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Evolution of water quality in a water system in northern Boyacá using the BMWP/Col index

Johan Hernán Pérez[1], Zulma Edelmira Rocha-Gil[2], Claudia Constanza Pérez-Rubiano[3], Dumar Ariel Parrales-Ramírez[4], Diego Hernando Angulo-Flórez[5]

Abstract

This study characterizes the water conditions in different sectors of the Comeza River in the municipality of Socotá, located in the northern part of the Boyacá Department, in order to estimate the quality and analyze possible changes associated with the socioeconomic activities present in its ecosystem. Aquatic macroinvertebrates were collected, and the BMWP/Col index was used to identify the evolution of water quality during the dry period (March) and the wet period (October) in the years 2019, 2020, and 2021. A total of 27 groups of macroinvertebrate families were recorded across all study periods, with the highest abundance observed in Leptophlebiidae, followed by Perlidae and Baetidae. The BMWP/Col index indicates that, on average, the river has water of class II quality (Acceptable), meaning slightly contaminated water mainly in P2 and P3. Of particular concern was the analysis of field data during the post-pandemic period (2021), where it was noted that P2 is in a critical state regarding water quality; this area is adjacent to the urban perimeter. The development of this type of research in high mountain water systems will allow for measures to be taken for the sustainable management of watercourses, as well as the mitigation of pollution in them. The identification and elimination of possible point sources of contamination, the use of good agro-environmental practices, and the restoration of riverbanks along the Comeza River may be essential for improving the ecological status of this river system.

Keywords: Water quality evolution, Benthic macroinvertebrates.

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[1] MSc. Research director at Universidad de Investigación y Desarrollo UDI, Research Group on teaching and innovation in science learning FIELDS. E-mail: johan.perez@uptc.edu.co
orcid.org/0000-0003-1501-5195 **Google Scholar**
[2] MSc. Professor at Universidad de Boyacá, Research Group Environmental Management.
E-mail: zerocha@uniboyaca.edu.co
orcid.org/0000-0001-8331-4707 **Google Scholar**
[3] MSc. Professor at Universidad Pedagógica y Tecnológica de Colombia, Research Group Micro and Macro Environmental Studies MICRAM. E-mail: claudia.perez01@uptc.edu.co
orcid.org/0000-0003-0698-1826 **Google Scholar**
[4] MSc. Professor at Universidad Internacional del Trópico Americano, Environmental Biology Program. E-mail: dumarparrales@unitropico.edu.co
orcid.org/0000-0001-7058-0897 **Google Scholar**
[5] PhD. Professor at Universidad Pedagógica y Tecnológica de Colombia. Chemical Program E-mail: diego.angulo@uptc.edu.co
orcid.org/0000-0002-8693-1097 **Google Scholar**

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Evolución de la calidad de agua en un sistema hídrico del norte de Boyacá utilizando el índice BMWP/Col

Resumen

Este trabajo caracteriza las condiciones hídricas en diferentes sectores del río Comeza del municipio de Socotá ubicado al norte del Departamento de Boyacá, con el fin de estimar la calidad y analizar posibles cambios asociados a las actividades socioeconómicas presentes en su ecosistema. Se colectaron macroinvertebrados acuáticos y se empleó el índice BMWP/Col para identificar la evolución de la calidad del agua en período seco (mes de marzo), y período húmedo (mes octubre), durante los años 2019, 2020 y 2021. Se registró un total de 27 grupos de familias de macroinvertebrados distribuidas en todos los periodos de estudio, con mayor abundancia se observaron: Leptophlebiidae, seguido de Perlidae y Baetidae. El índice BMWP/Col indica que, en promedio el río presenta aguas de calidad clase II (Aceptable), es decir aguas Ligeramente contaminadas principalmente en el P2 y P3. Un resultado de mayor atención, fue el análisis de la salida de campo en época pospandemia (año 2021), donde se distinguió que, en el P2 este se encuentra en estado crítico sobre la calidad del agua, esta zona es aledaña al perímetro urbano. El desarrollo de este tipo de investigaciones en sistemas hídricos de alta montaña, permitirá la toma de medidas para la gestión sostenible de los cursos de agua, así como la mitigación de contaminación en los mismos. La identificación y eliminación de posibles fuentes puntuales de contaminación, el uso de buenas prácticas agroambientales y la recuperación de riberas a lo largo del río Comeza, pueden ser esenciales para mejorar el estado ecológico de este sistema fluvial.

Palabras clave: Evolución calidad de agua, Macroinvertebrados bentónicos.

Introduction

The increase in human population and its anthropogenic activities lead to significant fragmentation in natural systems, prompting the implementation of short- and medium-term measures to address problematic situations associated with environmental pollution in natural resources, primarily in water resources (Arimoro and Keke, 2021; Edegbene et al., 2021). This ecological and environmental deterioration has been increasingly evident in the last decade and in multiple forms: severe droughts, hurricanes, loss of biodiversity, and soil erosion (Murillo-Montoya et al., 2018; Pérez et al., 2023). Therefore, the use of management and prevention tools is imperative to ensure the sustainable use of water resources in the country (Forero et al., 2014; Rodriguez et al., 2021).

One of the most commonly used biotic indices to assess water quality is the *Biological Monitoring Working Party* (BMWP), adapted for Colombia by Roldán-Pérez (2003) as the *Biological Monitoring Working Party-Colombia* (BMWP/Col). This is an optimal tool for recognizing the state and evolution of water ecosystems affected by organic pollution. According to Rocha et al. (2015), the BMWP system has been modified and adjusted based on macroinvertebrate studies conducted in some regions of the country, providing a BMWP/Col score with effective results for characterizing surface waters. This is because this group of insects offers various advantages, including wide distribution, adaptation to different physical-biotic variables, methodological simplicity, rapid results, and a retrospective view of contamination events (Fierro et al., 2012; Machado et al., 2018; Pérez et al., 2020).

Several areas in the department of Boyacá face serious challenges related to water quality, especially those areas whose main economy is mining, causing water scarcity, low water quality, and sanitation-related diseases (Navia et al., 2016; Pérez et al., 2021; Rocha et al., 2015; Vargas et al., 2019). In this sense, the Comeza River, which runs through the municipality of Socotá in the northeast of the department, represents an important natural system for human consumption and for socioeconomic activities in the region. The entire water flow is also tributary to the mining river, which, as stated by Agudelo-Calderón et al. (2016), presents contamination problems mainly associated with residual discharges from urban areas and, in general, organic waste from municipal centers, significantly detracting from the landscape and environmental quality of the high Andean ecosystem. Therefore, the objective of this work was to analyze the evolution of water quality in the Comeza River using the BMWP/Col index during two climatic periods in the years 2019, 2020, and 2021.

Materials and Methods

Study Area

The study was conducted in the Comeza River, Socotá municipality (06°02'47"N - 072°38'24"W), located in the Valderrama province, Boyacá-Colombia (Fig. 1). The municipality is characterized as the geographically largest in the province, with an area of approximately 679 km2, an elevation of 2400 meters above sea level (m.a.s.l.), an average annual temperature of 19°C, an average annual precipitation of 1216 mm, and an average annual humidity of 83%. Following Holdridge's classification, its ecosystem structure is of the "Low Montane Humid Forest" type (Bh-Mb).

The Comeza River is the most important tributary that Socotá provides to the Chicamocha River, with an extension of 134.361 km2, a perimeter of 104.06 km, a main drainage length of 20.814 km with a maximum altitude of 3650 m.a.s.l. and a minimum of 1900 m.a.s.l. There are two main discharges into the river; the first one discharges wastewater into the Guarruz stream, which is diverted by ditches for pasture irrigation on the hillside.

For sampling, the study area was divided into three parts. The first point in the upper basin (P1) is located at 3641 m.a.s.l. (05°59'54.6"N - 072°37'50.5"W), where the Comeza River originates (Fig. 1). The sampling site is formed by the confluence of two other rivers, and this area exhibits anthropogenic influences from mining, agriculture, and leachates from cemetery vaults, as well as interference from economic activities such as fish farming.

The second study point, the middle zone of the basin (P2), is located at 2195 m.a.s.l. (06°02'08"N - 072°38'29.8"W), just a few meters from the inter-municipal road leading to the municipality of Socotá (Fig. 1). There, the presence of houses and the influence of acidic waters from coal mines, as well as the presence of crops and livestock, are evident.

For the third point, the lower zone of the basin (P3), located at 1915 m.a.s.l. (06°03'39.7"N - 072°39'16.2"W), it is downstream from the urban area of the municipality (Fig. 1), leading to the mouth that connects to the Chicamocha River. Presence of livestock and coal mines along the water system is also evident.

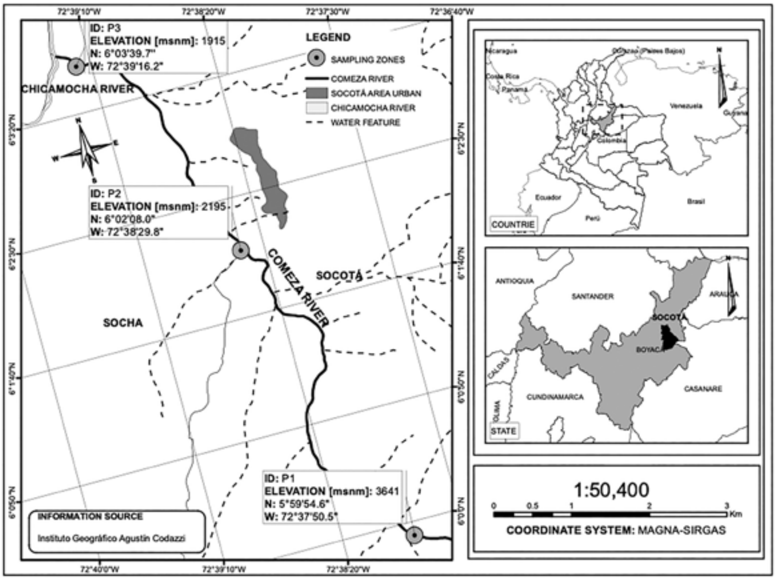

Figure 1. Study area and sampling points: P1 (upper basin), P2 (middle basin), and P3 (lower basin), Comeza River, Socotá, Boyacá-Colombia.

Study Design

Fieldwork was conducted according to the rainfall distribution in the area, determining two sampling campaigns, one during the dry season (March) and one during the rainy season (October), during the years 2019, 2020 and 2021. These periods were defined based on the development of socioeconomic activities such as coal mining, livestock farming, and agriculture, all of which are present in the influence area of the water system.

Collection and identification of biological samples

For the sampling of benthic macroinvertebrates, the methodology proposed by Roldán-Pérez (1999) was employed, which consists of collecting organisms attached to rocks found on the riverbed, surface, and shorelines. To obtain comparable results, sampling covered an area between 10 and 20 m^2 for a duration of 6 to 8 hours. Sample processing was carried out in the Biology laboratory of the University of Boyacá, using a stereoscope (NIKON SMZ 1500) for individual identification. Specialized literature by Roldán-Pérez (1996); Manzo (2005); Heckman (2006); Posada-García and Roldán-Pérez (2003); and Domínguez and Fernández (2009) was used for taxonomic determination.

Data Analysis

For the estimation of the BMWP/Col index, the methodology by Roldán-Pérez (2003) was considered. This index assigns values from 1 to 10 to the families of macroinvertebrates collected in the field. Values 1, 2, and 3 indicate contaminated waters, while high values 9 and 10 indicate uncontaminated waters. The obtained values reveal the degree of tolerance or sensitivity of each group of macroinvertebrates to organic contaminants, demonstrating the alteration of the ecosystem in which they inhabit.

Results

A total of 10,063 individuals distributed among seven (7) orders, twenty-seven (27) families, and thirty-six (36) morphospecies were collected. During the dry season, 6150 individuals were collected, compared to 3913 individuals during the rainy season. Abundance results per year reflect another significant variation; 3668 individuals were observed in 2019, 2574 in 2020, and 3821 individuals in 2021 (Table 1).

Regarding macroinvertebrate families, a total of 27 groups were recorded across all study periods. The most abundant were Leptophlebiidae with 2,855 individuals, followed by the Perlidae family with 2,070 individuals, and Baetidae with 1,670 individuals. Families with lower representation were Dytiscidae, Elmidae, and Lampyridae with 2, 3, and 4 individuals respectively (Table 1).

Table 1. Abundance of macroinvertebrates at sampling points along the Comeza River during the evaluated periods and years.

			Year	**2019**						**2020**						**2021**						**Total**
			Month	**March**			**October**			**March**			**October**			**March**			**October**			
Class	**Orden**	**Family**	**Genera**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	
Insecta	Coleoptera (3.7%)	Chrysomelidae	*Donacia* sp.	14			7									54			10			85
		Dytiscidae	*Dytiscus* sp.	2																		2
		Elmidae	*Disersus* sp.		2			1														3
		Lampyridae	sp 3	4																		4
		Psephenidae	*Psephenops* sp.		32	4		16	2		15			11						55	10	145
		Ptilodactylidae	*Anchytarsus* sp.	6		2	3		1	3						18		9				42
		Scirtidae	*Elodes* sp.	18			9			9						45			5			86
		Staphylinidae	*Pontamalota* sp.	6		2																8
	Diptera (10.6%)	Blephariceridae	*Limonicola* sp.	11	6		10	3		3	6		2			18			30			89
			Paltostoma sp.	4			2			6						108						120
		Chironomidae	*Chironomus* sp.	90			45			6						99			45			285
		Dixidae	*Dixella* sp.	2						3			2			108						115
		Muscidae	*Lispe* sp.	1						3			2			117						123
		Psychodidae	*Clogmia* sp.			2			1												5	8
			Maurina sp.	1						3			2									6
		Tipulidae	*Molophilus* sp.	2			1			3			2			198						206
			Tipula sp.	1			1			3						99			10			114
	Ephemeroptera (44.7%)	Baetidae	*Baetis* sp.		20			10			90			4								124
			Baetodes sp.	156	26	98	74	13	49	2	16	135	46	9	22				390	40	245	1321
			Dactylobaetis sp.	2	46		1	23		3	39		28						5	15		162

Insecta	Ephemeroptera (44.7%)	Ephemeridae	*Ephemera* sp.		6									28								34
		Leptophlebiidae	*Terpides* sp.		6			3														9
			Thraulodes sp.	284	355	402	137	178	200		1	315	250		80		288	116	15	200	25	2846
	Hemiptera (0.7%)	Veliidae	*Microvelia* sp.	4			2						48			9			5			68
	Neuroptera (1.5%)	Corydalidae	*Corydalus* sp.	2	10	10	1	5	5		6	12	24	4	8			45	5	5	10	152
	Plecoptera (20.6%)	Perlidae	*Anacroneuria* sp.	70	185	264	37	173	133	10	168	156	20	112	116	9	351	36	60	130	40	2070
	Trichoptera (18.2%)	Glossosomatidae	*Mortoniella* sp.	23	14		12	7			3		2	64					55	15		195
		Helicopsychidae	*Helicopsyche* sp.	60			31			45			30			135			15			316
		Hydrobiosidae	*Atopsyche* sp.	6		2	3		1	6		102	4		24	9		72				229
		Hydropsychidae	*Leptonema* sp.		8	34		1	17			96		22	2		9	9		10	80	288
			Smicridea sp.		16			8			12						54					90
		Hydroptilidae	*Hydroptila* sp.	55			26			48			32			99			10			270
			Ochrotrichia sp.	4			2			6			4									16
		Leptoceridae	*Atanatolica* sp.	2			1			3			22			9						37
			Nectopsyche sp.	18			10			6			26			81						141
		Philopotamidae	*Chimarra* sp.			2			1			129		46	4		27	45				254
Grand total by basin				848	732	822	415	441	410	171	356	945	546	300	256	1215	729	332	660	470	415	10063
Grand total per sampling event				2402			1266			1472			1102			2276			1545			
Grand total per year				3668						2574						3821						

Source: Own elaboration.

During the dry sampling conducted in 2019, the results of the BMWP/Col index for P1 show that this area has Good quality water (≥ 137), while P2 and P3 were considered "Slightly contaminated water: Evidence of contamination effects" (82 - 85) (Fig. 2). During the rainy period, all three points were classified as water quality class II (Acceptable), again considered "Slightly contaminated water: where contamination effects are evident" (≥ 79 - 113), demonstrating a significant change during this time interval at P1 (Fig. 3).

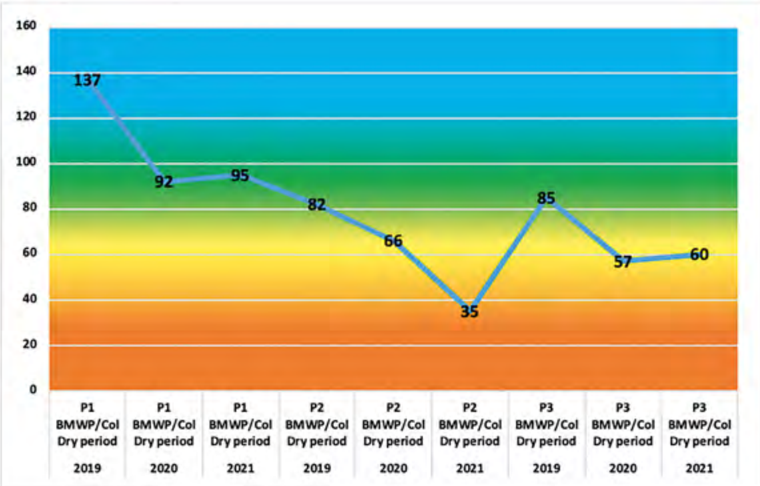

Figure 2. Variation of the BMWP-Col Index (dry season) in the course of the Comeza River in the municipality of Socotá-Boyacá, samplings carried out in the years 2019, 2020, and 2021.

For 2020 (pandemic times), the BMWP/Col results in March (dry season) showed a score of 92 for P1, "Slightly contaminated water: Evidence of contamination effects", while the other two sampling zones, P2 and P3, were considered of dubious water quality (66 - 57), that is, "Moderately contaminated water" (Fig. 2). The results for water quality during the rainy season (October) showed scores ranging from ≥ 57 to 106, again classifying P1 as "Slightly contaminated water" and P2 and P3 as "Moderately contaminated water" (Fig. 3).

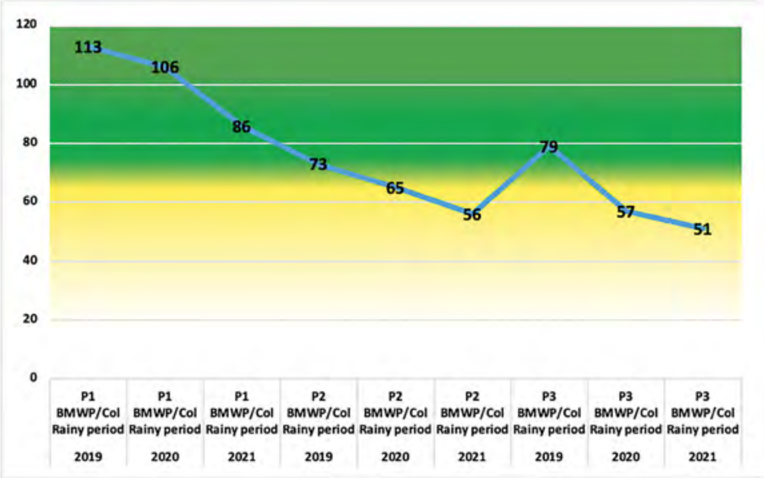

Figure 2. Variation of the BMWP-Col Index (rainy season) in the course of the Comeza River in the municipality of Socotá-Boyacá, samplings conducted in the years 2019, 2020, and 2021.

The samplings carried out in the Comeza River during 2021 (post-pandemic times), for the month of March, showed critical results regarding water quality, particularly for P2, an area adjacent to the urban perimeter, which obtained a BMWP/Col score of 35, considered as "Highly contaminated water". For P1 and P3, similar results to the 2020 period for the same season were observed, with "Slightly contaminated water" and "Moderately contaminated water" respectively (95 - 60) (Fig. 2). Regarding the results during the rainy season, scores ranging from ≥ 51 to 86 were observed, classifying P1 as "Slightly contaminated water" and P2 and P3 again as Moderately contaminated water (Fig. 3).

Discussion

Macroinvertebrate communities vary their composition and structure in response to the presence of contaminants generated by anthropogenic activities in lotic systems, which in turn affect the conditions of the water resource (Andrade et al., 2012; Vyas et al., 2015). During the sampling periods in the year 2020, following the health emergency caused by the COVID-19 pandemic in the municipality of Socotá-Boyacá, the discharge of domestic wastewater into the Comeza River increased the flow rate together with the level of contamination, which explains the low presence and/or absence of macroinvertebrates at the three sampling points.

These biological indicators assist in evaluating water properties and provide an estimate of ecological measures promoted by sources of contamination (Cárdenas-

Castro et al., 2018; Fierro et al., 2012; Gargiulo et al., 2016). Dissolved oxygen is a fundamental parameter, as its concentration determines the organisms that, according to their tolerance and range of adaptation, can survive in a given body of water (Gutiérrez and Virgilio, 2016). Based on this, most of these taxonomic groups have more than one feeding form, a condition recorded as an adaptation to the characteristics of the environment (Serna-Macías et al., 2019). The diffuse input of nutrients is the main factor affecting water quality, due to the indiscriminate use of fertilizers (especially phosphate and nitrate), organic contaminants, and settleable solids, as well as bacteria, which contribute to an increase in eutrophication in the system, modifying biological conditions and reducing diversity, and even causing the disappearance of these benthic individuals (Ríos-Tobón et al., 2017; Rocha et al., 2017; Terneus et al., 2012).

The strategic points along the Comeza River exhibit spatial heterogeneity, influenced by biophysical conditions. For P1, a high potential of macroinvertebrate individuals was observed, consistent with the findings of Walteros-Rodríguez et al. (2016), regarding the presence of groups such as Ephemeroptera, Trichoptera, and Plecoptera, communities typically found in mountain rivers, cold, transparent, oligotrophic waters with excellent oxygenation. The results of this research are similar to those found by Terneus et al. (2012), who stated that significant richness and abundance values are located before a mining intervention zone, highlighting a certain level of impact on the river's benthic community.

For points P2 and P3, a synergistic relationship seems to occur due to higher water mineralization, recording toxic residues that prevent the presence of Coleoptera order individuals, especially when sulfates are abundant, transforming later into hydrogen sulfide (Méndez-Rojas et al., 2012). The latter, when combined with oxygen, becomes a key factor in their specific typology in these sampling zones, as most families of this insect group are sensitive to decreasing dissolved oxygen, reducing their abundance or even disappearing within the aquatic ecosystem (García-Alzate et al., 2017; Miguélez et al., 2013; Quispe and Araujo, 2018).

Regarding the low variation in BMWP/Col scores in the three sampling zones during the pandemic period (2020), it is likely due to their shared environmental characteristics along the banks of the Comeza River. The highest BMWP/Col score was found in P1 during the first collection in March 2019, and the lowest score was observed in P2 during the field trip in the summer of 2021, with a class III classification, indicating changes in the system, highly polluted water, or a critical state. However, it is necessary to analyze the peculiar characteristics of the river, as it is a third-order watercourse according to Horton's classification (1945), modified by Vega-Sagarra (2020), being a water system of considerable length (20.814 km), with an average flow of 108.5 l/s, and average depth of 1.19m, which during dry periods may reduce habitat possibilities, food availability, and substrates for benthic species, as it reduces the supply of leaves that are carried along the stream (Serna-Macías et al., 2019; Zuñiga et al., 2016).

According to Pérez et al. (2020), the increase in the supply of allochthonous material transported to riverbeds, reservoirs, lagoons, among others, leading to an increase in volume, depth, and width of water during the rainy season, can contribute to the increase in habitats available for benthic macroinvertebrates. Another factor that may contribute to the increase of these organisms during drought periods is water temperature, as it increases the speed at which nutrients attached to suspended solids convert into soluble forms, becoming readily available to benthic fauna (Posada et al., 2013). Now, flow characteristics also affect the distribution of benthic macroinvertebrates, being another factor regarding the dilution of toxic substances in water (Pascual et al., 2019). Therefore, water current velocity likely directly affects organism displacement in lotic environments and indirectly impacts different types of substrates (Quesada-Alvarado and Solano-Ulate, 2020).

Conclusions

The selected sampling points were crucial for determining water quality and were easily accessible. According to the spatial variation within which the study was framed and the main activities for which the water of the Comeza River is used, it does not exceed any of the standards for irrigation; therefore, the river's quality is suitable for use in agriculture and livestock activities. However, the established ranges for human consumption based on parameters important for water quality control and surveillance systems do not fall within the permissible maximum value, meaning it is not suitable for human consumption.

Based on the results of this study, it is necessary to continue research using physicochemical parameters and biological indices in other urban rivers in the Boyacá department, in water systems with similar patterns of disorderly use and occupation as found in the Comeza River.

There is a high probability that the increase in conjunction with the phenomena of greater occupation of urban premises during the year 2020 has increased discharges from households and therefore water contamination, environmental quality degradation, sedimentation, eutrophication, and solid waste discharge.

There is a need to implement measures for the sustainable management of these watercourses, along with the mitigation of contaminants in them. The identification and elimination of possible point sources of contamination, the use of good agro-environmental practices, and the recovery of riverbanks along the Comeza River are essential factors for improving the ecological status of this river system. Additionally, it is necessary to raise awareness among the population in order to generate public awareness of these issues and thus foster a decisive role in the sustainable management of this natural resource.

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