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Articles

Physicochemical quality of the Mulato River in Mocoa Putumayo-Colombia

Calidad fisicoquímica del río Mulato en Mocoa Putumayo-Colombia

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Abstract

The Mulato River supplies water for human consumption to the center of the municipality of Mocoa, department of Putumayo; the water sources in this area of Colombia do not have updated quality studies. Therefore, this study focused on the analysis of the physicochemical parameters: pH, turbidity, OD, DBO_5, conductivity, temperature, DQO and SST, then the statistical analysis was compared with Colombian regulations and the ICA was established. It was found that the Mulato River receives pollutant loads from 35 discharges from two tributary streams, which had an impact on the alterations of the turbidity and pH parameters; as for the first, in the middle part the value was 6.38 NTU, the highest of the three points, and in the lower zone, 3.73 NTU, and the second, referring to pH, is between 5.6 and 5.8. With the data obtained from the water samples of the three zones, taken in situ and ex situ, it was established that, although there is a certain degree of turbidity and contamination, the water quality of the Mulato River is acceptable with a green alert.

Keywords: Wastewater, physicochemical analysis, basic sanitation, environmental management.

Resumen

El río Mulato abastece de agua para consumo humano el centro del municipio de Mocoa, departamento del Putumayo, Colombia. Las fuentes hídricas de esta zona del país no cuentan con estudios de calidad actualizados. Por ello, en el presente artículo se informa el análisis de los parámetros fisicoquímicos: pH, turbidez, OD, DBO_5 conductividad, temperatura, DQO y SST; posteriormente, se comparó el análisis estadístico con la normatividad colombiana y se estableció el ICA. Se evidenció que el río Mulato recibe las cargas contaminantes de 35 vertimientos provenientes de dos quebradas tributarias, que incidieron en las alteraciones de los parámetros de turbiedad y pH; en cuanto a la primera, en la parte media el valor fue de 6.38 NTU, el más alto de 3 NTU y en la zona baja de 3.73 NTU; el segundo referente al pH se encuentra entre 5.6 y 5.8. Con los datos obtenidos de las muestras de agua de las tres zonas, tomadas *in situ* y *ex situ*, se estableció que aunque existe cierto grado de turbidez y contaminación, la calidad del agua del río Mulato se encuentra en aceptable, con alerta verde.

Palabras clave: aguas residuales, análisis fisicoquímicos, saneamiento básico, gestión ambiental.

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Introduction

Colombia, is a territory known worldwide for its water wealth and biodiversity, important in the development of different economic activities Domínguez, Rivera, Vanegas and Moreno (2008), states that the surface water supply in Colombia is 1 150 km^3 per year, a high estimate in terms of the supply system of the resource in the country, and one of the sectors with the highest water demand is agriculture. There are four main watersheds in the country: Caribbean, Pacific, Orinoco and Amazon. Nearly 70% of the population is settled on the Caribbean slopes, with the Cauca and Magdalena rivers being the most representative, and the Orinoco and Amazon slopes are home to the country's largest rivers. (Gualdrón, 2018). Within the Colombian hydrography, one of the most important water components in the country is the Amazon River, a natural and representative source that encompasses a series of processes that contribute to the environmental dynamics that develop in the area. According to the IDEAM (Instituto de Hidrología, Meteorología y Estudios ambientales) (IDEAM, 2015) in the results of the national water study, it is estimated that the highest average flow obtained in the Amazon River corresponds to 35.111 m^3 /s in May, while in September the statistical analysis yielded a figure of 18.797 m^3 /s. This variation may be caused by two main aspects, the extensive course of the river and the different climatic conditions in the area.

The Colombian Amazon, despite being known as an area rich in natural resources, its water sources are exposed to different anthropic disturbances such as; dumping of untreated wastewater, disposal of solid waste, agricultural activities, swine, livestock and extraction of drag material, which alter the properties of the water, as in other areas of the country as is the case of the Jui stream tributary of the Sinu River "the parameters presented higher concentrations in the stations located in the area of predominantly urban area, characterized by the influence of anthropogenic activities, such as dumping of domestic wastewater, solid waste, swine farming and sand mining" (Hernández, Pinedo, Paternina, & Marrugo, 2021). According to Torres (2012), "developing countries are generally located in tropical and subtropical climate regions and have the lowest coverage in terms of collection and adequate treatment of domestic wastewater". Faced with this situation, countries are implementing alternatives that allow them to control wastewater and minimize the impact on human health and ecosystems. Buelow *et al*. (2020) emphasizes that ecosystems and their natural dynamics have been seriously threatened by wastewater discharges and their inevitable control, and this is verified by Salma, Hossain, Hussain and Hasan (2020) when they state that wastewater is a receptor source for the propagation of microbes and their resistance in the environment. These discharges not only affect aquatic ecosystems, but also generate health problems in the communities and, above all, reduce the possibility of giving other uses to water sources. In the words of García (2016), in the quality studies, another associated variable is population growth and subsistence activities such as agriculture, as stated by Jaramillo, Cardona and Galvis (2020). And, within the Amazon region is the Putumayo River, located in the municipality of San Francisco with a total area of 1479 ha. The water flow corresponds to 2.96 m^3/s. This river is used to supply the urban area of the municipality of San Francisco (Corpoamazonia, 2010). One of the problems of the rivers located in the southern part of Colombia is the lack of quality studies, and for this reason, their results are not very clear and accurate in terms of the information obtained (Barrera, 2017). In the same way, Rodríguez (2012) refers to this situation as a crisis of governance over the resource, since the articulation of public policies has been in decline, which has implied a lack of control over the productive sectors that demand large quantities of water in their industries or companies as well as in the homes of the population. The situation described above is experienced in the department of Putumayo, where none of the 13 municipalities that make up the department has drinking water or a wastewater treatment plant. On the other hand, the water supply and supply systems constitute one of the important factors for the provisioning, quality and well-being of life of the population. These mechanisms are entirely rooted in environmental and economic sustainability, which give way to the construction and structuring of water service providers. These services are based on compliance with the payment of monetary tariffs that should have an optimal and considerable level with respect to the service costs and the payment capacity of the users (Briseño & Rubiano, 2018).

At the local level, in the municipality of Mocoa, aqueduct management is managed by the public utility company Aguas Mocoa S.A. E.S.P. Entity that manages and promotes water supply to the urban and rural population of the territory. Among the supply sources is the Mulato River, which supplies a certain part of the center of the municipality and in which a socioeconomic dynamic is developed (National Unit for Disaster Risk Management) UNGRD (2018). In terms of water resource management, the companies that provide water services are obliged to carry out a Spill Monitoring and Follow-up Plan because untreated wastewater is causing significant changes in quality. In these last three decades, the negative effects generated on water resources have led to a constant environmental concern, which is gaining more and more followers as stated by Oñate and Cortés (2020). This study was conducted in the micro-watershed of the Mulato river located towards the center of the municipality of Mocoa, and to the west of the urban sector, in the department of Putumayo, it flows into the Mocoa river, in the Amazonian foothills, on the eastern edge of the Eastern Cordillera, making part of the Caqueta river basin and nationally of the great Amazon river basin, it is the supply source of the central aqueduct of Mocoa, belonging to the area of influence of the micro-watershed a total of 10.There are 2 indigenous reservations Camentsa Biya and Inga, they own an area of 556.37 hectares in Baldíos and it is an area of mining protection (Corpoamazonia, 2011). In it’s middle basin, anthropic intervention and human settlements are evident, where rural dwellings predominate along with mosaics of pastures with natural spaces and secondary forests. In its transit through the San Luis de Chontayaco and Líbano hamlet, the stream passes through the Inga de Líbano indigenous reservation, which shares territory with multiple rural housing arrangements built and located linearly to the main channel of the Mulato River sometimes in areas vulnerable to the effects of torrential hydrofluvial threat generating events, which were seriously affected by the catastrophic event of March 31, 2017 (UNGRD, 2018).

The objective of this article is to present information on the analysis of the physicochemical parameters that were evaluated to find the ICA of the Mulato river water source, taking into account that the rivers of Putumayo in their management process do not have updated information on water quality, which added to population growth and the lack of basic sanitation alternatives, are causing the community to dispose of wastewater without any treatment and that it is used by the aqueducts as a source of supply for human consumption.

Materials and methods

The wastewater under study came from the village of El Líbano, located in the municipality of Mocoa, and is discharged into the Mulato River. For the study, the area was divided into high (where the intake is located), medium (first tributary stream), and low (second tributary stream). During the survey, the discharges were identified and characterized and the physicochemical parameters were evaluated. The process of identifying and characterizing the discharges took into account the following variables: coordinates, type of discharge, flow and origin. The physicochemical analysis was oriented by means of the parameters: pH, conductivity, chemical oxygen demand, biochemical oxygen demand, dissolved oxygen, total suspended solids, temperature, turbidity, color and smell. The protocol, sampling and results were developed by the LAGSA laboratory, certified by IDEAM.

Study area

Mocoa is one of the municipalities of Colombia, is located in the northern part of the department of Putumayo at coordinates 1° 08′ 57″ N, 76° 38′ 47″ O, area of 1 263 km^2, temperature of 24.8 °C, and tropical climate according to data from the municipal mayor's office. The Mulato River is located to the west of the municipality of Mocoa (Figure 1), it crosses the southwest of the municipality and during its journey it runs through places such as: Vereda el Líbano, Miraflores neighborhood, Avenida 17 de julio, Centro neighborhood, 5 de enero neighborhood and el Naranjito neighborhood. The ecological importance of the river is diverse, and it is home to a wealth and abundance of species in its surroundings. It receives pollutant loads from populated centers in its area of influence, such as wastewater discharge, livestock activities, extraction of dragging material, agricultural activities.

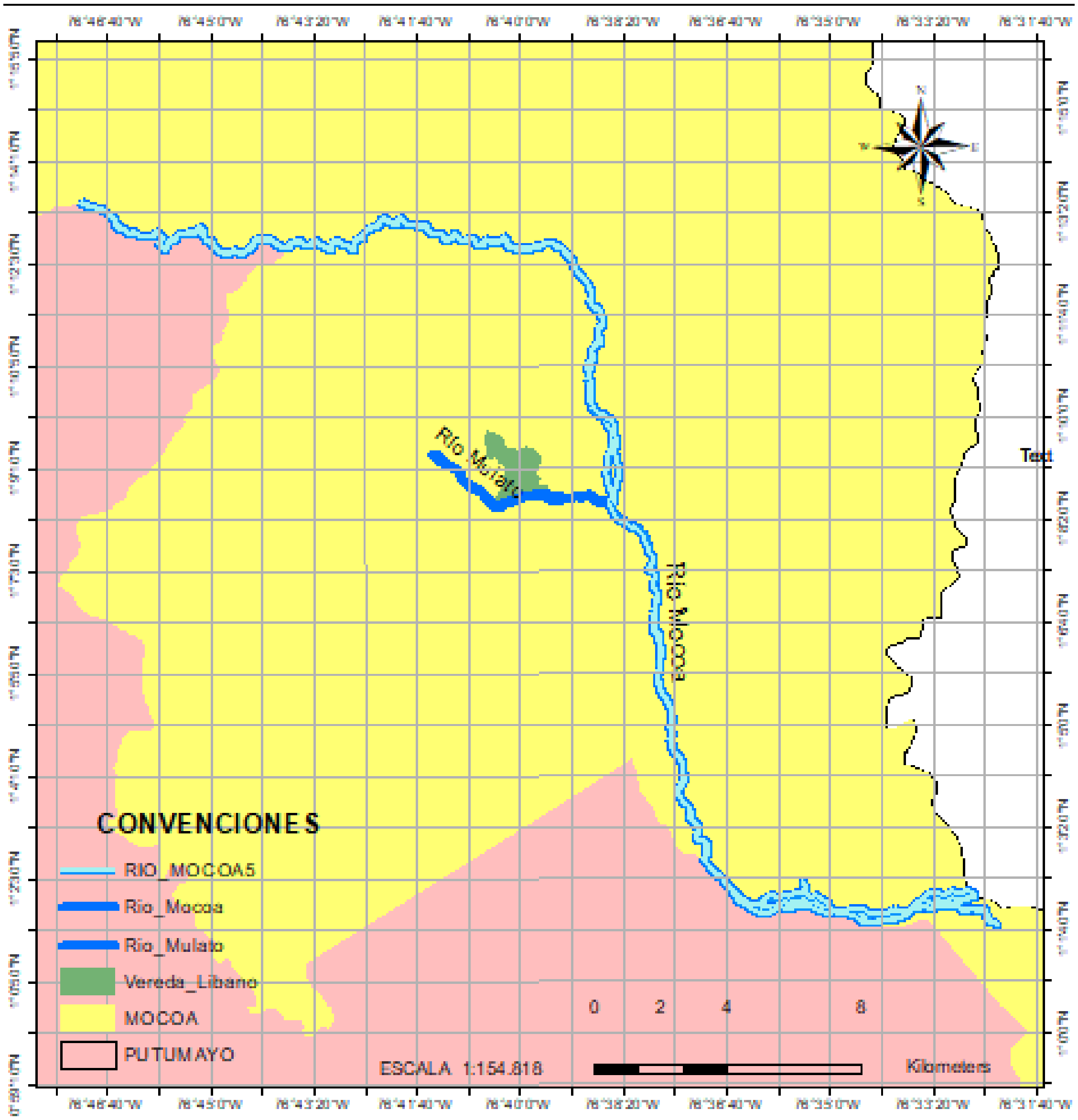

Figure 1. Geographical location of the study area.

For the identification and characterization of discharges. The zone was subdivided into three parts: the high zone, where the aqueduct intake is located; the middle zone, where the first tributary stream, the first tributary of the Mulato River, is located; and the low zone, where the second tributary stream is located.

A total of 35 wastewater discharges were confirmed, which are detailed in Table 1, classified as domestic or gray water and black water from toilets. These two types of wastewater were combined at several points in a single type of pipe to reach their disposal in soil and/or water. In addition, the volumetric flow rate was verified and classified according to the location zone (high, medium, low), in order to establish the magnitude and difference of the concentration discharged into the river. Next, the points of greatest disturbance were described, the type of flow, measurement of the pipe material, location of the discharge, type of discharge, altitude and their respective coordinates were estimated. The discharge points were organized graphically in (Figure 2).

Table 1. Geographical location of the study area.

Date	No. Monitoring	Dumping coordinate		Type of discharge		Flow rate (l/s)	Place of origin
		N	W	Intermittent	Continuo		
4/11/2020	1	01º O8’ 32.6”	76º 40’ 22.8 “		X	0.16286645	Housing and shed
4/11/2020	2	01º O8’ 33.9”	76º 40’ 21.2 “		X	0.00449059	Laundry
4/11/2020	3	01º O8’ 34.0”	76º 40’ 21.1 “		X	0.01807229	Sanitary
4/11/2020	4	01º O8’ 38.1”	76º 40’ 19.6 “	X			Sanitary and laundry
4/11/2020	5	01º O8’ 39.7”	76º 40’ 12.5 “	X			Sanitary
4/11/2020	6	01º O8’ 37.7”	76º 40’ 17.0“	X			Sanitary and gray domestic wastewater (shower)

Date	No. Monitoring	Dumping coordinate		Type of discharge		Flow rate (l/s)	Place of origin
		N	W	Intermittent	Continuo		
4/11/2020	7	01º O8’ 46.2”	76º 39’ 58.3 “		X	0.05164934	Sanitary and domestic wastewater
4/11/2020	8	01º O8’ 46.3”	76º 39’ 58.2 “		X	0.00402659	Sanitary and domestic wastewater
4/11/2020	9	01º O8’ 47.6”	76º 39’ 57.4 “		X	0.02068224	Sanitary and domestic wastewater
4/11/2020	10	01º O8’ 47.2”	76º 39’ 56.5 “	X			Domestic gray and sanitary wastewater
4/11/2020	11	01º O8’ 47.3”	76º 39’ 56.4 “		X	0.02519167	Gray domestic wastewater, sanitary
4/11/2020	12	01º O8’ 47.5”	76º 39’ 56.4 “	X			Sanitary and gray domestic wastewater
4/11/2020	13	01º O8’ 47.1”	76º 39’ 56.3 “	X			Gray wastewater (kitchen)
4/11/2020	14	01º O8’ 47.5”	76º 39’ 56.5 “		X	0.00305491	Domestic and sanitary wastewater
4/11/2020	15	01º O8’ 47.4”	76º 39’ 56.1 “		X	0.03571173	Domestic gray and sanitary wastewater
4/11/2020	16	01º O8’ 47.3”	76º 39’ 56.1 “	X			Gray domestic wastewater
4/11/2020	17	01º O8’ 47.5”	76º 39’ 56.1 “	X			Gray domestic wastewater
4/11/2020	18	01º O8’ 47.6”	76º 39’ 56.0 “	X			Gray domestic wastewater grises

Date	No. Monitoring	Dumping coordinate		Type of discharge		Flow rate (l/s)	Place of origin
		N	W	Intermittent	Continuo		
4/11/2020	19	01º 08′ 47.7″	76º 39′ 55.3 ‟	X			Gray domestic wastewater
4/11/2020	20	01º 08′ 47.6″	76º 39′ 55.7 ‟	X			Gray domestic wastewater
4/11/2020	21	01º 08′ 47.5″	76º 39′ 55.8 ‟		X	0.59535622	Toilets and gray domestic wastewater (laundry, shower)
4/11/2020	22	01º 08′ 47.9″	76º 39′ 55.7 ‟		X	0.16617737	Sanitary and gray domestic wastewater
4/11/2020	23	01º 08′ 49.8″	76º 39′ 55.6 ‟		X	0.1997071	Sanitary and gray domestic wastewater
4/11/2020	24	01º 08′ 49.9″	76º 39′ 57.1 ‟	X			Gray domestic wastewater (kitchen)
4/11/2020	25	01º 08′ 47.2″	76º 39′ 53.2 ‟		X	0.6	Black domestic wastewater
4/11/2020	26	01º 08′ 47.2″	76º 39′ 53.3 ‟		X	0.00308642	Black domestic wastewater
4/11/2020	27	01º 08′ 47.2″	76º 39′ 53.2 ‟	X			Gray domestic wastewater (kitchen)
4/11/2020	28	01º 08′ 47.1″	76º 39′ 53.3 ‟		X	0.2	Sanitary and gray domestic wastewater

Date	No. Monitoring	Dumping coordinate		Type of discharge		Flow rate (l/s)	Place of origin
		N	W	Intermittent	Continuo		
4/11/2020	29	01º O8' 47.0"	76º 39' 53. "	X			Gray domestic wastewater (kitchen and laundry)
4/11/2020	30	01º O8' 46.4"	76º 39' 53.3 "	X			Gray domestic wastewater (kitchen and shower)
4/11/2020	31	01º O8' 46.2"	76º 39' 53.3 "		X	0.49742995	Sanitary and gray domestic wastewater (kitchen, laundry and shower)
4/11/2020	32	01º O8' 45.9"	76º 39' 53.2 "		X	0.13636364	Sanitary and gray domestic wastewater (kitchen, shower)
4/11/2020	33	01º O8' 45.9"	76º 39' 53.0 "	X			Gray domestic wastewater (kitchen)
4/11/2020	34	01º O8' 45.6"	76º 39' 54.0 "	X			Gray domestic wastewater (kitchen and laundry)
4/11/2020	35	01º O8' 45.4"	76º 39' 52.2"	X			Gray domestic wastewater (kitchen and laundry)

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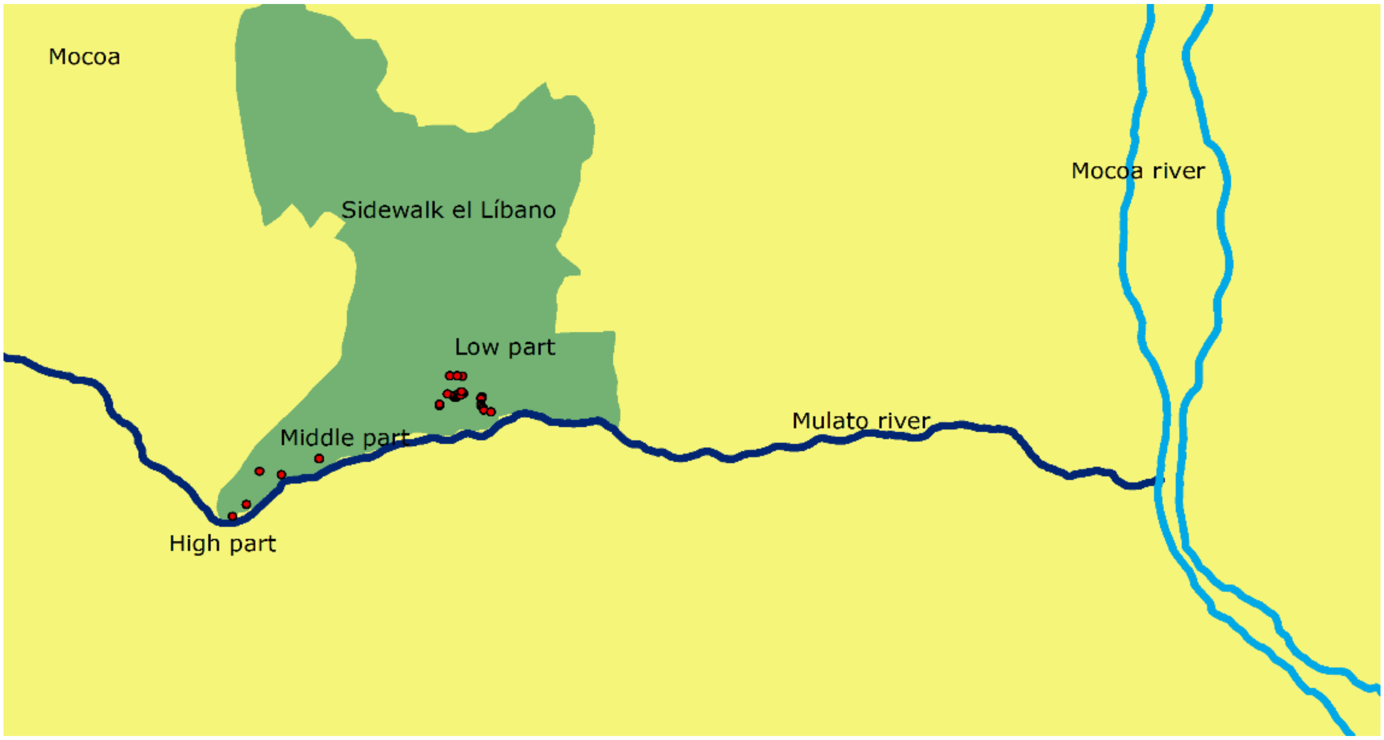

Figure 2. Geographical location of discharges.

Capacity of the Mulato River

Table 2 shows the flow measurement. For this purpose, a section of approximately 20 meters long and 12 meters wide was selected, which presented a wide channel with a high manifestation of rocky material, which implies that the river maintains a strong torrential current.

Table 2. Flow (*Q*) of the upper section of the Mulato River.

Speed (V)		Area (A)		Flow rate (V * A)
Travel distance (m)	Time (s)	Depth (cm)	Width (m)	
20	12.85	14	12	5.119 m^3/s
20	18.43	26	12	
20	19.64	32	12	
20	21.44	40	12	
20	16.37	41	12	
20	23.06	72	12	
20	20.47	57	12	
20	19.79	56	12	
20	23	48	12	
20	17.85	42	12	
20	24.39	45	12	
20	23.22	40.5	12	
Average	20.04	42.79		

Sample collection and analysis

To evaluate the physicochemical parameters, pH, temperature, dissolved oxygen, color and odor, we proceeded in an (in-situ) manner, and the parameters: chemical oxygen demand, biological oxygen demand, turbidity and total suspended solids (ex-situ), all in a punctual manner. The sampling of each in-situ and ex-situ parameter required taking homogenized water samples in the upper, middle and lower zones, collected under the collection criteria established for these cases. The analysis of these parameters required the collection of water samples in the high, medium and low zones in order to determine the physicochemical properties that were being altered by the discharges from the village. The methods used by the LAGSA laboratory were those shown in Table 3.

Table 3. Techniques for sampling and analysis of physicochemical parameters.

Parameter	Method	Units
pH	SM 4500-H+B	pH units
Conductivity	SM 2510 B	µS/cm
Chemical Oxygen demand	SM 5220 D	mg O_2/l
Biochemical Oxygen demand	SM 5210 B, SM 4500O-C, SM 4500 O-G	mg O_2/l
Dissolved oxygen	ASTM D888 Met C	mg O_2/l
Total Suspended Solids	SM 2540 D	mg/l
Temperature	SM 2550 B	°C
Turbidity	SM 2130 B	NTU

Sampling in the upper zone

The area selected for the first sampling point was the intake, the supply source of the aqueduct system. In situ (a) sampling was performed at the selected point and *ex situ* (b) homogenized samples were taken for the parameters described. For DQO, 15 drops of sulfuric acid had to be added as a preservative and, in this way, the sample maintained a pH < 2.

Sampling in the middle zone

At this point, the first tributary stream tributary to the Mulato River was identified, which discharges intermittent flows. The sampling point for the parameters was done at a medium flow with little torrent, no rock collisions and medium depth.

Sampling in the lower zone

In this sector, about 28 discharges of continuous and intermittent flow were recognized along the course of the stream. Also, a series of disturbances were observed and the presence of vectors such as flies and bad odors due to the discharge of wastewater was confirmed. Next, in order to take the physicochemical parameters in situ, it was necessary to do it a few meters downstream, in the water source, in order to know its variability in the river. Ex situ parameters were taken (turbidity, TSS, DQO, DBO_5). Table 4 shows the data collected in the field.

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Table 4. Field results for the lower zone of the Mulato River.

Item	**Item 1**	**Item 2**	**Item 3**
Sampling point	**Intake**	**Middle zone**	**Lower zone**
Date (a/m/d)	20/10/2020	20/10/2020	20/10/2020
Latitude (N)	1° 08' 32.1"	01º 08' 38.9"	01º 08' 43.9"
Length (W)	76° 40' 20.5 "	76º 40' 08.4"	76º 39' 50.3"
pH (pH units)	5.60	5.80	5.67
Water temperature (℃)	24.2	24.8	25.2
Conductivity (μS/cm)	67.6	65.2	67.2
Dissolved oxygen (mg/L)	7.34	7.13	7.19
Smell*	Acceptable	Acceptable	Unacceptable
Color*	< 10	< 10	>10

*Organoleptic parameters.

Results

The following results were obtained from the data collected in the research, in terms of the characterization of the discharges from the El Líbano district and the physicochemical properties of the Mulato River.

Thirty-five discharges from two tributary streams, shown in Table 1, from domestic wastewater, were characterized.

The flow evaluated in the Mulato River was 5,119 m^3 /sec, as shown in Table 2, according to the RAS 2000, in numbers 3.4.2.6, with this flow it is categorized as an ecological water source since it maintains an adequate level for water catchment within the supply system for human consumption and, above all, for the permanence of ecological processes such as riparian vegetation, located along the margin of its course. In addition, being located in an Amazonian area implies the presence of high rainfall, which generates an increase in the river's flow and its purification capacity.

The following operations were used to calculate the flow rate:

- Speed calculation:

$$V = \frac{D}{t}$$

$$V = \frac{20\ m}{20.04\ sec}$$

$$V = 0.998 \frac{m}{sec}$$

- Area calculation:

$$A = depth * width$$

$$A = 0.4279 \text{ m} * 12 \text{ m}$$

$$A = 5.13\, m^2$$

- Calculation of flow rate (Q):

$$Q = speed * \text{area}$$

$$Q = 0.998\, \frac{m}{sec} * 5.13\, m^2$$

$$Q = 5.119\, \frac{m^3}{sec}$$

The results of the in situ and ex situ analyses in the three zones delimited for the study allowed us to understand the behavior of the source and the alterations generated by the discharge of domestic wastewater into the Mulato River from the El Líbano district. The parameters studied were;

pH. The water in the three stations of the Mulato River presented a hydrogen potential (pH) of 5.6 - 5.8 (Figure 3), an acidic characteristic. In the upper and lower parts of the river, the pH did not vary and remained in a range between 5.60 - 5.67, although there was an increase of the parameter in the middle zone of 5.8, it was observed that this part of the river is exposed to human activities such as sand extraction.

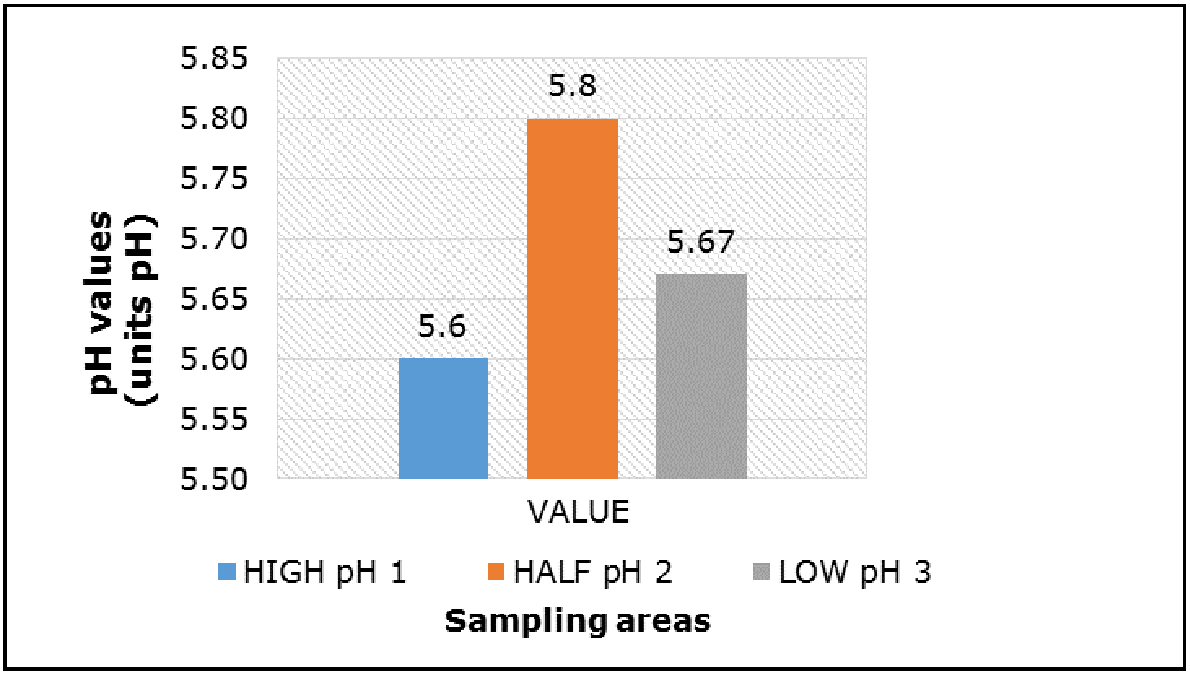

Figure 3. Estimated variability for the in situ pH parameter.

Conductivity. The highest value in relation to the three zones (Figure 4), was found in the upper and lower part of the river, with a score between 67.6 and 67.7 μS/cm, the latter being influenced by the tributary stream that was most affected by the discharge of wastewater. The middle zone had a low value, with 65.2 μS/cm, for the three zones, the stipulated values were within the range established by the RAS 2000 Title B, with a maximum allowable value of 1.000 μS/cm.

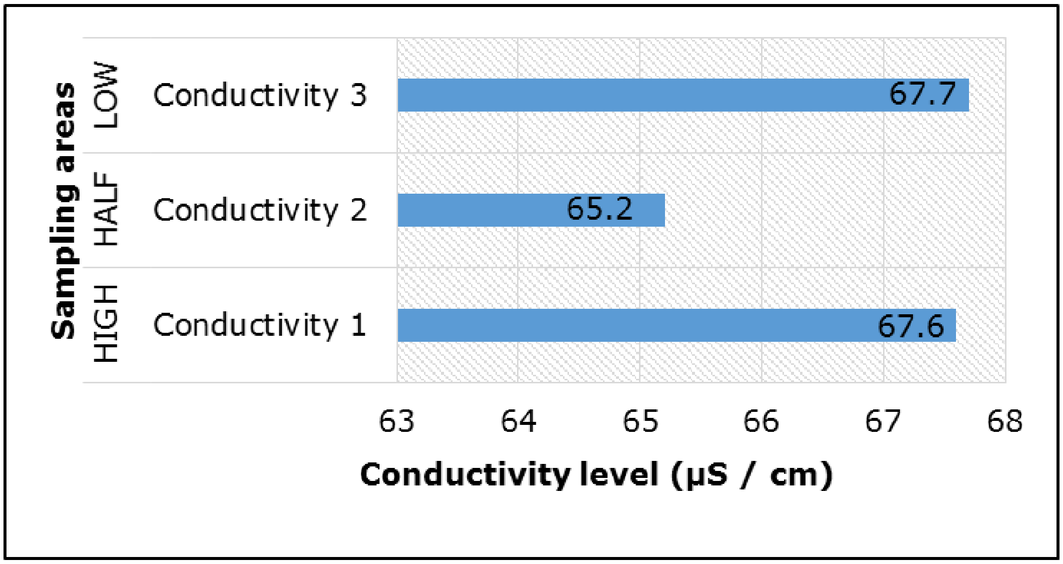

Figure 4. Conductivity assessment.

Chemical oxygen demand. In the three sampling zones, a balance in the concentration of <2mg O_2/l was evidenced, according to the laboratory analysis. Considering the data obtained in the three points (Figure 5), the <2 DQO level is within the range established by Resolution 0631 of 2015, which establishes a maximum admissible value of 200 mg O_2/L. In addition, the self-purification of the river is aided by the presence of rocky material and the high rainfall that generates sudden growths, which generates a constant ecological change.

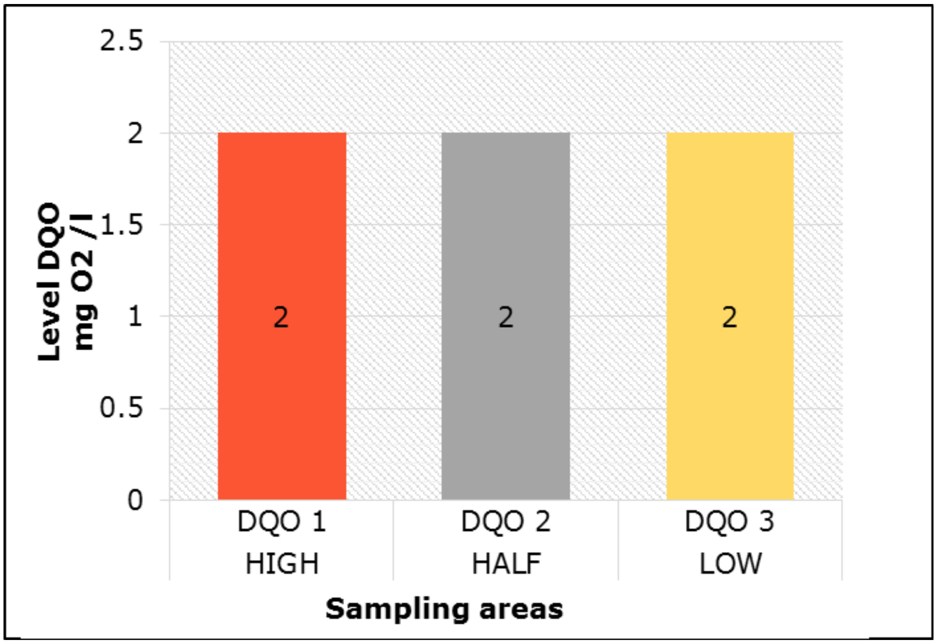

Figure 5. Comparison of DQO parameter.

Biological oxygen demand. The balanced trend that was analyzed showed that there was no variability at the three sampling points. In relation to the indices given in the three stations of the Mulato river (Figure 6), the DBO_5 levels remained in a low equilibrium of <2 and, among the standard stipulated by the RAS 2000, the ranges of 1-3 mg O_2/L, are given as acceptable values for water quality, in this case, in the upper zone where the intake is located.

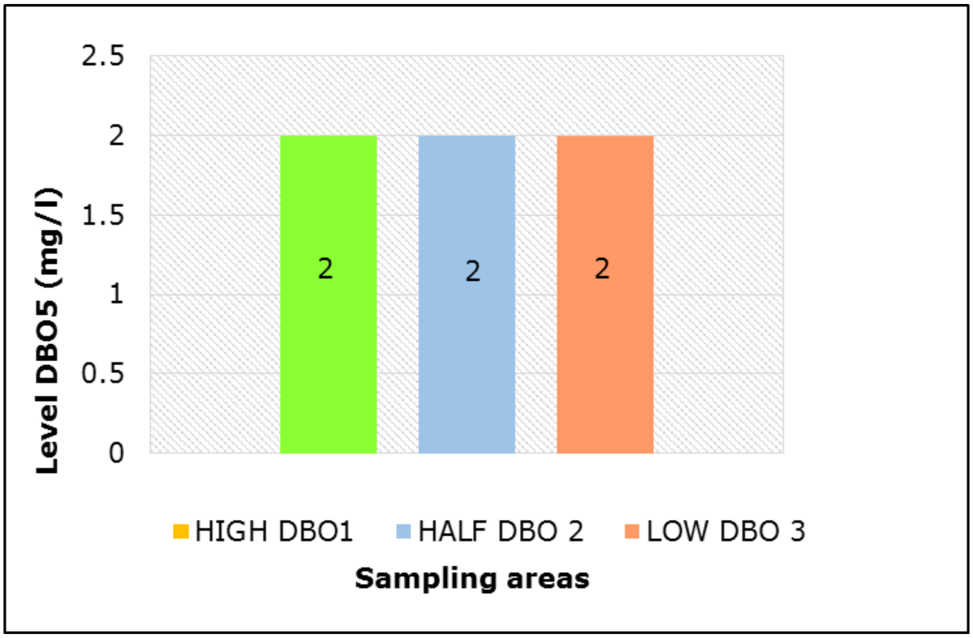

Figure 6. DBO_5 behavior.

Dissolved oxygen. The three sampling points in the Mulato River (Figure 7), presented a range between 7.19 - 7.34 mg/l O_2, the first being the lowest value for the first zone and the second the highest level for the point where the intake is located. The statistical balances established that, with respect to Resolution 1 096 of 2 000, this parameter requires an admissible value ≥ 4.0 to qualify the source as acceptable.

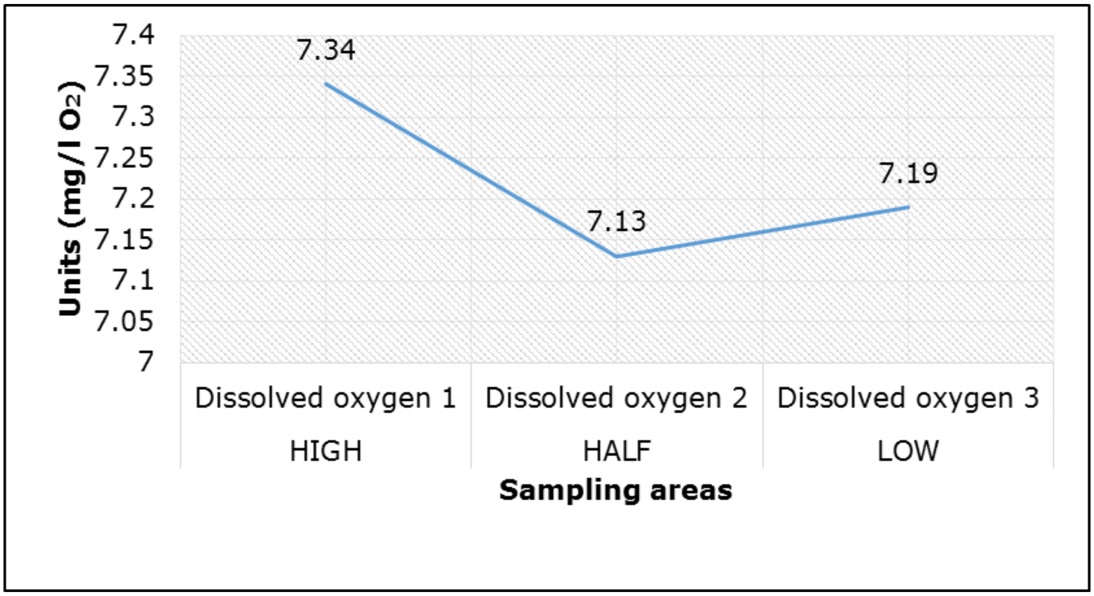

Figure 7. Dissolved oxygen measurement.

Total suspended solids (TSS). Figure 8 shows that the concentration of this parameter was weighted as <15 mg/L in the three sampling zones, which shows that there was no variation and a constant value in the three zones. The estimated results are within the maximum permissible limit of 100 mg/l.

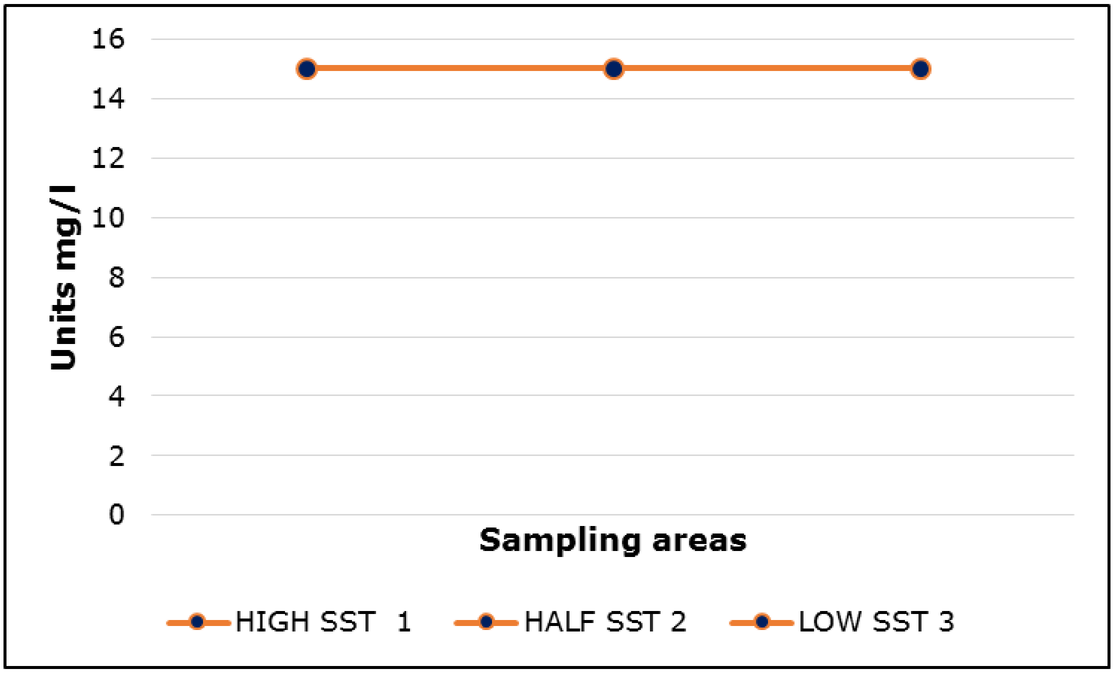

Figure 8. STT concentration.

Temperature. The temperature variation in the three zones studied is notable with respect to the consecutive increase in the water source's temperature (Figure 9). In the upper zone of the intake, the temperature is 24.2°C, while in the middle zone it increases by 0.6°C, it has a temperature of 24.8°C, compared to the first one. However, in the lower zone, the highest temperature index is observed, with a value of 25.2ºC, perhaps due to the lack of vegetation, since there is no forest capacity. The weighted temperature range in the high, medium and low zones is at an optimum level, and is a significant variable for the ecological stability of the system and other factors.

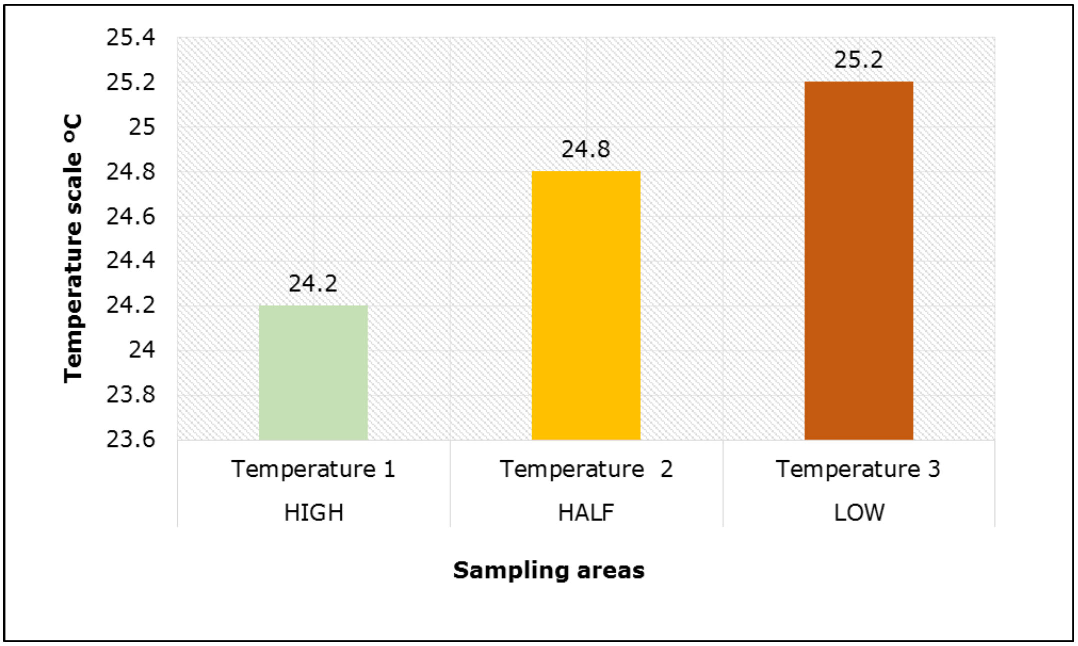

Figure 9. Temperature values for the high, medium and low zones.

Turbidity. The turbidity evaluated shows marked oscillations that vary in the three sampling zones and indicate vulnerability at the source (Figure 10). Regarding this parameter, the turbidity result showed outstanding values since the river is located in a mountainous area, under vegetation and tropical climate, which is why rainfall is common. In the case of the middle zone, its value was 6.38 NTU, the highest of the three points, and in the low zone, 3.73 NTU, a low estimate that exceeds the permitted limit. If turbidity levels increase, they can generate a resistance in the microorganisms that would prevent correct disinfection of the liquid.

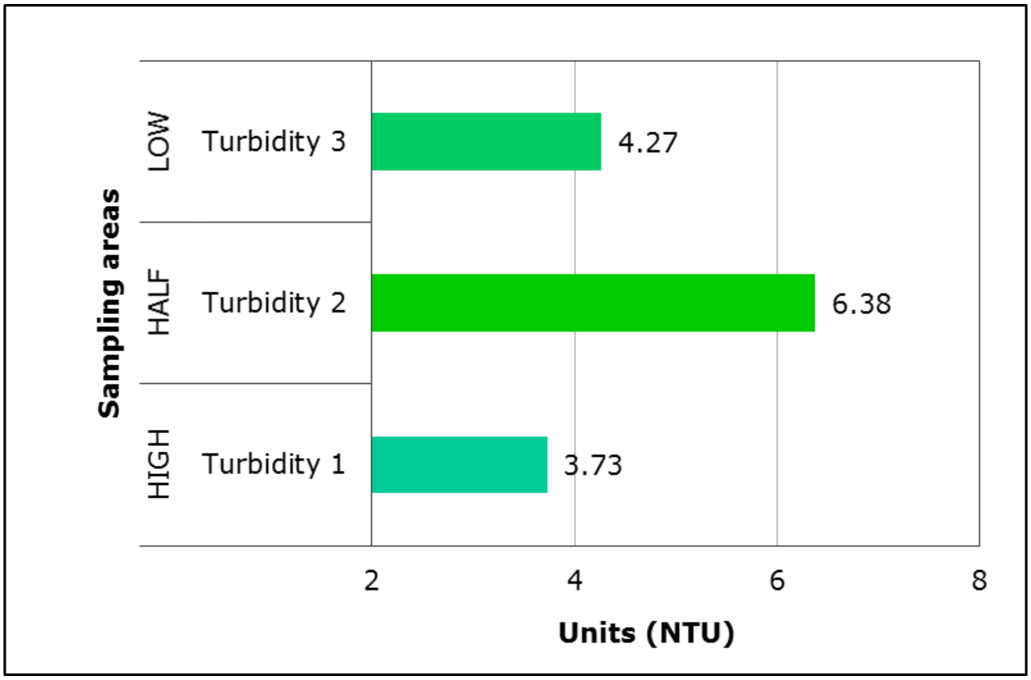

Figure 10. Turbidity values in the three sampling zones.

Color and smell. The organoleptic analysis showed that the color parameter in the high and medium zones is acceptable and unacceptable in the low zone (Figure 11), due to the disturbance generated by the discharge of wastewater into the stream. Likewise, for the odor parameter in the high and medium zones there was no alteration whatsoever, and in the low zone, unpleasant odors can be perceived as a result of the wastewater discharged without any treatment.

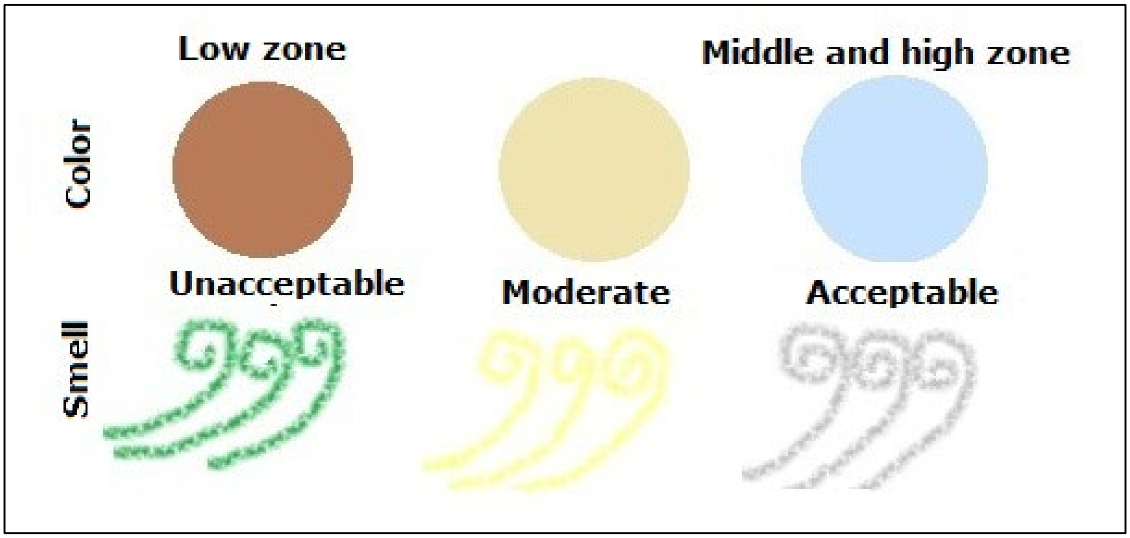

Figure 11. Color and Smell values in the three sampling zones.

Water quality index for high and low water quality points

To determine the water quality index of the Mulato River in the upper and lower zones, the methodological guide of the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) was taken into account.

The formula used to find the index of each parameter assigned in the sampling stations, where:

$$ICA_{njk} = \left(\sum_{i=1}^{n} Wi \ * I_{ikjt} \right)$$

Where ICA_{njk}: The water quality index of a given surface stream, at water quality monitoring station *j* at time *t*, evaluated based on *n* variables; *Wi* is the weight or relative weight assigned to the quality variable *i*; I_{ikjt} is the calculated value of variable *i* (obtained by applying the corresponding functional curve or equation), at monitoring station *j*, recorded during the measurement made in quarter *k*, of period *t*; *n* is the number of quality variables involved in the calculation of the indicator; *n* is equal to 5 or 6, depending on the ICA measurement selected.

This formula was used to find the average ICA in the two sampled zones, where:

$$ICA\ Promedio_{njk} = \sum_{k=1}^{m} \left(\sum_{i=1}^{n} Wi * I_{ikjt} \right) / m$$

Where *m* it is the number of samplings in which, the quality variables involved in the calculation of the indicator $1 \leq m \leq 4$ were measured, if the period is annual.

The calculations made were compared with what is determined by Colombian regulations, taking into account that the water source is being used to supply an aqueduct. The IDEAM establishes a qualitative and quantitative description of Table 5.

Table 5. Water quality qualification according to the values taken by the ICA.

Categories of values that the indicator can take	Water quality qualification	Warning signal
0.00-0.25	Very bad	Red
0.26-0-50	Bad	Orange
0.51-0.70	Regular	Yellow
0.71-0.90	Acceptable	Green
0.91-1.00	Good	Blue

Source: IDEAM (2015).

The ICA for the Mulato River water source is shown in Table 6, the quality index for the high zone is 0.76, and for the low zone 0.758, according to the ICA rating and taking into account the parameters of Table 5 of IDEAM, the water quality is considered acceptable and, with a green alert signal, it does not represent a danger to human health; however, it does not refer to direct consumption, but the water subjected to the treatments established by the regulations can be used for this purpose. Although the IDEAM reference and the ICA result is favorable, the water company must take into account some variables such as population growth, the settlement in these areas of Mocoa and the scarce resources of the rural population for the construction of septic tanks to minimize the impact on water sources.

Table 6. Water quality index values for five parameters.

Evaluating parameter	**Units of measure**	**Parameter index value high zone (Z1)**	**Parameter index value low zone (Z2)**
pH	pH unit	1	1
Conductivity	μS/cm	0.15	0.15
Chemical Oxygen Demand (DQO)	mg/l	0.91	0.91
Total suspended solids (SST)	mg/l	0.975	0.975
Dissolved Oxygen	% saturation	0.74	0.73
Total Water Quality Index(ICA)		0.76	0.758
Quality descriptor		Acceptable with green alert	

Discussion

The Mulato River has a flow rate of 5.119 m^3 /sec, which favors the natural purification process and allows it to control the pollutant loads contributed by its two tributary streams. On the other hand, the biological indices provide information on the momentary situation and what happened before sampling. The most stable environments are very diversified, although small alterations do not affect diversity, but rather induce its increase, because the intolerant or opportunistic species disappear or diminish (Guzy, 2019). For this reason, measuring diversity is a way of detecting contamination. The problem consists in matching a certain index value with a meaning with respect to quality.

The Mulato River has a hydrogen potential (pH) between 5.6 - 5.8. And when compared to a study conducted in Costa Rica in which the pH was analyzed to evaluate the quality of water for human consumption in three sectors. According to Pérez (2016) differences between zones were found, establishing that "the variability of pH from one sector to another may be influenced by the treatment applied to the water or by the type of basin from which it comes, due to the richness of minerals it possesses, which alters the hydrogen potential present in the water". In physicochemical studies carried out by Aguas Mocoa, in the palm trees sector in the upper part of the Mulato River, a pH of 7.13 was recorded, which compared with the data collected, shows that the water source has a considerable loss of this parameter as it descends.

Regarding conductivity, the value obtained in the upper and lower part of the river was 67.6 and 67.7 µS/cm, and coincides with other studies referenced by Aveiga, Noles, De-la-Cruz, Peñarrieta and Alcantara (2019), in which it is stated that "higher conductivity in disturbed sites has been reported and is associated with the greater input of organic matter, nutrients and higher concentration of ions due to human impact and also with the greater input of sediments due to the lack of riparian vegetation and agrees with Sulbarán-Rangel, Madrigal-Olveira, Romero-Arellano and Guzmán-González (2019), when he states that "Conductivity had high values in monitoring stations where wastewater was present". Two months after the samples were taken in the El Líbano area, the aqueduct company conducted physical-chemical studies in the upstream part of the Mulato River, Las Palmeras sector, in which conductivity had a value of 164.2 µs/cm, these variations could have been influenced by the time the sample was taken and the high area of the water source surrounded by mountains.

Regarding the Dissolved Oxygen, there was difference between the sampling zones ranged between 7.19 and 7.34 mg/l O_2; the highest level was recorded in the area where the intake is located, These results compared with the study carried out in Ecuador, which established the environmental impact generated by the discharge of wastewater on the self-purification capacity of the Portoviejo River, the lowest values of the oxygen consumption and reoxygenation constants, respectively, and which indicate the sections of the river in which the self-purification capacity was lower (Gutiérrez, 2018). Similarly, in the study of the impact of wastewater from the municipality of Ayapel on the water quality of the Ciénaga, sampling zones were established and the hourly variations were taken into account, considering that the hourly temporal differences in the water quality of the Ciénaga are not always the same (Chalarca, Mejía, & Aguirre, 2006) considering that the hourly temporal differences in OD concentrations are representative. However, authors such as Pérez, Nardini and Galindo (2018), questioning the requirements established by the WHO, state that ideal dissolved oxygen levels of 14.6 mg/l, which is evidently an extreme additional requirement, this value is only possible at a temperature of 0 °C.

In reference to temperature, the lower zone presented an increase of 0.7 °C, in relation to the upper zone; according to Chatanga, Ntuli, Mugomeri, Keketsi and Chikowore (2019), the temperature increase could be due to the fact that the river segment in that section is more open and shallower, which allows for greater heat exchange with the atmosphere. Considering Posada, Mojica, Pino, Bustamante and Monzón (2013) "There is abundant evidence that the temperature of a water current, under equilibrium conditions, is related to the temperature of the ambient air in a way that is specific to each current considered, with a behavior that conforms to a trend line that in some cases may be linear and in others has a slightly more complex behavior".

The DBO_5 levels remained in equilibrium, according to Gualdrón (2018), the results of the research conducted on Colombian rivers in 2016, the Biological Oxygen Demand in five days (DBO_5) presented an average value of 6.7 mg/l, considered within the permissible limit for water quality for fish habitat. Different studies have considered that the variations in DBO_5 are due to wastewater discharges, taking into account Jaramillo *et al*. (2016). The monthly variation of DBO_5 presents maximum values in the months of April and May, months in which the main coffee harvest takes place in the region. This implies a greater generation of pollutant load (2.3 tons DBO_5 /day). On the other hand, Cerdeña, Lázaro and Vàsquez (2014) in their study of water pollution in the Itaya River in Peru, showed that the DBO_5 /DQO quotient in the Masusa port is 0.46 and that of the Amazon River is 0.5, both considering that in both cases the organic matter present in the water is easily biodegradable.

Escobal, Chávez and Roncal (2020) refers that water with abundant solids is usually not drinkable and can induce an unfavorable physiological reaction in the consumer. As noted by Aveiga *et al*. (2019), the highest concentration of total solids (360 $mg.l^{-1}$) was found at the control point (Azucena), which is related to the high concentration of sulfates (212 $mg.l^{-1}$); while, for suspended solids (SS), the tendency was to increase at the level of the reservoir (zone 2) and the sub-basin (zone 3). This evidenced the incorporation of sediments and wastewater from domestic activities along the watercourse.

Turbidity had variations in the three zones, according to Rodríguez, Polania, Zapata, Villegas and Montañez (2019), according to Colombian regulations, a large number of Colombian rivers have suspended particles that reduce the transparency of the water, which is exhibited by the processes of dragging and removal of soil and industrial and/or urban discharges.

In the department of Putumayo, there are no published articles that refer to similar research, however, there is some gray literature that was used as input to generate the contrast with the results obtained. In this way, Muñoz (2017), in the study carried out with the Corporation for the Sustainable Development of the Southern Colombian Amazon (Corpoamazonia), the physicochemical parameters pH and conductivity were low with respect to those analyzed in this research. The opposite was true for dissolved oxygen, which increased significantly in the analyses carried out. Referring to the study cited above, the pH in the upper part had a value of 7.37 and 5.60 pH units for the current results, a factor that could generate this decrease is the high amount of rocky material and the type of soil present in the water source, which makes possible a greater dissolution of its components in the water, such as aluminum, another aspect to consider is the presence of organic matter

Barahona-Palomo and Beita-Sandi (2011), affirms that the concentration of organic matter generates a control in the pH in correlation with the dissolution of aluminum, which will cause a release of H+ reducing the pH in the water.

Another parameter that evidenced changes was conductivity, the values that showed significant difference were obtained in the middle part of the source 93 for the cited study, and 65.2mS/cm respectively, being one of the incident variables the flow of the Mulato river; equivalent to 1.462 and 5.119 l/s. The conductivity obtained was higher in relation to the study carried out by Muñoz (2017), this may be attributed to the fact that the latter's study was carried out days after a fluvial-torrential flood in the area and the present study three years after that event. In addition, conductivity showed a reduction caused by the increase of ions in the source, originated by the increase in precipitation in the area (Morell-Bayard, Bergues-Garrido, & Portuondo-Ferrer, 2015).

The agents that could have caused the increase in dissolved oxygen are precipitation, sunlight and Amazonian vegetation present around the river, since the relationship between them promotes an increase in oxygen in the water, as Muñoz *et al*. (2015) emphasizes that solar radiation increases the temperature of the water and therefore a greater photosynthesis in the riverbed, so dissolved oxygen is greater than the consumption. In the case of the Mulato River, the values were 5.09 mg/l for the study cited above and 7.34 mg/l recorded in the present investigation.

Conclusions

The Mulato River receives wastewater discharges from two streams located at coordinates 01º 08' 39.7" N and 76º 40' 12.5" W for the first stream, and 01º 08' 47.2" N and 76º 39' 53.2" W for the second. Although there is a certain degree of turbidity and contamination, the water quality of the Mulato River does not present a serious environmental impact, thanks to the natural self-purification action and the influence of the rocky material that flows through it. The tributary streams do not discharge the same amount of pollutant load and, since there is no direct alteration, there is no evidence of an indirect impact, despite the discharges in the three areas under study.

The lack of public sewage systems prevents the community from properly managing and disposing of wastewater and discharging it into the streams, without taking into account its ecological importance. Within the framework of integrated water resource management, the community has a co-responsibility in the management of wastewater; however, the various investigations warn that economic resources do not allow them to build septic tanks that could minimize the problem. For this reason, this research considers that, in attention to environmental interests and the availability of resources, the implementation of water reconversion programs, environmental awareness and the use of waste from the economic activities of the community of El Líbano are alternatives that can be worked efficiently, in an articulated process between academia, community and institutions.

The lack of water potabilization and the absence of a wastewater treatment plant and public sewage system in Mocoa, capital of the department of Putumayo, together with the lack of information published in the form of new knowledge products inherent to water quality studies in the region, make this article a valuable bibliographic contribution for the community to implement actions in accordance with its resources and that guarantee water sustainability.

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