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EVALUATION OF THE WATER QUALITY OF THE MANAURE RIVER USING BMWP/COL AND ASTP INDICES AND PHYSICAL-CHEMICAL PARAMETERS

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Abstract: The study evaluated the water quality of the Manaure River through physicochemical analysis and bioindication with macroinvertebrates at four points, covering wastewater discharge and the village of La Vega de Jacob. pH, temperature, conductivity, and dissolved oxygen were measured in situ, while BOD_5, COD, phosphorus, and nitrogen were determined in the laboratory. Macroinvertebrates were identified to calculate Shannon-Wiener, Simpson, Margalef, Dominance, BMWP/COL, and ASTP. The results reflected high COD (140 mg/L), BOD_5 (35 mg/L), and total phosphorus (0.71 mg/L) values at the discharge point, as well as decreased diversity and increased dominance. The BMWP/COL ranged from 34 (class IV) to 89 (class II), while the ASTP ranged from 4.25 to 7.50. The coexistence of sensitive and tolerant families was evident, with deterioration at the discharge point and partial recovery downstream. The river shows moderate impact but maintains ecological resilience.

Keywords: BMWP/COL index, ASTP indices, Bioindicators

INTRODUCTION

The quality and availability of fresh water has become one of the most pressing environmental issues of our time. Its progressive degradation directly affects ecological balance, food security, public health, and the sustainability of territories [1]. Globally, pressure on water bodies is increasing due to rising demand, population growth, climate change, and the continuous discharge of wastewater. By 2022, more than 2.2 billion people did not have a secure supply of drinking water and at least 3.5 billion lacked adequate sanitation services, highlighting a persistent vulnerability in water resource management [2]. This reality not only threatens the integrity of aquatic ecosystems, but also compromises the social, productive, and health development of communities that depend on river sources for consumption, agriculture, and the local economy.

Various studies have shown that rivers subjected to domestic or municipal discharges show progressive deterioration in their physicochemical parameters and biological composition, even when the discharges do not derive from large-scale industrial activities [3]. In these lotic systems, the accumulation of organic matter ( ), the increase in nutrients such as nitrogen and phosphorus, the decrease in dissolved oxygen, and the increase in BOD and COD are recurring indicators of environmental disturbance. However, physicochemical parameters alone may be insufficient to assess the actual extent of deterioration, due to their temporal variability and because they do not capture the cumulative effect of pollution. For this reason, the use of bioindicator organisms has become established as a useful tool for interpreting the ecological response to anthropogenic pressure and habitat conditions [4].

In Colombia, the use of benthic macroinvertebrates as ecological indicators is widely recognized for their differentiated sensitivity to pollution and their ability to reflect water quality over time. The BMWP/COL index and its derivative ASTP have been implemented in various studies applied to Andean watersheds, allowing water bodies to be classified into categories ranging from good conditions to critical states of structural disturbance [5]. Their strength lies in the assignment of sensitivity scores to each registered family, which facilitates the quantification of environmental impact according to the tolerance or vulnerability of the taxa present. In turn, richness, diversity, and dominance are metrics that complement the interpretation of ecological status by describing the degree of biological heterogeneity and changes in community structure in response to environmental stress [6].

Despite existing methodological developments, significant gaps still exist in regions where water monitoring is not carried out frequently or where bioassessment tools are applied in a limited manner. This is the case in the municipality of Manaure Balcón del Cesar, where the Manaure River is the main source of local water supply and, at the same time, the direct recipient of wastewater. Institutional records point to historical failures in the operation of the treatment system, low decontamination coverage, and a lack of continuous technical monitoring, which has led to uncertainty about the actual state of the aquatic ecosystem and its purification capacity. The lack of updated data and poor technical monitoring hinder the implementation of effective environmental management policies, as well as decision-making aimed at restoring or preserving the resource.

Given this situation, it is necessary to develop research that integrates physicochemical measurements with ecological sensitivity bioindicators, allowing for an objective diagnosis of the state of the river and its levels of environmental impact. The application of the BMWP/COL and ASTP indices, together with the analysis of macro- and microinvertebrates and variables such as pH, dissolved oxygen, BOD, COD, and nutrients, constitutes a methodological approach capable of revealing the cumulative anthropogenic impact and, simultaneously, the current ecosystem resilience. This approach allows scientific evidence to be generated for public management, territorial planning, and the design of environmental recovery strategies in areas where pressure from untreated discharges threatens water quality and the ecological functionality of the riverbed.

MATERIALS AND METHOD

The municipality of Manaure Balcón del Cesar, located in the northeast of the department of Cesar, Colombia, is situated on the western slope of the Serranía del Perijá, at 775 m above sea level, with coordinates 10°24' N and 73°10' W, and 34 km from Valledupar. Founded in 1875 and established as a municipality by Ordinance 019 of 1980, it is distinguished by its temperate climate and an average annual rainfall of 1361 mm. Its main tributary is the Manaure River, which originates in Cerro Pintado, on the Colombian-Venezuelan border, and flows into the Cesar River after passing through a basin fed by several seasonal streams.

Characterization of the study area

The sampling points were georeferenced using Google Earth, based on the coordinates provided in the Table 1

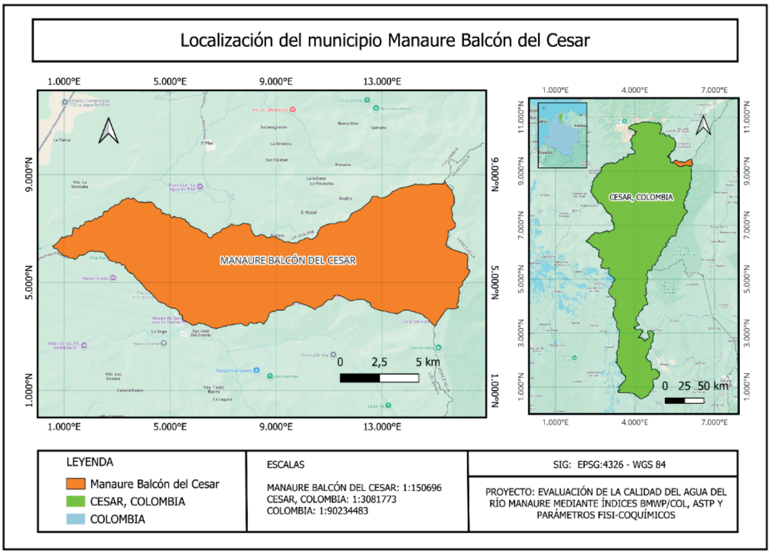

Figure1 . General study area (geographical boundary of the zone: Manaure Balcón del Cesar – Cesar – Colombia)

Point		North	West
1	Before Wastewater Discharge	10°23'2.81"N	73° 2'9.85"W
2	Wastewater discharge	10°23'2.20"N	73° 2'10.36"W
3	Tananeos Reserve	10°23'16.43"N	73° 3'21.54"W
4	La Vega de Jacob Village	10°23'41.77"N	73° 5'52.26"W

Table 1 . Sampling points

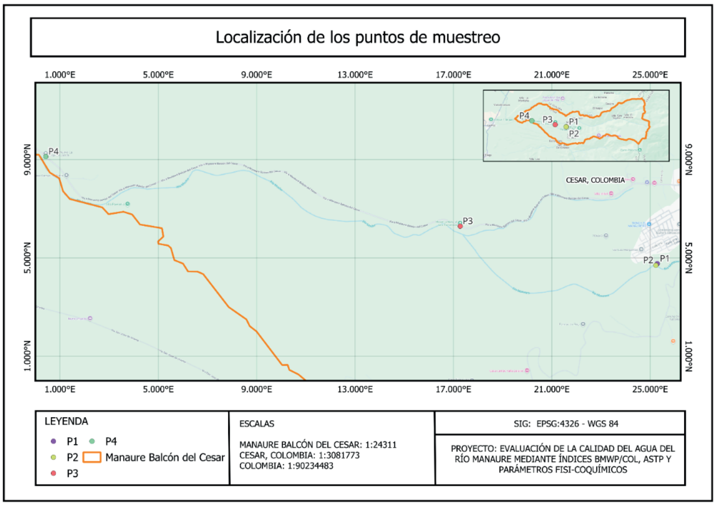

Figure 2. Location of sampling points

Stages of implementation

STAGE I: Characterization of macro- and micro-invertebrates and physicochemical parameters (pH, dissolved oxygen, temperature, conductivity, BOD5, COD, nitrogen, and phosphorus) of the Manaure River from the wastewater discharge point to Vereda La Vega de Jacob

The first stage consisted of selecting sampling points along the section between the wastewater discharge point and La Vega de Jacob, for which an initial survey of aquatic habitats was carried out, considering variations in depth, current speed, substrate type, and vegetation presence, following the selection criteria proposed by Arango et al. (2008). Four GPS-georeferenced points were established to represent the heterogeneity of the lotic system. At each point, water and sediments were collected using hand nets, dredge shovels, and aseptic containers, ensuring the representativeness of relevant microhabitats. pH, temperature, dissolved oxygen, and conductivity were measured in situ with calibrated multiparametric instruments, while samples for BOD_5, COD, total nitrogen, and phosphorus analysis were preserved and transferred to the laboratory under chain of custody. Macro- and microinvertebrates were collected using manual screening and mesh retention techniques; the organisms obtained were fixed in ethanol and subsequently identified using a magnifying glass and binocular microscope, following the taxonomic classification proposed by Roldán-Pérez (2003) and the IDEAM guidelines for taxonomic quality control. This procedure allowed the biological composition and physicochemical conditions of the ecosystem to be characterized for subsequent ecological analysis and interpretation of water quality.

STAGE 2. Determination of the diversity and abundance indices of the macro- and micro-invertebrates identified at different points along the study section to determine variations in water quality

In the second stage, the macro- and microinvertebrates identified at the four sampling points were analyzed to determine patterns of diversity, abundance, and taxonomic composition along the evaluated section. To this end, individuals were quantified by family and functional group, and then the Shannon–Wiener, Simpson, Margalef, and Dominance ecological indices were calculated, widely used in the biological evaluation of lotic systems. The Shannon–Wiener Index (H') was estimated using the expression:

$$H' = -\sum_{i=1}^{S} p_i \, \mathrm{Ln}(p_i) \quad (1)$$

Where $p_i = \frac{n_i}{N}$ Represents the proportion of the number of individuals of the species or family relative to the total N. The Simpson Index (D) was calculated as:

$$D = \sum_{i=1}^{S} p_i^2 \quad (2)$$

While its complementary form of diversity was expressed as . The Margalef Index (d) was estimated using:

$$d = \frac{S-1}{\mathrm{Ln}\,(N)} \quad (3)$$

Where S corresponds to the total number of families or taxa, and N to the total number of individuals recorded in each season. Finally, Dominance (λ) was determined following McNaughton's formula:

$$\lambda = \left(\frac{N_{\text{Dom1}} + N_{\text{Dom2}}}{N} \right) \times 100 \quad (4)$$

Where N_{Dom1} and N_{Dom2} are the two most abundant taxa. The results were subjected to comparative spatial analysis between stations to identify variations in biological structure associated with changes in water quality. Descriptive statistical and graphical analyses were also applied to facilitate the interpretation of the ecological patterns observed.

STAGE 3. Correlation of the results of the BMWP/COL and ASTP bioindicator analysis with physicochemical parameters of the water to establish the level of environmental impact on the aquatic ecosystem

In this stage, the values obtained from the BMWP/COL and ASTP biological indices were correlated with the physicochemical parameters recorded at each sampling point in order to identify the relationship between environmental conditions and the structure of macroinvertebrate communities. The **BMWP/COL** was calculated by adding the scores assigned to each recorded family, according to the biological sensitivity table proposed for Colombian lotic ecosystems. Its mathematical expression is:

$$BMWP/COL = \sum_{i=1}^{n} Puntaje_i \quad (5)$$

where **Score_i** corresponds to the value assigned to taxon *i* according to its tolerance to pollution and *n* is the total number of families present in the sample. The **ASTP** was obtained by dividing the BMWP/COL value by the number of identified taxa, as follows:

$$ASTP = \frac{BMWP/COL}{n} \quad (6)$$

These values were classified based on the scales defined by Álvarez (2006) and Roldán-Pérez (2003), which allow the biological status of water to be interpreted from "good" (>101–120) to "very critical" (<15) conditions. For the correlation process, comparative statistical analyses and scatter plots were applied between the BMWP/COL, ASTP, and physicochemical variables (pH, DO, BOD_5, COD, nutrients), evaluating similarities and dissimilarities between stations. In addition, the scoring matrix for macroinvertebrate families sensitive or tolerant to pollution was used, which facilitated the ecological interpretation of the spatial patterns observed in the Manaure River. The scores of the macroinvertebrate families were taken into account to obtain BMWP/Col present in the Table **2**

Once the index was obtained, the sections evaluated were classified using the BMWP/Col method, which categorizes water quality into different levels (very good, good, doubtful, critical, or very critical), according to established ranges. This procedure made it possible to determine the degree of environmental alteration and the impact of discharges on the biological community, constituting a fundamental tool for the ecological diagnosis of the aquatic ecosystem studied, as presented in Table 3

Score	Families
10	Anomalopsychidae, Atriplectididae, Blepharoceridae, Calamoceratidae, Ptilodactylidae, Chordodidae, Gomphidae, Hydriidae, Lampyridae, Lymnessiidae, Odontoceridae, Oligoneuridae, Perlidae, Polythoridae, Psephenidae
9	Ampullariidae, Dytiscidae, Ephemeridae, Euthyplociidae, Gyrinidae, Hydraenidae, Hydrobiopsidae, Leptophlebiidae, Philopotamidae, Polycentropodidae, Polymitarcyidae, Xiphocentronidae
8	Gerridae, Hebridae, Helicopsychidae, Hydrobiidae, Leptoceridae, Lestidae, Palaemonidae, Pleidae, Pseudothelpusidae, Saldidae, Simuliidae, Veliidae
7	Baetidae, Caenidae, Calopterygidae, Coenagrionidae, Corixidae, Dixidae, Dryopidae, Glossosomatidae, Hyalellidae, Hydroptilidae, Hydropsychidae, Leptohyphidae, Naucoridae, Notonectidae, Planariidae, Psychodidae, Scirtidae
6	Aeshnidae, Ancylidae, Corydalidae, Elmidae, Libellulidae, Limnichidae, Lutrochidae, Megapodagrionidae, Sialidae, Staphylinidae
5	Belostomatidae, Gelastocoridae, Mesoveliidae, Nepidae, Planorbidae, Pyralidae, Tabanidae, Thiaridae
4	Chrysomelidae, Stratiomyidae, Haliplidae, Empididae, Dolichopodidae, Sphaeriidae, Lymnaeidae, Hydrometridae, Noteridae
3	Ceratopogonidae, Glossiphoniidae, Cyclobdellidae, Hydrophilidae, Physidae, Tipulidae
2	Culicidae, Chironomidae, Muscidae, Sciomyzidae, Syrphidae
1	Tubificidae

Table 2. Scoring of macroinvertebrate families to obtain BMWP/Col

Source: Roldán-Pérez (2003)

Class	Quality	BMWP/Col	Meaning	Color
I	Good	>100	Very clean to clean waters	
II	Acceptable	61–100	Slightly polluted water	
III	Questionable	36–60	Moderately polluted water	36–60
IV	Critical	16–35	Heavily polluted waters	
V	Very critical	<16	Heavily polluted waters	

Table 3 . BMWP/Col method

Source: Roldán-Pérez (2003)

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Subsequently, the results of the BMWP/COL and ASTP bioindicator analysis were correlated with physicochemical parameters of the water to establish the level of environmental impact on the aquatic ecosystem.

RESULTS

Stage I

Physicochemical characterization of the water

The physicochemical characterization of the water was carried out at the four sampling points established along the evaluated section of the Manaure River. At each station, pH, conductivity, temperature, dissolved oxygen, COD, BOD_5, total phosphorus, ammoniacal nitrogen, and Kjeldahl nitrogen were measured. The values obtained are presented in Table 4 and correspond to the direct records obtained in the field and in the laboratory, allowing the spatial variations of the evaluated parameters to be observed.

The pH values recorded ranged from 6.6 to 6.9 at the four sampling points, falling within a slightly acidic to neutral range. Conductivity was highest at the discharge point (351.7 µS/cm), while the lowest value was observed at La Vega de Jacob (278.33 µS/cm). The water temperature varied slightly, between 18.8 °C at point 1 and 20 °C at point 2. Dissolved oxygen fluctuated between 5.0 and 5.71 mg/L, with the minimum value recorded at the discharge site. COD reached its maximum value at point 2 (140 mg/L), while the lowest value was observed at point 4 (53.3 mg/L). BOD_5 followed the same trend, with values between 18 mg/L and 35 mg/L. Total phosphorus remained below the detection limit (<0.15 mg/L) at all points except at the discharge point, where it reached 0.71 mg/L. Ammoniacal nitrogen varied between 0.13 mg/L and 0.24 mg/L, while Kjeldahl nitrogen remained below <3.5 mg/L at all sites evaluated.

Identification of macro- and macroinvertebrates

The taxonomic identification of the organisms collected allowed representatives of various orders and families of macroinvertebrates to be recorded at the four sampling points on the Manaure River. The specimens were classified to genus level when morphology allowed, using a binocular stereoscope and specialized taxonomic keys. Table 5 REF _Ref215258211 \h presents the taxa identified during the biological characterization phase.

During the identification process, organisms belonging to seven main orders were recorded: Hemiptera, Plecoptera, Odonata, Ephemeroptera, Trichoptera, Calamoceratidae, and Haplotaxida. Fifteen families were recognized within these groups, among which Gomphidae, Hydropsychidae, Leptophlebiidae, and Tricorythidae stood out due to their recurrence at the sampling points. The classification allowed for the identification of genera characteristic of lotic environments, such as *Hetaerina*, *Smicridea*, *Leptonema*, *Leptohyphes*, and *Thraulodes*. Likewise, the presence of *Tubifex*, a genus associated with the Tubificidae family, was recorded. The organisms were preserved, photographed, and organized according to their order and family, forming the basis for the calculation of biological indices and subsequent ecological analysis.

PARAMETERS	SAMPLING POINTS (MANAURE RIVER, CESAR)			
	POINT 1— BEFORE WASTEWATER DISCHARGE	POINT 2-WASTEWATER DISCHARGE	POINT 3- LOS TANANEOS RESERVE	POINT 4-LA VEGA DE JACOB VILLAGE
PH	6.8	6.6	6.7	6.9
Conductivity (U3)	334.7	351.7	338.3	278.33
TEMPERATURE °C	18.8	20	19.5	19.8
Dissolved oxygen (mg/l)	5.5	5	5.7	5.71
COD	120	140	60	53.3
BOD	30	35	20	18
TOTAL PHOSPHORUS (mg P/L)	<0.15	0.71	<0.15	<0.15
Ammoniacal nitrogen mg NH_3-N/L	0.15	0.15	0.13	0.24
Kjeldahl nitrogen mg NH_3-N/L	<3.5	<3.5	<3.5	<3.5

Table4 . Physicochemical characterization

ORDER	FAMILY	GENUS	IMAGE
Hemiptera	Naucoridae	Placomerus Micans	
Plecoptera	Perlidae	Apacroneuria Sp.	
Odonata	Gomphidae	Ophiogomphus	
Odonata	Gomphidae	Progomphus	
Ephemeroptera	TRICORYTHIDAE	Leptohyphes	
Odonata	Calopterygidae	Hetaerina	

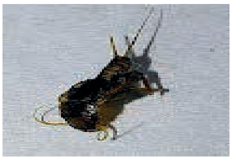
ORDER	FAMILY	GENUS	IMAGE
Trichoptera	Hydropsychidae	Smicridea	
Odonata	CALOPTERYGIDAE H	Hetaerina	
Mayflies	LEPTOPHLEBIIDAE	Traverella	
Trichoptera	Hydropsychidae	Leptonema	
Hemiptera	GELASTOCORIDAE	Nerthra	
Ephemeroptera	LEPTOPHLEBIIDAE	Thraulodes	
Trichoptera	ODONTOCERIDAE	Marilia	
Trichoptera	CALAMOCERA TIDAE	Phylloicus	
Haplotaxida	Tubificidae	Tubifex	

Table5 . Identification of macro- and macroinvertebrates

Distribution of macroinvertebrates by sampling point

The distribution of macroinvertebrates collected at the four sampling points showed variations in the composition and abundance of the taxa recorded in the Manaure River section. The organisms were quantified and organized according to order, family, and genus, allowing the richness and total number of individuals present at each station to be established. Table 6 summarizes the taxonomic distribution and abundance observed at each sampling point.

The distribution of macroinvertebrates showed differences in total abundance and taxon composition between the four sampling points. At point 1, ten families distributed across four main orders were recorded, with a total of 80 individuals. Point 2 had eight families and a total of 51 individuals, with *Tubifex* standing out as the most abundant taxon. Point 3 recorded the highest number of individuals (109) and the greatest diversity of genera, including representatives of all orders identified in the study area. At point 4, 74 individuals were quantified, grouped into multiple families of Plecoptera, Hemiptera, Odonata, Trichoptera, and Ephemeroptera. The genera *Placomerus micans*, *Hetaerina*, *Thraulodes*, *Leptohyphes*, *Apacroneuria,* and *Progomphus* were found at several points, evidencing their recurrent presence in the evaluated section.

Stage 2.

Diversity and abundance indices

The values obtained for the Shannon-Wiener (H'), Simpson (D), Dominance (λ), and Margalef (DMg) indices, calculated for the macroinvertebrates collected at the four points of the Manaure River, are summarized in the following table

The ecological index values revealed differences in the diversity, richness, and dominance of macroinvertebrates between the four points of the evaluated section. The Shannon-Wiener index (H′) presented values between 1.901 and 2.171, with the lowest value recorded at the point corresponding to the discharge and the highest at the point prior to the discharge. The Simpson index (D) varied between 0.823 and 0.869, showing relatively high values at all sites. Dominance (λ) ranged from 0.131 to 0.177, with the highest values observed at points 2 and 3. The Margalef index (DMg), associated with taxon richness, recorded values between 1.597 and 2.738, with point 3 showing the highest recorded richness. Taken together, these values revealed spatial variations in the structure of the macroinvertebrate community along the studied section of the Manaure River.

Statistical Analysis

The statistical analysis was based on the abundance distribution of the genera identified at each sampling point on the Manaure River. For this purpose, graphical representations were created to visualize the variation in biological composition before, during, and after wastewater discharge. The graphs were constructed based on the absolute abundance of each genus at the four points evaluated, which made it easier to identify differences in the community structure of the studied section. These representations revealed the presence of dominant genera and the distribution of those with fewer individuals, providing a quantitative

DISTRIBUTION OF MACROINVERTE-BRATES BY SAMPLING POINT			
ORDER	FAMILY	GENUS	Quantity
Point 1 – Before discharge			
Hemiptera	Naucoridae	Placomerus micans	20
Plecoptera	Perlidae	Apacroneuria sp.	10
Odonata	Gomphidae	Ophiogomphus	5
Odonata	Gomphidae	Progomphus	8
Ephemeroptera	TRICORYTHIDAE	Leptohyphes	8
ODONATA	CALOPTERYGIDAE	Hetaerina	6
Trichoptera	Hydropsychidae	Smicridea	9
Ephemeroptera	LEPTOPHLEBIIDAE	Thraulodes	3
Trichoptera	ODONTOCERIDAE	Marilia	6
Trichoptera	CALAMOCERA TIDAE	Phylloicus	5
TOTAL		**80**	
Point 2 – Wastewater discharge			
Haplotaxida	Tubificidae	*Tubifex*	15
Trichoptera	Hydropsychidae	*Smicridea*	8
Trichoptera	Hydropsychidae	*Leptonema*	8
Hemiptera	Gelastocoridae	*Nerthra*	4
Ephemeroptera	Tricorythidae	*Leptohyphes*	5
Ephemeroptera	Leptophlebiidae	*Traverella*	5
Ephemeroptera	Leptophlebiidae	*Thraulodes*	5
Odonata	Calopterygidae	*Hetaerina*	1
TOTAL		**51**	
Point 3 – Los Tananeos Reserve			
Plecoptera	Perlidae	*Apacroneuria sp.*	10
Hemiptera	Naucoridae	*Placomerus micans*	40
Odonata	Gomphidae	*Ophiogomphus*	8
Odonata	Gomphidae	*Progomphus*	6
Odonata	Calopterygidae	*Hetaerina*	10
Ephemeroptera	Leptophlebiidae	*Thraulodes*	8
Ephemeroptera	Tricorythidae	*Leptohyphes*	6
Trichoptera	Hydropsychidae	*Smicridea*	2
Trichoptera	Hydropsychidae	*Leptonema*	2
Trichoptera	Calamoceratidae	*Phylloicus*	2
Trichoptera	Odontoceridae	*Marilia*	2
Hemiptera	Gelastocoridae	*Nerthra*	5
Ephemeroptera	Leptophlebiidae	*Traverella*	8
TOTAL		**109**	
Point 4 – La Vega de Jacob trail			
Plecoptera	Perlidae	*Apacroneuria sp.*	8
Hemiptera	Naucoridae	*Placomerus micans*	20
Odonata	Calopterygidae	*Hetaerina*	8
Odonata	Gomphidae	*Ophiogomphus*	4
Odonata	Gomphidae	*Progomphus*	8

DISTRIBUTION OF MACROINVERTEBRATES BY SAMPLING POINT			
ORDER	**FAMILY**	**GENUS**	**Quantity**
Trichoptera	Calamoceratidae	*Phylloicus*	2
Trichoptera	Odontoceridae	*Marilia*	1
Trichoptera	Hydropsychidae	*Smicridea*	2
Trichoptera	Hydropsychidae	*Leptonema*	2
Ephemeroptera	Leptophlebiidae	*Thraulodes*	4
Ephemeroptera	Tricorythidae	*Leptohyphes*	5
Hemiptera	Gelastocoridae	*Nerthra*	10
TOTAL		**74**	

Table 6 . Distribution of macroinvertebrates by sampling point

Sampling Point	H′ (Shannon-Wiener)	D (Simpson)	λ (Dominance)	DMg (Margalef)
Point 1 – Before discharge	2.171	0.869	0.131	2.054
Point 2 – Wastewater discharge	1,901	0.829	0.171	1,597
Point 3 – Los Tananeos Reserve	2.135	0.823	0.177	2,738
Point 4 – La Vega de Jacob Trail	2,079	0.838	0.162	2,282

Table 7. Diversity, dominance, and richness indices per sampling point in the Manaure River

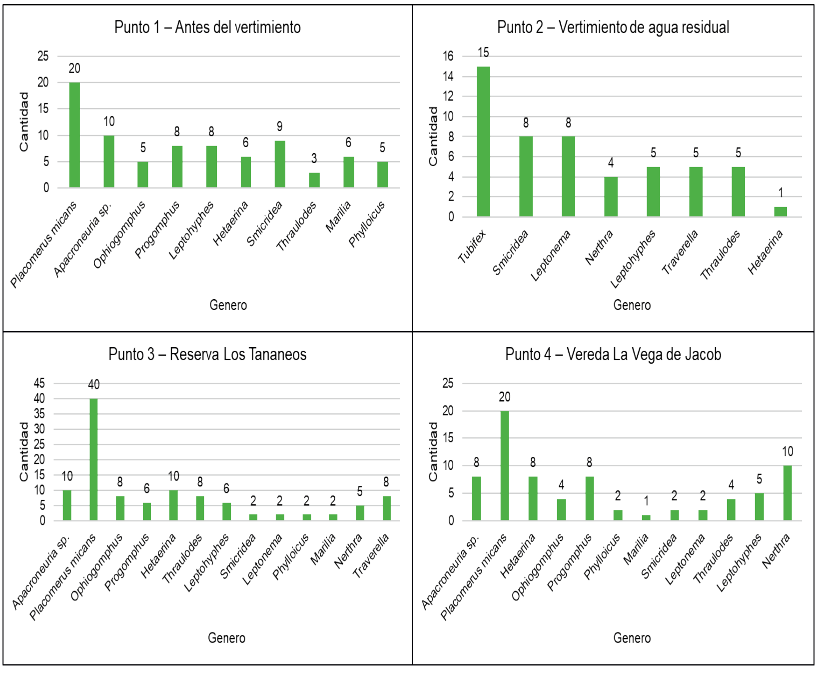


Figure3 . Variation of micro- and macroinvertebrates at each sampling point

view of spatial changes in biological richness and abundance. The graphs corresponding to each sampling point are presented below.

Stage 3

BMWP/COL index

The BMWP/Col index was calculated for the four sampling points based on the sum of the scores assigned to the recorded macroinvertebrate families. The values obtained allowed the water to be biologically classified according to the proposal established for lotic systems in Colombia. Table 9 presents the index values, the assigned class, and the corresponding interpretation for each station analyzed.

The BMWP/Col index values showed differences between sampling points, with values ranging from 34 to 89. The lowest score corresponded to point 2, located directly in the discharge area, classified in category IV, which indicated a critical biological condition. Points 1, 3, and 4 obtained values corresponding to class II, representing acceptable conditions with slight contamination. The maximum value was obtained at point 3, followed by point 4 and then point 1. These results showed variation in the biological response of the system to different environmental conditions in the evaluated section.

ASTP Index

This index was calculated to represent the average score per taxon identified at each sampling point. The results are presented in the following table

The ASTP index showed values between 4.25 and 7.50 along the sampled section. The lowest value corresponded to point 2, the discharge area, while the highest values were recorded at points 1 and 4, followed by point 3 with an intermediate score. These results showed differences in the average sensitivity of the taxa present at each site, reflecting contrasts in biological composition between areas exposed to greater or lesser environmental pressure.

Correlation of Bioindicators and Physicochemical Parameters

A descriptive correlation was performed between the BMWP/Col index, as shown in Table 10, the average value per taxon (ASTP), and the physicochemical parameters measured at the four points of the Manaure River. The relationship was evaluated based on the simultaneous variations between the biological values and the physicochemical characteristics, identifying direct or inverse correspondences between the sites evaluated.

The BMWP/Col and ASTP values showed changes associated with physicochemical variations between sampling points. A trend was observed in which both indices reached their highest values when the temperature remained between 19.5 and 20°C and when the pH approached the slightly acidic-neutral range (6.6–6.9). The decrease in COD and BOD coincided with increases in biological values at points 3 and 4. Total phosphorus only showed a high value at point 2 without coinciding with the highest biological indices, while ammoniacal nitrogen showed an inverse relationship, decreasing the value of the bioindicators at the point with the highest concentration. Kjeldahl nitrogen did not vary between stations, so it was not possible to establish a comparative correlation.

Sampling points	BMWP-COL	Class	Qua-lity	Meaning	Color
Point 1 – Befo-re discharge	75	**II**	Ac-cep-table	Slightly polluted water	
Point 2 – Was-tewater discharge	34	**IV**	Cri-tical	Heavily pollu-ted waters	
Point 3 – Los Tananeos Reserve	89	**II**	Ac-cep-table	Slightly pollu-ted waters	
Point 4 – La Vega de Jacob Trail	80	**II**	Ac-cep-table	Slightly conta-minated water	

Table 8. BMWP/COL Index Results

Sampling point	ASTP = BMWP/n
Point 1 – Before discharge	7.50
Point 2 – Wastewater discharge	4.25
Point 3 – Los Tananeos Reserve	6.84
Point 4 – La Vega de Jacob trail	7.27

Table 9. ASTP Index Results

Parameter	P1	P2	P3	P4	Observed relationship with BMWP/Col	Relationship observed with ASTP
pH	6.8	6.6	6.7	6.9	Higher BMWP in P3–P4 within the same acid–neutral range	Higher ASTP at pH 6.8–6.9 (P1–P4)
Conductivity (µS/cm)	334.7	351.7	338.3	278.3	P3 and P4 with higher BMWP despite lower conductivity than P2	Higher ASTP in medium-high conductivity (P1 and P3–4)
Temperature (°C)	18.8	20.0	19.5	19.8	Highest BMWP at temperatures between 19.5–20°C (P3–P4)	Highest ASTP in the same temperature range (P1, P4)
Dissolved oxygen (mg/L)	5.5	5.0	5.7	5.71	P3–P4 with higher BMWP and equal OD, non-linear with P2	ASTP with no apparent direct correlation
COD (mg/L)	120	140	60	53.3	P3–P4 high score with lower COD	ASTP decreases when COD is higher (P2)
BOD (mg/L)	30	35	20	18	Higher BMWP with low BOD (P3–4)	ASTP follows the same trend

Total phosphorus (mg P/L)	<0.15	0.71	<0.15	<0.15	Single high P2 value does not match maximum BMWP	ASTP not related to elevated phosphorus
Ammoniacal nitrogen (mg/L)	0.15	0.15	0.13	0.24	BMWP decreases in high ammonium (P4)	Lower ASTP with elevated ammonium (P4)
Kjeldahl nitrogen (mg/L)	<3.5	<3.5	<3.5	<3.5	No correlation (constant value)	Same condition

Table10 . General descriptive correlation between bioindicators and physicochemical parameters according to sampling point

DISCUSSION (OR ANALYSIS OF RESULTS)

The interpretation of the results shows that the section of the Manaure River is affected by the input of organic matter and nutrients associated with wastewater discharges, a phenomenon characteristic of water systems affected by urban settlements with poor wastewater treatment, as warned by global analyses of the sanitation crisis and the growing pressure on water bodies [1]. The combination of physicochemical and biological indicators confirms that water quality does not follow a uniform pattern, but rather manifests itself as a gradient where there is deterioration prior to the discharge point, a marked increase in impact in the discharge area, and partial recovery downstream, a dynamic widely described in tropical rivers under moderate organic loads [12]. This behavior has direct implications for the region's water and ecological security, consistent with international approaches that highlight the urgency of strengthening policies for the comprehensive treatment and monitoring of this resource [3].

The ecological assessment based on macroinvertebrates indicates that the discharge produces a notable reduction in the structural complexity of the community, a condition reflected in lower diversity, greater dominance, and decreased average sensitivity of the taxa at that point, while the sections located before and after retain greater biological heterogeneity. This confirms that the organic impact alters the biological composition without completely eliminating sensitive organisms, a state that coincides with diagnoses of Andean rivers subjected to intermediate anthropogenic stress [6]. The joint presence of families associated with good quality and tolerant families indicates that the system has not reached a critical level of irreversible degradation, but rather a state of pressure that modifies the relative proportion between vulnerable and resistant groups, as indicated in the specialized literature on biomonitoring with macroinvertebrates [4].

The simultaneous coexistence of Perlidae, Leptophlebiidae, Tricorythidae, Hydropsychidae, and Gomphidae with Tubificidae is a solid indicator of the quality gradient present in the analyzed section. While the former are associated with oxygenated waters and low organic load, Tubificidae is characteristic of eutrophicated and nutrient-enriched environments, a situation that confirms the presence of areas with contrasting conditions within the same watercourse [10]. This distribution pattern, where sensitive families are mainly observed outside the discharge sector and tolerant families are concentrated in the impacted area, is recurrent in lotic systems with domestic disturbance and partial self-purification capacity [8].

The BMWP/COL index showed a sharp drop at the discharge station and acceptable values before and after the discharge, which shows that the contaminated section clearly responds to the impact while the adjacent sections maintain ecological functionality and resilience. This trend is consistent with research where BMWP/COL clearly differentiates contaminated areas from recovering segments in mountain rivers [15]. The recovery recorded downstream, without reaching high-quality values, suggests a balance between organic input and biological degradation capacity, a behavior that has been documented especially in basins with active flow, slope, and microhabitat heterogeneity [11].

The ASTP index, reflecting the average biological sensitivity per taxon, complements this analysis by showing a clear decrease at the discharge point and higher values in the remaining sections. This behavior confirms that the deterioration gradient affects sensitivity structure more than absolute richness, a finding consistent with studies that have validated ASTP as a discriminating metric against organic and urban disturbances [7]. The similarity between the ASTP and BMWP/COL patterns reinforces the effectiveness of both indicators in representing the ecological status of the system.

The conceptual relationship between physicochemical parameters and bioindicators shows a clear trend: the decrease in biological indices coincides with increases in BOD, COD, and reactive phosphorus, parameters directly associated with organic input and the absence of effluent treatment, a pattern that has also been reported in tropical rivers with significant domestic load [9]. Likewise, the increase in ammoniacal nitrogen in the impacted section correlates with reduced biological scores, which supports its value as an indicator of ecological disturbance and stress for sensitive macroinvertebrates [13]. The stability of Kjeldahl nitrogen between stations prevented the establishment of robust associations; however, the consistent response of bioindicators compared to the rest of the parameters confirms the functional sensitivity of the benthic assemblage for diagnosing ecological water quality [14].

The deteriorated condition prior to the spill suggests additional diffuse inputs, probably associated with land use, livestock, or discontinuous domestic discharges, a recurring feature in intervened basins where point source pollution acts on an already stressed scenario [5]. In contrast, the sector associated with the Los Tananeos Reserve shows greater richness and diversity, indicating that there are still microhabitats with sufficient ecological integrity to sustain organisms of high biological quality, a phenomenon observed in rivers where riparian vegetation and structural connectivity cushion the disturbance [16].

The use of the BMWP/COL in combination with the ASTP confirms the usefulness of these indices in the ecological interpretation of the Manaure River, validating their application for biological diagnosis and environmental management in similar watersheds. The national literature has already emphasized the relevance of these bioindicators for assessing water quality in Colombia and their ability to discriminate between acceptable states and critical conditions [4]. However, it is necessary to recognize methodological limitations associated with spot sampling, which does not represent annual hydrological variability or seasonal effects on biological dynamics. The literature recommends continuous and multi-temporal monitoring, including functional metrics and complementary analyses that increase the sensitivity of the diagnosis [6].

In summary, the discussion shows that the section of the Manaure River responds to a scenario of moderate organic impact, with evident degradation in the discharge area and partial recovery downstream. The biota confirms the deterioration, but also the existence of ecological resilience and structural responsiveness of the system, which supports bioassessment as a tool to guide management, remediation, and water conservation decisions in the region [10].

CONCLUSIONS

The analysis carried out on the Manaure River allows us to conclude that the environmental quality of the section evaluated shows moderate alteration associated with waste discharges, with a noticeable impact at the point of discharge and better biological performance in the sectors located upstream and downstream. This behavior shows an impacted but still functional ecosystem, capable of sustaining sensitive organisms and, therefore, with ecological margin for recovery if anthropic pressure decreases.

Biological indices confirmed that the macroinvertebrate composition clearly responds to the pollution gradient, reflecting a reduction in sensitivity and diversity at the point of highest organic load. Likewise, the sections with less intervention showed greater richness, heterogeneity, and presence of families indicative of good quality, suggesting that the river retains ecological resilience and self-regulating capacity.

The physicochemical parameters supported this behavior, showing that variations in nutrients and organic matter are reflected in the structure and distribution of macroinvertebrates. However, the system maintains conditions that allow mixed communities to remain, indicating that the deterioration has not progressed to states of high severity.

The study provides a useful reference point for environmental monitoring of the Manaure River and strengthens understanding of its behavior in the face of anthropogenic pressure. The results allow for the projection of future lines of research, including: temporal monitoring at different hydrological times, inclusion of functional and trophic indices, evaluation of the efficiency of treatment systems, and assessment of the effect of riparian restoration on biological recovery.

In summary, the Manaure River is not in an irreversible critical state, but it requires control measures, continuous monitoring, and environmental planning to prevent further degradation and promote its progressive recovery. This work contributes to local environmental decision-making and opens up the possibility of expanding monitoring to consolidate medium- and long-term water conservation strategies.

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