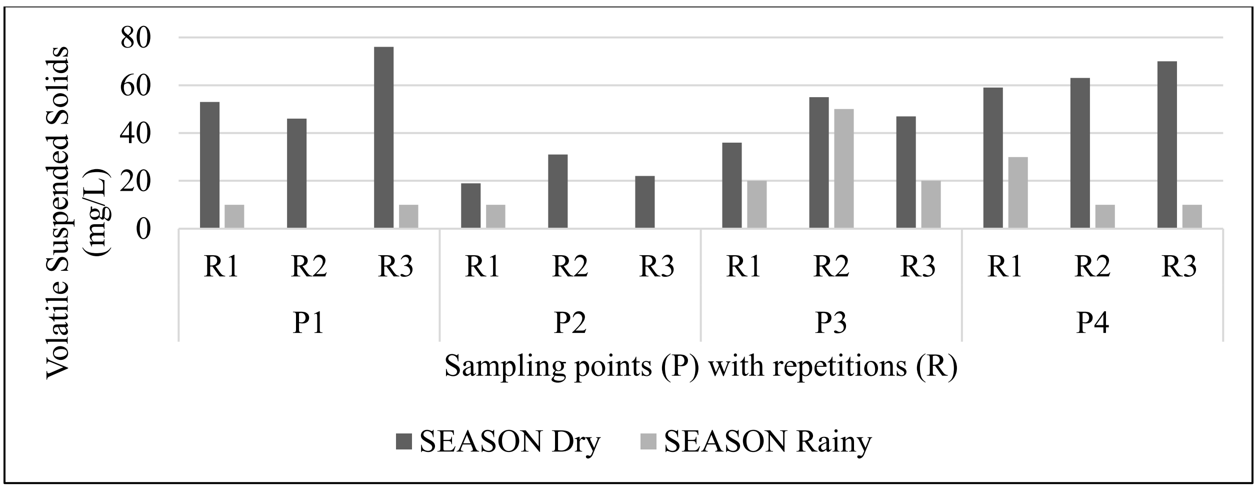

Figure 5b. Results of volatile suspended solids during the rainy and dry seasons.

According to the dissolved oxygen (DO) parameter results at the monitoring sites, as shown in Figure 7, the average concentration at the sampling points during the dry season remained close to 4 mg/L of O_2. This value is considered a minimum acceptable threshold for the survival of aquatic organisms, especially fish, which require concentrations equal to or above this level to maintain proper metabolic functions. Therefore, ensuring optimal DO levels is essential for preserving the ecological and functional integrity of aquatic ecosystems. This parameter reflects the water body's capacity to sustain life and perform self-purification processes (Jiménez, 2023).

During the rainy season, dissolved oxygen concentrations increased significantly at all evaluated points. This increase is attributed to greater natural aeration of the fluid, associated with flow turbulence, surface agitation, and foam formation along the river's course, which facilitates gas exchange with the atmosphere. According to Hurtado and Silva (2022), high DO levels may indicate low pollutant loads, thus reducing bacterial activity related to organic matter degradation. Additionally, factors such as the presence of aquatic vegetation, aerobic microorganisms, and inorganic reduction processes influence DO variability, enhancing the river ecosystem's self-purification capacity.

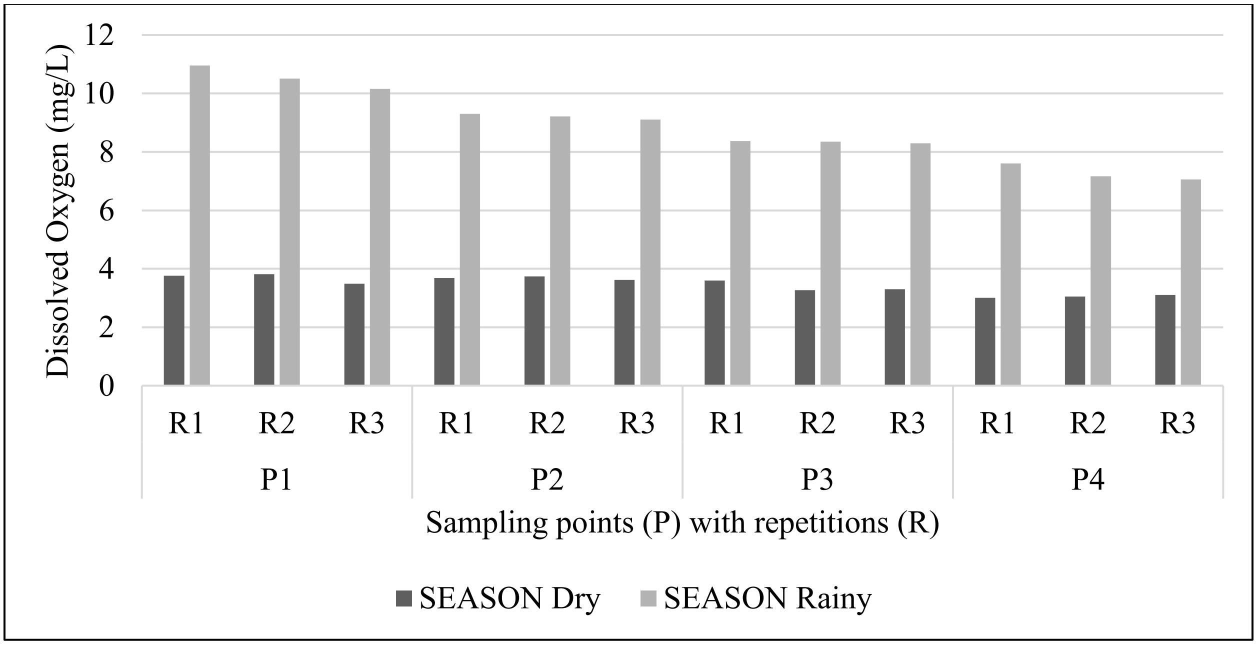

Figure 6. Dissolved oxygen results during the rainy and dry seasons.

The results obtained regarding the Biochemical Oxygen Demand (BOD), represented in Figure 8, revealed a variable behavior between seasons. During the dry season, a progressive reduction in BOD levels was observed from sampling point one to point three, decreasing from 50 mg/L to 22 mg/L, suggesting a possible decrease in biodegradable organic load downstream. However, at point four, a significant increase was recorded, reaching values close to 45 mg/L, which may be associated with the accumulation of organic matter due to low flow and limited water renewal in this section, as well as potential point or diffuse discharges of anthropogenic origin (Rincón & Pérez, 2020).

During the rainy season, an opposite trend was evident, with a sustained increase in BOD levels across the sampling points, starting at 60 mg/L at point one and reaching a maximum value of 120 mg/L at point four. This increase can be explained by the intensification of surface runoff processes, which transport organic residues, fertilizers, and agricultural and livestock waste, as noted by Hernández et al. (2021) and Mora & García (2020), contributing to a higher organic load in the water body.

Regarding the Chemical Oxygen Demand (COD), illustrated in Figure 8, high concentrations were observed in both seasons. Values ranged from 77 to 226 mg/L, remaining especially elevated at point four (117.3 mg/L during the dry season and 226.7 mg/L during the rainy season), reflecting the presence of organic and inorganic compounds that are difficult to biodegrade and require chemical oxidation. Point four showed the lowest concentrations (99.3 mg/L in the dry season and 120 mg/L in the rainy season), possibly due to its intermediate location and lesser influence from direct pollution sources. According to Pineda (2022), high COD levels are indicative of accumulated organic and chemical pollution, which compromises the self-purification capacity of the water body.

The relationship between BOD and COD suggests that pollution sources in the study area include both biodegradable organic matter and more persistent chemical substances, many of which are associated with agricultural, livestock, and potential domestic wastewater activities. This scenario aligns with the findings of Muñoz et al. (2024), who emphasize the importance of continuous monitoring to establish water quality patterns and propose environmental mitigation strategies.

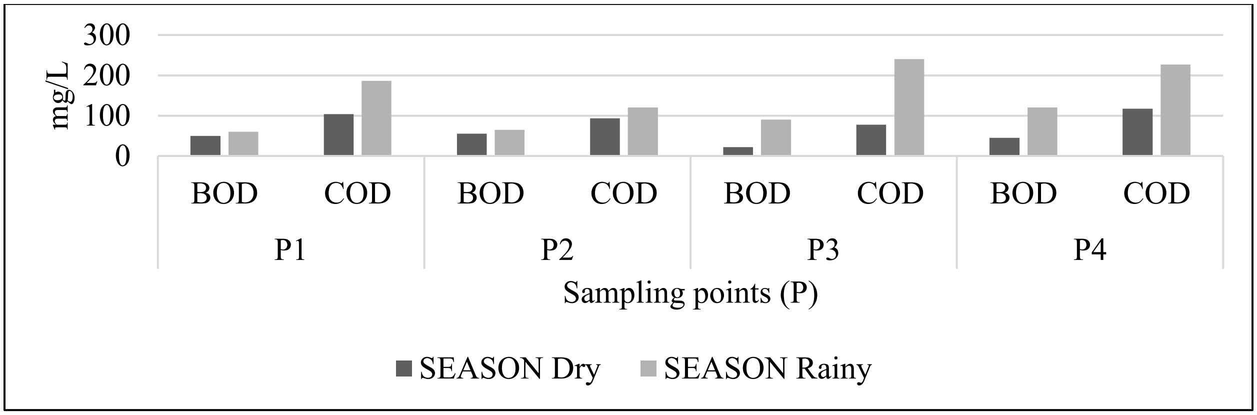

Figure 7. Results of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) during rainy and dry seasons.

Based on the phosphate levels described in Figure 9, elevated phosphate concentrations were recorded during the dry season, with estimated values ranging from 0.75 to 0.95 mg PO_4/L, particularly at sampling sites 3 and 4. This behavior indicates a possible accumulation of nutrients in the fluvial system due to the low flow rate and limited dilution capacity. In contrast, during the rainy season, phosphate levels significantly decreased, reaching concentrations between 0.20 and 0.45 mg PO_4/L. This reduction could be attributed to a dilution effect resulting from increased river flow and the dispersion of pollutants.

According to Saldaña et al. (2024), the presence of phosphates in water bodies can originate from multiple sources, including the excessive use of agricultural fertilizers, the discharge of domestic wastewater, and the use of detergents. In the case of the Cesar River, these contributions may be linked to discharges from wastewater treatment plants located upstream, whose effluents directly affect water quality. This phenomenon is closely related to parameters such as BOD and COD, since an increase in the concentration of biodegradable organic matter is often accompanied by a higher nutrient load, such as phosphates, and an increase in electrical conductivity, indicating a higher ionic content dissolved in the water.

Rojas et al. (2023) argue that variables such as phosphates, BOD, and COD are associated with redox processes of organic matter, which reflect a high input of organic substances into the water body. This condition is characteristic of fluvial systems subjected to high pollutant loads, especially during dry seasons when the water renewal capacity is reduced. Under these conditions, eutrophication processes are favored, leading to significant alterations in the ecological balance of the aquatic ecosystem.

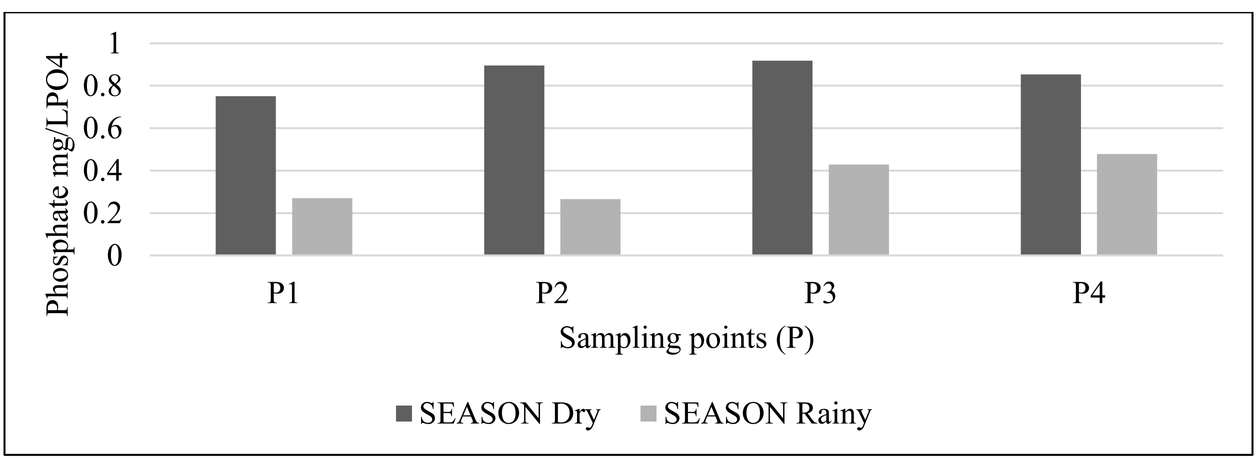

Figure 8. Phosphate results during rainy and dry seasons.

In contrast, the nitrate levels described in Figure 10 showed an opposite trend to that observed for phosphates. During the dry season, concentrations were minimal, with values close to 0.2 mg NO_3^-/L, representing the detection limit of the laboratory equipment used. However, in the rainy season, a significant and uniform increase was recorded across all sampling stations, reaching average values of 0.866 mg NO_3^-/L. This behavior suggests that precipitation and surface runoff play a fundamental role in transporting nitrogen compounds into the water body.

According to Paucar et al. (2023), nitrates present in rivers mainly originate from agricultural activities, such as the intensive use of fertilizers, insecticides, and fungicides, whose residues are transported by rainwater through soil infiltration or surface runoff—especially in areas with steep slopes or limited vegetation cover. While nitrates are essential nutrients in aquatic ecosystems, their excess can lead to negative effects. As Carrillo (2025) warns, when these concentrations exceed the ecosystem's assimilation capacity, they can promote eutrophication processes, resulting in excessive proliferation of algae and microorganisms, reduced dissolved oxygen levels, and disruptions in aquatic biodiversity. This situation, common in riparian zones with intense agricultural, urban, or rural activity, poses a risk to the water quality of the Cesar River and can directly affect both aquatic fauna and flora.

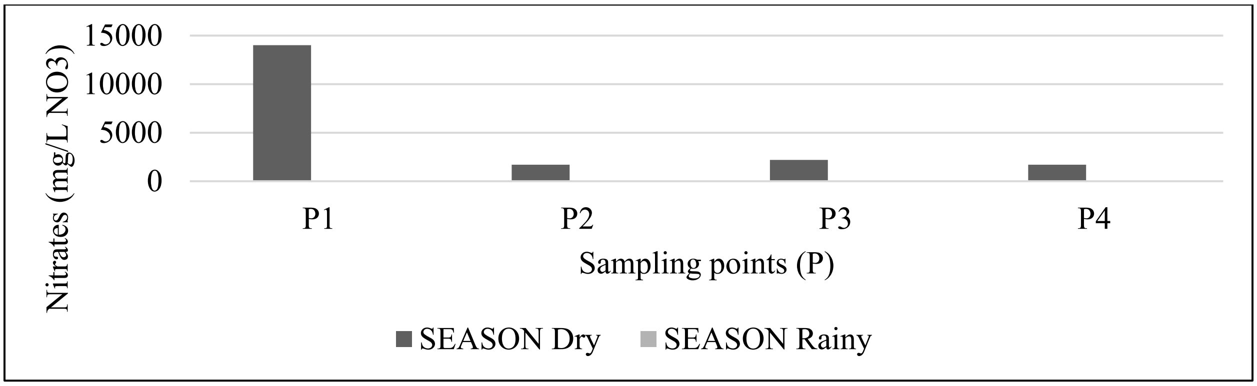

Figure 9. Nitrate results during rainy and dry seasons.

According to the results presented in Figure 11 regarding fecal coliforms, a significant increase in this parameter was observed during the dry season, particularly at sampling point one, reaching a maximum value of 14,000 MPN/100 mL. This high concentration is mainly attributed to the proximity of the village of Saloa, an area where a direct discharge of untreated wastewater was identified, placing significant pressure on the microbiological quality of the water resource. As the river flows toward points 2, 3, and 4, a decrease in fecal coliform levels is observed (ranging from 1,700 to 2,200 MPN/100 mL), suggesting a natural dilution process and a certain degree of self-purification capacity of the fluvial system. However, these levels do not reach safe or acceptable standards from a public health perspective.

This concentration pattern correlates with the values observed for parameters such as Chemical Oxygen Demand (COD) and phosphates, as high levels of organic matter and nutrients in the area promote bacterial growth. According to Mosquera and Peña (2021), fecal coliforms are closely linked to organic contamination and serve as a key indicator of anthropogenic impact on water bodies, especially in areas where domestic discharges and a lack of sanitation infrastructure prevail.

During the rainy season, fecal coliform levels decreased considerably, dropping below 50 MPN/100 mL. This decline is explained by the increased river flow, which enhances the dilution effect and the downstream transport of contaminants. However, this apparent improvement does not guarantee adequate water quality for human consumption, recreational, or agricultural use, given that the presence of any level of fecal coliforms represents a significant microbiological risk (Novoa & Rico, 2024).
Therefore, the persistence of this type of contaminant reflects structural deficiencies in wastewater management and unplanned land use in riparian areas. As highlighted by Mojica et al. (2014), the increase in coliforms can have direct consequences on aquatic biodiversity and public health, necessitating

comprehensive interventions aimed at wastewater treatment and the conservation of the ecological quality of water bodies. Likewise, studies conducted by Zayas and Correa (2024) regarding water use for human consumption emphasize that parameters related to the presence of bacteria, viruses, and other pathogens in water—such as fecal coliforms—indicate potential microbiological contamination, thus representing a health risk manifested in possible gastrointestinal diseases.

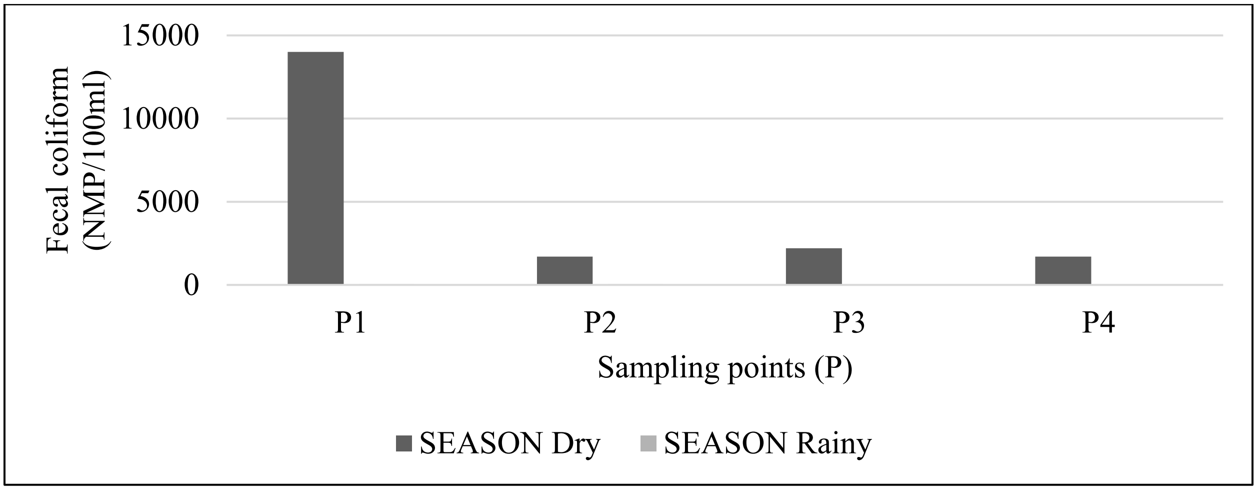

Figure 10. Fecal coliform parameter during rainy and dry seasons.

Application of the Water Quality Index (WQI) using the IDEAM methodology

According to the WQI determination methodology proposed by IDEAM (2020), as detailed in Table 4 and Figure 12 of this research article, it was found that the water quality index for both the dry and rainy seasons poses a risk for human consumption. The qualitative result showed that during the dry season, the WQI category was POOR, while during the rainy season, the category improved to FAIR. When comparing both seasons, it can be inferred that water quality improved during the rainy season in the study area. This improvement was mainly due to parameters such as dissolved oxygen, chemical oxygen demand (COD), and pH, which yielded higher-than-expected values, thus affecting the corresponding classification.

These results corroborate the current situation of the lower basin of the Cesar River based on the findings described by Ariza et al. (2023) regarding water quality in the river's middle basin. These findings indicate that the environmental conditions of the Cesar River occasionally deviate from their natural state, which can limit certain potential uses of this water body. That is, the river can be used under specific activities and during certain times of the year when the risk level is lower (depending on the intended use). Specifically, it is advisable to use this resource during the rainy season, due to the considerable improvement in water quality, which may allow its use for lower-risk activities. It is also emphasized that this classification is unlikely to improve significantly because the main sources of contamination in the Cesar River stem from the wastewater treatment plants in the departments of Cesar and La Guajira, which discharge into this watershed, thereby conditioning or restricting its use.

Comparatively, similar studies have reported analogous situations in other Latin American watersheds. For example, in the Mashcón River basin (Peru), Machuca and Eugenio (2023) applied the NSF-WQI method and documented water quality ranging from "Poor" to "Acceptable," depending on the area and evaluation period, also highlighting the influence of unregulated urban and agricultural activities. Similarly, Mancilla et al. (2024) reported that in the Ayuquila-Armería River basin (Mexico), although the water was suitable for agricultural irrigation, the physicochemical and microbiological parameters indicated poor quality for potable use and aquatic life protection. This was attributed to urban discharges and intensive use of agrochemicals. In the case of the Cesar River, it is notable that critical values of BOD, COD, fecal coliforms, and nutrients such as phosphates and nitrates directly contribute to the reduction of the WQI. These parameters reflect a high organic load and continuous pressure from human activities, as noted by García et al. (2021) and Castillo (2019) in similar studies on water bodies in rural and urban contexts.

Tabla 4. Determinación del índice ICA – IDEAM en temporada de sequía y lluvia.

Variable	Weight ICA	DRY SEASON							
		(i) Point 1		(i) Point 2		(i) Point 3		(i) Point 4	
		Calculated	Assigned	Calculated	Assigned	Calculated	Assigned	Calculated	Assigned
Dissolved Oxygen (DO)	0,17	0,569	0,569	0,569	0,569	0,523	0,523	0,477	0,477
Suspended Solids	0,17	0,070	1,000	0,780	1,000	0,471	1,000	0,114	1,000
Chemical Oxygen Demand (COD)	0,17	104,000	0,125	93,330	0,125	77,300	0,260	117,300	0,125
Electrical Conductivity	0,17	-0,316	0,000	-0,452	0,000	-0,217	0,000	-1,796	0,000
Total N / Total P Ratio	0,17	0,266	0,150	0,223	0,150	0,218	0,150	0,234	0,150
pH	0,15	7,900	1,000	8,000	1,000	8,000	1,000	8,000	1,000
WQI	Value	0,464		0,464		0,479		0,448	
	Quality	Poor		Poor		Poor		Poor	

Variable	Weight ICA	RAINY SEASON							
		(i) Point 1		(i) Point 2		(i) Point 3		(i) Point 4	
		Calculated	Assigned	Calculated	Assigned	Calculated	Assigned	Calculated	Assigned
Dissolved Oxygen (DO)	0,17	1,615	1,615	1,415	1,415	1,277	1,277	1,123	1,123
Suspended Solids	0,17	0,980	1,000	0,980	1,000	0,780	1,000	0,900	1,000
Chemical Oxygen Demand (COD)	0,17	60,000	0,260	65,000	0,260	90,000	0,125	120,000	0,125
Electrical Conductivity	0,17	0,639	0,000	0,633	0,000	0,576	0,000	0,562	0,000
Total N / Total P Ratio	0,17	3,207	0,150	3,343	0,150	2,070	0,150	2,238	0,150
pH	0,15	6,400	0,733	8,000	1,000	6,700	0,857	6,700	0,857
WQI	Value	0,624		0,630		0,562		0,536	
	Quality	Fair		Fair		Fair		Fair	

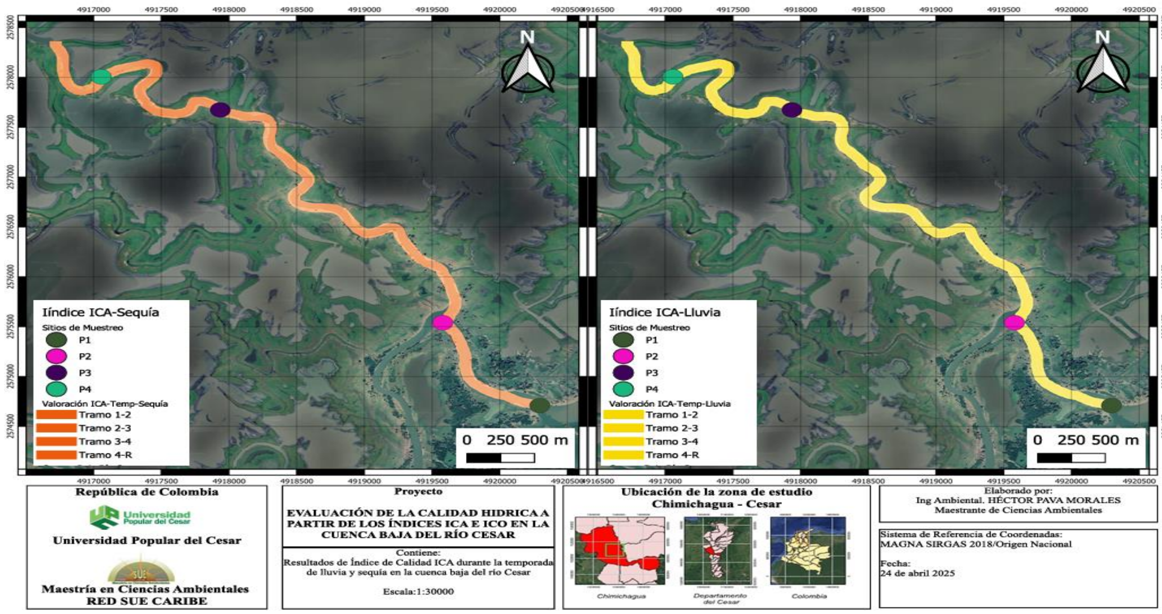

Figure 11. *Map of the study area with Water Quality Index (WQI – IDEAM) results for both seasons.*

Studies conducted by Melo (2021) highlight that when water quality is found to be degraded, it is primarily caused by the clustering of key parameters such as BOD, COD, and total coliforms, which result from various decomposing waste materials or contaminated domestic wastewater from properties adjacent to the water source. In this case, that includes the township of Saloa and farms located within the river's study area, as well as the discharge of wastewater from municipalities located upstream in the Cesar River basin. This is confirmed by Uribe et al. (2023), whose study shows that poor water quality is caused by multiple discharges along the river, further worsened by productive activities near the riverbanks, due to high levels of organic matter from agricultural and domestic sources.

This deterioration in water quality, reflected in the WQI as proposed by IDEAM (2020), is supported by similar studies such as Rojas (2024), who states that this situation is associated with changes in land use, vegetation cover, population growth, and overexploitation of surface water bodies in the area, significantly affecting both the quantity and quality of available water. In other words, the productive activities and wastewater discharges along the course of the Cesar River have steadily degraded its condition over time, without clear or strengthened environmental and sanitation policies related to monitoring and controlling discharges—including the adoption of sustainable agricultural practices, as proposed by Mazzeo and Pérez (2019) and Jaimes and Sepúlveda (2019) in their respective studies on water quality in rural contexts.

Likewise, one of the key factors exacerbating the water quality of the Cesar River—particularly in the study area—is the civic behavior of residents along the riverbanks in the municipality of Chimichagua, Cesar. According to studies conducted by Solano (2021), it is clearly emphasized that the deterioration of water quality in the Tejo and Chiquito rivers in Ocaña, Norte de Santander, is mainly caused by the civic habits and customs of residents who use the riverbanks as open-air dumping sites for solid waste and as discharge points for untreated wastewater. This presents a scenario similar to that found in the present study area, which is further worsened by productive activities such as cattle ranching, agriculture, material extraction, and especially the discharge of untreated wastewater (Guzmán, 2013; Ariza et al., 2023).

4. Conclusions

The comprehensive analysis of physicochemical and microbiological parameters revealed that high levels of suspended solids, turbidity, BOD, COD, phosphates, nitrates, and fecal coliforms are closely linked to anthropogenic activities such as intensive agriculture, extensive livestock farming, untreated wastewater discharges, and material extraction from the riverbed.

These factors have a negative impact on the quality of the water resource, especially at critical points like the township of Saloa, where a direct discharge of sewage was clearly identified.

Furthermore, comparison with similar studies in other river basins in Colombia and Latin America revealed a common pattern of water quality degradation in areas with low coverage of public utilities, unregulated agricultural pressure, and poor wastewater management. This positions the Cesar River within a scenario of environmental vulnerability that requires urgent control and restoration measures.

The assessment of water quality in the lower Cesar River basin, using the Water Quality Index (WQI) methodology proposed by IDEAM (2020), demonstrated unfavorable conditions for human consumption. The results categorized the water quality as “Poor” during the dry season and “Fair” during the rainy season, showing a slight improvement attributable to dilution effects and increases in parameters such as dissolved oxygen and pH during the latter period.

Therefore, the water quality of the lower Cesar River remains compromised. Although the rainy season marginally improves its condition, contamination levels still exceed permissible limits for safe use. This underscores the need to implement comprehensive environmental management strategies, including the strengthening of wastewater treatment facilities, adoption of sustainable agricultural practices, continuous monitoring, and environmental education for local communities, aiming to progressively restore the ecological functionality of the fluvial ecosystem.

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