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Research article

Influence of geomorphology and flow on the water quality of Guano River, Ecuador

Influencia de la geomorfología y el caudal en la calidad del agua del río Guano, Ecuador

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Abstract: The present study determines the water quality of the Guano River in Ecuador through the water quality indices WQI-NSF, WQI-Dinius, and a variant of the WQI-Dinius index that includes the average slope of the riverbed and the flow. To obtain qualitative values of water quality that allow better use of the river water. The results obtained with the three indices show that there is slight contamination in river sections caused by human activities, decreased flow, and wastewater discharge. Furthermore, the work shows that when applying the WQI-Dinius modified, the values of the weights of the water quality are lower concerning the other indices. But, even when the WQI-Dinius modified values are common, the valuation range for agricultural use is similar among the three indices, maintaining the criterion that the Guano River is slightly contaminated. Therefore, treating the water before using it in agricultural activities is necessary.

Keywords: Flow, geomorfología, solpe, water quality, WQI.

Resumen: *El presente estudio determina la calidad del agua del río Guano en Ecuador mediante los índices de calidad del agua ICA-NSF, ICA-Dinius y una variante al índice ICA-Dinius que incluye la pendiente media del cauce y el caudal. Para de esta manera obtener valores cualitativos de calidad de agua que permitan un mejor aprovechamiento del agua del río. Los resultados obtenidos con los tres ínidces muestran que existe contaminación leve en ciertos tramos del río, provocada por las actividades humanas, la disminución del caudal en el río y por la descarga de aguas residuales. Por otra parte, muestra que al aplicar el ICA-Dinius modificado los valores de las ponderaciones de la calidad del agua son más bajos respecto a los otros índices. Aún cuando los valores presentados por ICA- Dinius modificado son bajos, el rango de valoración para uso agropecuario es similar entre los tres índices, manteniendo el criterio que el río Guano está levemente contaminado. Por lo tanto, es necesario dar tratamiento al agua del río antes de usarla en actividades agropecuarias.*

Palabras clave: *Calidad del agua, caudal, geomorfología, ICA, pendiente.*

1. Introduction

Water is the most abundant natural resource on the planet; its quantity is approximately 1.385 billion km^3. Out of this overall volume, as little as 1% is usable freshwater; 81% of it is present in glaciers and polar zones, while the remaining 18% is distributed among soil moisture, lakes, atmospheric vapor, rivers, and living organisms (Bitsch *et al.*, 2021). All lifeforms on our planet, including flora, fauna, and human beings, have developed due to water availability (Singh, Yadav, Pal, & Mishra, 2020). Ecuador possesses a significant quantity of water resources; its average total runoff is 43,500 m^3 per inhabitant a year, four times greater than the world average of 10800 m^3 per inhabitant (Machado, dos Santos, Alves, & Quindeler, 2019). Water quality is at risk due to human activities near water sources. These activities are usually related to urban areas, mining areas, oil exploitation, and agriculture. These activities generate pollutant discharges with high concentrations of organic matter, nitrogen, phosphorus, heavy metals, and hydrocarbons (Ustaoğlu, Tepe, & Taş, 2020). Agricultural activity is extensive in the province of Chimborazo due to favorable climatic and geographical conditions (Moreano-Logroño & Mancheno-Herrera, 2020). In the last ten years, the Guano River has been used mainly in agricultural activities; in its course, it receives sanitary, agricultural, and industrial discharges. In addition, its flow has been reduced by 50%, changing the water quality and affecting the balance of the aquatic ecosystem, the soil, and people's health (Shakir, Chaudhry, & Qazi, 2012).

To study the characteristics of water resources, quality indexes are used to verify whether the water complies with the specifications for its intended use; in addition, the effects of pollutants need to be assessed *(Akhtar et al.*, 2021; Gupta & Gupta, 2021; Nong, Shao, Zhong, & Liang, 2020; Uddin, Nash, & Olbert, 2021; Villa-Achupallas, Rosado, Aguilar, & Galindo-Riaño, 2018). These indexes allow researchers to gather information on trends and identify river disturbances sources. Additionally, these indexes are necessary to study the characteristics of water resources and their quality to ensure the balance between human activities and the water ecosystem (Rivera, Encina, Muñoz-Pedreros, & Mejias, 2004). The US National Sanitation Foundation - water quality index (WQI-NSF) is used worldwide for this type of study. This method referred to here as Ramirez's approach, is based on characteristics of North American rivers, which relate physical-chemical variables to average weights assigned to each for evaluating the specific pollution type (Gradilla-Hernández *et al.*, 2020; Nugraha, Cahyo, & Hardyanti, 2020).

Works carried out in the area it is shown that the Guano River is affected by human activities, such as the excessive use of water for irrigation and the reception of wastewater (Castillejos & Arévalo, 2018; Castillo-López, Salas-Cisneros, Logroño-Veloz, & Vinueza-Veloz, 2021; Cevallos, 2015; Quevedo, 2020). But in these works, contamination is not related to other characteristics present in the area, such as geomorphology and flow.

Therefore, this work proposes a novel study to determine the water quality of the Guano River, using a variation of the WQI-Dinius that includes variables such as the average slope and the river's flow. In addition, this work compares the results obtained with this variant in the index with WQI-NSF and WQI-Dinius.

2. Methodology

2.1. *Sampling sites*

The Guano River basin (Figure 1) is located in the Ecuadorian highland between Tungurahua and Chimborazo; the river is the product of the thaws from Chimborazo's volcano and the runoffs generated in the Igualata moorland. The river's source is downstream of Andaluza, in the area of Llío, where the Agags and Puluchaca streams merge at 3090 masl. The Guano River flows from northwest to southeast and runs into the Chambo River after traveling 21 km. Runoff from slopes in the area feeds the Guano River on its course (Chidichimo *et al.*, 2018).

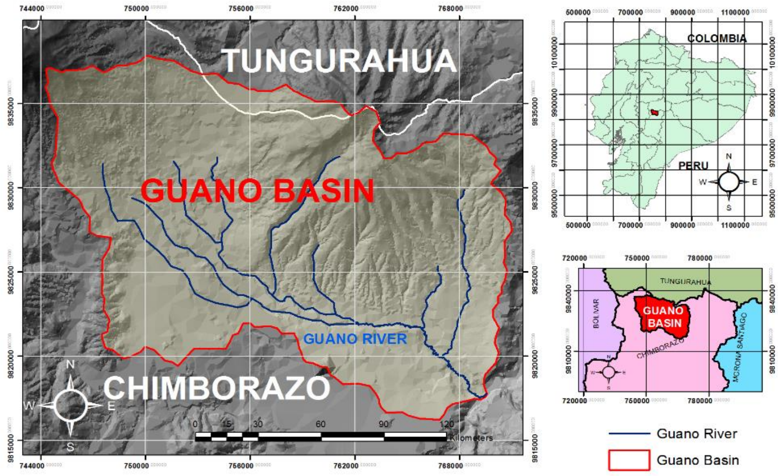

Figure 1: Location of the Guano River basin.

According to the vegetation cover and the use of the soil (Table 1), the main anthropic activity is agriculture since it has a higher percentage of the area than the rest of the micro basin areas. In addition, the rate of population area corresponds mainly to the town of Guano, which sits on the banks of the river and is the one that shows the most significant interference in its quality. To determine the sampling points, vegetation and land use information (Mendoza *et al.*, 2021) were analyzed (Table 1). The river was traversed from the upper part to the river mouth, corroborating what was identified in the characteristics of land use and vegetation data.

Table 1: Area of the vegetal coverage and use of soil.

Vegetal coverage and use of soil	Area (km^2)
Natural forest	3.60
Crops	277.58
Grass	28.01
Paramo	69.44
Cities	5.65

In addition, the anthropic activities that affect the environmental conditions of the same are identified from the preliminary information on the cover and soil use. The river was explored from the mouth, identifying the characteristics of vegetation cover and soil use and the human activities that affect the river's environmental conditions; thus, 29 observation points of anthropic activities were found (Table 2).

Table 2: Observation points of anthropic activities with their UTM coordinates.

Code	Description	X	Y	Masl.
P_RIVER 1	Guano river, Llío	754395	9826549	3120
P_CHANNEL 1	Irrigation Channel 1	759572	9822858	2800
P_DISCHARGE 1	Wastewater discharge Colegio Pérez Guerrero	761098	9822398	2760
P_DISCHARGE 2	Wastewater discharge 80 m before the town of Guano1	761646	9822235	2725
P_DISCHARGE 3	Waste water discharge beginning of the town of Guano	761717	9822241	2720
P_DISCHARGE 4	Waste water discharge 70 m downstream	761753	9822178	2720
P_DISCHARGE 5	Waste water discharge 25 m downstream	761774	9822169	2720
P_DISCHARGE 6	Waste water discharge 27 m downstream	761799	9822159	2720
P_DISCHARGE 7	Waste water discharge 25 m downstream	761857	9822135	2720
P_DISCHARGE 8	Discharge of wastewater before the town of Guano	761891	9822121	2720
P_SLOPE 1	Spring Park of the slopes	761940	9822074	2720
P_SLOPE 2	Spring Park of the slopes	761969	9822046	2720
P_DISCHARGE 6	Discharge of residual water 40 m after the park of the slopes	762003	9822014	2720
P_SLOPE 3	Spring Park of the slopes	762029	9822004	2720
P_DISCHARGE 7	Discharge of residual water 40 m after the park of the slopes	762057	9821994	2720
P_SLOPE 4	Spring Park of the slopes	762093	9821980	2720
P_DISCHARGE 8	Discharge of residual water 40 m after the park of the slopes	762122	9821969	2720
P_SLOPE 5	Spring Park of the slopes	762179	9821922	2720
P_RIVER 2	Guano River, before Pebble Spinning Mill	762877	9821879	2680
P_DISCHARGE 9	Wastewater discharge Pebble Spinning Mill	763684	9821858	2680
P_RIVER 3	Guano River, before unloading Santa Teresita sector	763959	9821894	2673
P_DISCHARGE 10	Waste water discharge Santa Teresita	764249	9821860	2640
P_RIVER 4	Guano River, before the Chingazo Canal - Pungal	765041	9821806	2640
P_CHANNEL 3	Canal Chingazo - Pungal	765533	9821776	2607
P_SLOPE 6	Spring of the Elenes	765959	9821465	2600
P_SLOPE 7	Spring of the Elenes	766022	9821436	2600
P_DISCHARGE 13	Wastewater discharge San José Alto	767236	9819720	2560
P_DISCHARGE 14	Waste water discharge Quimiac sector	767383	9819519	2556
P_RIVER 5	Guano River, before the mouth of the Chambo River	769511	9817696	2480

From these sampling points: P_RIVER1, P_RIVER 2, P_RIVER 3, P_RIVER 4, and P_RIVER 5 were selected to determine the water quality of the Guano River concerning the interference of human activities. In addition to these sampling points, by areas, from the upper part to the mouth of the river. Once these sampling points were chosen, over the time frame encompassing July to November 2018 (dry season), the water samples were taken in triplicate for 18 days at each monitoring point, giving 240 pieces for water quality analysis. All models were collected by the authors manually in plastic containers. For the physical-chemical parameters, the bottle (1000 mL) was submerged 20 cm below the water surface with the peak of the bottle in the direction of the current until filled the bottle free of bubbles that may form at the mouth of the bottle. For the microbiological analysis, 100 mL of sample was taken in a sterile plastic container (Rice, Baird, & Eaton, 2017).

2.2. *Parameters used in the indexes*

Laboratory analysis for water was performed according to the Standard Methods for the Examination of Water and Wastewater (23rd ed.) (Rice *et al.*, 2017) as described below:

The Electrometric Method 4550-H+ B for pH was carried out with a Model HI99121 pH meter, using a model HI1230B electrode by HANNA INSTRUMENTS of Woonsocket, Rhode Island, United States, which enables a measuring range from pH 2.00 to 16.00. The method consists of shaking a 100 mL aliquot of water to ensure homogeneity. Then the electrode is immersed in the sample for 1 min and the pH value is read when the equipment stabilizes.

The Electrical Conductivity Method 2510 B was performed using a Model SEVEN COMPACT CONDUCTIVITY S230 conductivity meter, with an electrode Cond probe InLab 710 by METTLER TOLEDO of Greifensee, Switzerland. The range of measurement was from 0.001 to 1000 mS/cm. The method involves shaking an aliquot of 100 mL of water to ensure homogeneity. Then, the electrode was immersed in the sample for 1 min, and the conductivity value was read when the equipment stabilized.

The Total Dissolved Solids Method 2540 C was conducted with the previous equipment, with a measuring range from 0.00 mg/L...1000 g/L. The method involves shaking an aliquot of 100 mL of water to ensure homogeneity. Then the electrode is immersed in the sample for 1 min, and the total dissolved solids value is read when the equipment stabilizes.

The Membrane Electrode Method 4500-O G for determining Dissolved Oxygen was carried out with the Model HI98198 OD and a model HI764113 electrode by HANNA INSTRUMENTS of Woonsocket, Rhode Island, United States; the measuring range was from 0.00 to 50 mg/L. This method consists of introducing the electrode into the river bed so that the water covers the electrode membrane completely. The equipment is allowed to stabilize for 1 min, and the optical density (OD) value is reported as a concentration in mg/L.

The Nephelometric Method 2130 B for determining Turbidity is carried out with a Model HI93703 (HANNA INSTRUMENTS of Woonsocket, Rhode Island, United States) with a measuring range from 0.00 a 1000 FTU. This method involves gently agitating the sample for 1 min; then the sample is poured into the cell of HANNA INSTRUMENTS HI93700d tr of Woonsocket, Rhode Island, United States. The turbidity value is read when the equipment stabilizes and all air bubbles disappear.

A modified phosphates Method 4500-P-E was applied with a range of 0.02 to 2.50 mg/L PO_4^{-3}. This method is carried out with the spectrophotometer HACH DR 5000 of Loveland, Colorado, United States, using sample cells of 10 mL (HACH 2495402 5000 of Loveland, Colorado, United States). This method involves gently agitating the sample for 1 min before placing it into the cell. Then, the contents of one PhosVer3 Reagent Powder Pillow (HACH, catalog number: 2106069 5000 of Loveland, Colorado, United States) is added to the cell; a blue color develops if phosphorus is present in the sample. If so, the sample cell should be closed immediately and shaken vigorously for 20-30 s. After this, the sample should be allowed to stand still for 2 min. Next, start program 490 P with the spectrophotometer set to a wavelength of 880 nm. Insert the blank into the cell holder, push zero, and the display shows 0.00 mg/L PO_4^{-3}. Then, the prepared sample cell is cleaned with reagent, and the prepared sample is inserted into the cell holder; results are displayed in mg/L PO_4^{-3}.

The Nitrogen Method (Nitrate) 4500 NO_3^- E modified to HACH method 8039 had a measuring range from 0.3 to 30.0 mg/L NO_3^-. This method is carried out with a HACH DR 5000 spectrophotometer and Model HACH 2495402 sample cells of 10 mL 5000 of Loveland, Colorado, United States. This method involves gently agitating the sample for 1 min. Then, the sample is placed in the cell, and the contents of one NitraVer 5 Reagent Powder Pillow are added. The sample cell was closed immediately, shaken vigorously for 60 s, and let to still stand for 5 min. Next, prepare the blank and fill it in a second sample cell. Start program 355 N with wavelength set to 500 nm. Zero the instrument for the blank, clean the sample cell with reagent, and introduce the sample into the cell holder; results will be shown in mg/L NO_3^-.

EDTA Titrimetric Method 2340 C for Total hardness (mg$CaCO_3$/L). This method needs 25 mL of sample. First, one adds to the sample 1 to 2 mL buffer solution (ammonium chloride and ammonium hydroxide) to give a pH of 10.0 to 10.1. Next, 1 to 2 drops of indicator solution or an appropriate amount of dry-powder indicator formulation (Eriochrome Black T -NET) are added. Add standard EDTA (0.01M) titrant slowly, under continuous magnetic stirring, until the last reddish tinge disappears. The last few drops should be added at 3 to 5 s intervals. At the endpoint, the solution typically turns blue.

The Titration Method 2320 CB for Alkalinity (mg$CaCO_3$/L). In this method, 25 mL of sample 1 to 2 drops indicator solution (Methyl Orange) are added and titrated with a standard 0.1 N sulfuric acid solution. The reagent should be added slowly, under continuous stirring, until the sample color changes to purple.

Biochemical Oxygen Demand (BOD) 5210 B. 5-Day BOD modified to VELP BOD EVO Sensor of Usmate, Italy; for this measurement, one used a BOD sensor set consisting of a BOD Sensor, a dark glass bottle, an alkali holder to absorb the carbon dioxide, and a stirring bar. BOD (mg/L) value will be obtained directly from the display at any time, even after five days. For 5 days, the set is kept in an incubator VELP SCIENTIFICA FOC 120I at 20 °C in Usmate, Italy. Then, a magnetic stirrer is inserted in an amber glass bottle (500 mL), and the BOD sensor is installed. The sensor reports that the value after 5 days is the one that determines the BOD5.

Chemical Oxygen Demand (COD) 5220 D, Closed Reflux, Colorimetric Method. One used HACH DR 5000 spectrophotometer 5000 of Loveland, Colorado, United States. Samples were gently agitated for 1 min and held in a vial reagent HACH LR (range 3-150 mg COD/L) at an angle of 45º. A clean pipet was utilized for dispensing 2.00 mL of sample to the vial. The same procedure was used for another vial filled with deionized water and utilized as the blank. After closing the vial it should be held by the cap, over a sink. The content of the vial can be mixed by inverting the vial gently several times. Next, vials are placed in A preheated DRB200 reactor for 2 h at 120 ºC. After turning off the heat, vials should cool in the reactor for 20 min to 120 ºC or less and then cool to room temperature in a tube rack. The spectrophotometer should be set at 420 nm, and 430 COD LR program should be started. Samples are recorded relative to the blank, and results are displayed in mg/L COD.

Membrane filter technique for members of the coliform group 9222 modified to Petrifilm Coliform Count Plate of Northern Minnesota, United States. This method consists of gently agitating samples for 1 min and placing Petrifilm Coliform Count Plates on the surface. Lift the top film and, with Pipettor or equivalent held perpendicularly to the plate, place 1 mL of sample or diluted sample onto the center of the bottom film. Prevent pushing sample off film to avoid entrapping air bubbles. Do not let top film drop. With the flat side down, place 3MTM PetrifilmTM Spreader on top film over inoculum. Gently apply pressure on the 3M Petrifilm Spreader to distribute inoculum over a circular area before the gel is formed. Do not twist or slide the spreader. Lift 3M Petrifilm Spreader. Wait a minimum of 1 min for the gel to solidify. Incubate plates clear side up in stacks of up to 20. It may be necessary to humidify the incubator MEMMERT model BE500. 3M Petrifilm Coliform Count Plates can be counted using the 3MTM Petrifilm Plate Reader on a standard colony counter or other illuminated magnifiers. Colonies may be isolated for further identification. Lift the top film and pick the colony from the gel.

The flow was obtained with the float method, this is based on the speed-area principle, where (n) cross-sectional areas (depth and width) were measured, and the velocity was obtained from the time the float takes to travel a distance (5m). The Manning coefficient corrects the flow (Davids et al., 2019). Flow information of the different sampling points was obtained according to equation (1).

$$Q = V * (AT) * K \tag{1}$$

Where: Q is the flow rate (m^3/s), V is the velocity (m/s), AT is the transverse area (m^2), K is a correction factor (Manning coefficient) for rivers with a depth greater than 15 cm.

From the heights of the contour lines, the tool-created TIN is used to develop the digital terrain elevation model (DEM). Owing to the transform tool of TIN, the elevation raster of the study area is generated. From this raster, the Spatial Analysis slope tool is used to spatially determine the Slope (Sc) in the basin. This is done in the ArcGis 10.1 software (Mendoza *et al.*, 2021).

2.2. Water Quality Indexes

In this study, the river course was divided into transects according to the natural conditions and the human activities present, leaving five monitoring points for studying the water quality; these points were chosen based on the pressure on different transects, as shown in table 2. The methodology of the water quality indices applied at the sampling points is described below.

The first methodology is the WQI-NSF, proposed by the National Sanitation Foundation; this is used to assess changes in water quality in specific sections of rivers at different times. The calculations of this method were carried out by weighting according to the parameter type (Table 3); that is, a percentage value was assigned to each parameter analyzed, their total sum being 1. This value was then transformed into a percentage value, with a range from 0 to 100 (Akhtar *et al.*, 2021; Gupta & Gupta, 2021; Mukate, Wagh, Panaskar, Jacobs, & Sawant, 2019; Uddin *et al.*, 2021; Ustaoğlu *et al.*, 2020). Finally, equation (2) was used to calculate the WQI.

$$WQI - NSF = \frac{\sum_{i=1}^{n} I_i W_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

where W_i is the weighting coefficient for parameter i, I is the index for each parameter, and n is the total number of parameters.

Table 3. Parameter of quality index WQI-NSF (Akhtar *et al.*, 2021; Gupta & Gupta, 2021; Mukate *et al.*, 2019; Uddin *et al.*, 2021; Ustaoğlu *et al.*, 2020)

Parameter	Weigth
DO	0.17
Faecal Coliforms	0.16
pH	0.11
BOD	0.11
Nitrates	0.10
Phosphates	0.10
Temperature	0.10
Turbitity	0.08
Dissolved solids	0.07

The second methodology described by Dinius determines the water quality of the sample according to the degree of water pollution. Thus, it will have a quality index close to 0 for utterly contaminated water. The index will be 100 for water with excellent conditions (Hoseinzadeh, Khorsandi, Wei, & Alipour, 2015; Mukate et al., 2019; Zotou, Tsihrintzis, & Gikas, 2019, 2020). Subsequently, this index indicates that a correction should be made to the results (Table 4). Each parameter has a weighting value of W that allows obtaining the corresponding WQI; the weight for each parameter was given in table 4.

Table 4. Parameter of WQI-Dinius (Hoseinzadeh *et al.*, 2015; Mukate *et al.*, 2019; Zotou *et al.*, 2019, 2020)

Parameter	I for WQI calculation	W for WQI calculation
Dissolved Oxygen - OD	0.82*OD + 10.56	0.109
Chemical Oxygen Demand - COD	$108\ (COD)^{-0.3494}$	0.097
Total Coliforms - CT	$136\ (ColiTotal)^{-0.1311}$	0.090
Fecal Coliforms -CF	$106\ (EColi)^{-0.1286}$	0.116
Conductivity	$506\ (SPC)^{-0.3315}$	0.079
Chloride	$391\ (CL)^{-0.3480}$	0.074
Total Hardness	$552(Hardness)^{-0.4488}$	0.065
Alkalinity	$110(Alc)^{-0.1342}$	0.063
pH < 6.9	$10^{0.6803+0.1856(pH)}$	
pH = 6.9 – 7.1	1	0.077
pH > 7.1	$10^{3.65+0.2216(pH)}$	
Nitrates	$125(N)^{-0.2718}$	0.09
Color Pt-Co	$127(Color)^{-0.2394}$	0.063
Turbidity	$10^{2.004-0.382\|Ta-Ts\|}$	0.077

The numerical evaluation of the WQI-Dinius is obtained from the geometric mean (Equation (3)):

$$WQI - Dinius = \prod_{i=1}^{n}\left[Q_i^{W_i}\right] \quad (3)$$

where W_i are the specific weights assigned to each parameter (i), and weighed between 0 and 1, so the sum is equal to 1. Q_i is the quality of the parameter (i), which depends on its concentration, and is rated from 0 to 100. *PI* represents the multiplication of the variables Q elevated to power W.

To contemplate the geomorphology and flow of the Guano River in the calculation of water quality, the WQI-Dinius was modified; therefore three steps were considered: (i) selecting the parameters, (ii) determining the sub-indexes, and (iii) determining the index by aggregation (Mukate *et al.,* 2019; Samboni *et al.,* 2007). For this purpose, the selection of parameters was separated into groups as follows: (a) organic matter: dissolved oxygen in % saturation and mg/L, biochemical oxygen demand and chemical oxygen demand, (b) bacteriological matter: total coliforms and fecal coliforms, (c) physical characteristics of water: color, Turbidity and electrical conductivity, (d) inorganic matter: alkalinity, hardness, chlorides, hydrogen ion concentration (pH), suspended solids, and total dissolved solids, (e) nutrients: nitrates, nitrites, phosphates, total phosphorus, and sulfates, (f) geomorphology characteristics: mean average of the Slope, Slope of the river course in the area under study, and flow. To apply the WQI-Dinius Modified, equation (4) was used. The I values were obtained from table 4, and the geomorphological characteristics (I) are equal to 1. The importance of W (WQI- Dinius Modified) for this method are described in table 5.

$$WQI - \text{Dinius Modified} = \frac{\sum_{i=1}^{n} W_i I_i}{\sum_{i=1}^{n} W_i} \quad (4)$$

where Wi is the weighting coefficient for parameter i, I is the index for each parameter, and n is the total number of parameters.

The importance of parameter groups is identified for this case. Then the importance of the parameters within the parameter group is identified and the weight value is given at the end

Table 5: Weighing (W) for WQI- Dinius Modified.

Importance between groups	Parameter	Weighing (W) Dinius	Importance between parameters	Weighing (W) WQI- Dinius Modified
1	Dissolved Oxygen	0.109	1	10.9
	COD	0.097	2	9.7
2	Fecal Coliforms	0.116	1	11.6
	Total Coliforms	0.09	2	9
3	Flow	-	1	7.25
	Average slope of the main cause	-	2	6.45
4	Nitrates	0.09	1	9
5	Conductivity	0.079	1	7.9
	Turbidity	0.077	2	7.7
	pH	0.077	1	7.7
	Total Hardness	0.065	2	6.5
	Alkalinity	0.063	3	6.3

The criteria that were used to determine the quality of the water once calculated with the WQI-NSF, Dinius-WQI, and modified WQI are shown in table 6 (Akhtar et al., 2021; Gradilla-Hernández et al., 2020; Gupta & Gupta, 2021; Hoseinzadeh et al., 2015; Mukate et al., 2019; Nong et al., 2020; Nugraha et al., 2020; Uddin *et al.*, 2021; Ustaoğlu *et al.*, 2020; Zotou *et al.*, 2020, 2019). The results obtained by this methodology are analyzed according to the information in table 5 to identify whether the quality is excellent or bad as endpoints of the valuation.

Table 6: General criteria of WQI (Akhtar *et al.*, 2021).

Type of use	Color	Evaluation range	Quality description	Treatment
USE IN AGRICULTURE	**E**	**90-100**	EXCELLENT	It does not require purification to be consumed
	A	**79-90**	ACCEPTABLE	Minor purification is needed for crops that require high water quality
	LC	**50-79**	SLIGHTLY CONTAMINATED	Treatment required for most crops
	C	**30-50**	CONTAMINATED	Treatment required for most crops
	FC	**20-30**	STRONGLY CONTAMINATED	Use only in very resistant crops
	EC	**0-20**	EXCESSIVE	Inacceptable for irrigation

3. Results

The geomorphology of the Guano River (Table 7) shows that the micro-basin is small according to the area. The average slope of the micro-basin is medium-rough, the sections of the leading cause have medium-rough slopes in the upper part, and the lower part has gentle slopes.

Table 7: Geomophology of the Guano river.

Parameter	Initials	Unit	Value
Area	A	km^2	384.28
Perimeter	P	km	94.26
Length of the main channel	Lc	km	39.15
The average slope of the basin	Sm	%	13.74
The average slope of the main channel	Sc	%	16.35
Slope first section	Sc1	%	11.2
Slope the second section	Sc2	%	3.93
Slope third section	Sc3	%	0.07
Slope fourth section	Sc4	%	2.59
Slope the fifth section	Sc5	%	2.39

In the high areas, the Guano River has an average flow of 0.68 m^3/s, reaching the mouth with a flow of 1.83 m^3/s. The flow decreases in the central region because there are irrigation channels along the river that redirect water from the river's natural course (Table 8). Still, the flow recovers because springs provide additional fresh water to the river. Moreover, the physical-chemical and microbiological parameters that constitute the WQI were analyzed and performed for the five sampling points, as shown in Tables 9, 10, 11, 12, and 13.

Table 8: Average flow of the Guano river at the sampling points (m^3/s).

Sampling	P_RIVER 1	P_RIVER 2	P_RIVER 3	P_RIVER 4	P_RIVER 5
Sampling 1	0.79	0.97	0.94	1.83	2.14
Sampling 2	0.81	0.99	0.96	1.87	2.19
Sampling 3	0.60	0.74	0.71	1.39	1.63
Sampling 4	0.73	0.90	0.87	1.70	1.99
Sampling 5	0.75	0.92	0.90	1.74	2.04
Sampling 6	0.56	0.69	0.66	1.29	1.51
Sampling 7	0.68	0.84	0.81	1.58	1.85
Sampling 8	0.70	0.86	0.83	1.62	1.90
Sampling 9	0.52	0.64	0.62	1.20	1.41
Sampling 10	0.64	0.78	0.76	1.47	1.72
Sampling 11	0.65	0.80	0.77	1.51	1.76
Sampling 12	0.48	0.59	0.57	1.12	1.31
Sampling 13	0.59	0.73	0.70	1.37	1.60
Sampling 14	0.61	0.74	0.72	1.40	1.64
Sampling 15	0.73	0.90	0.87	1.70	1.99
Sampling 16	0.83	1.02	0.99	1.93	2.26
Sampling 17	0.85	1.05	1.02	1.98	2.31
Sampling 18	0.63	0.78	0.75	1.47	1.72

Table 9: Results of the physical-chemical and microbiological analysis in P_RIVER 1.

Sampling	pH	Conductivity	Temperature	Dissolved Oxygen	Turbidity	STD	Phosphate	Nitrate	Total hardness	Alkalinity	BOD	COD	Total Coliforms	Fecal Coliforms
	-	µS/cm	ºC	mg/L	NTU	mg/L	mg/L	mg/L	mg $CaCO_3$ /L	mg $CaCO_3$/L	mg O_2/L	mg/L	ufc/100 mL	ufc/100 mL
1	7.75	617	17.15	6.39	5.80	273	0.99	15.47	292	54.40	1.89	16.80	321	130
2	7.80	599	17.56	5.96	6.30	279	1.80	10.14	311	48.93	2.15	27.39	239	59
3	7.60	616	16.82	5.03	9.11	272	0.98	10.60	291	48.93	1.65	16.43	333	83
4	7.67	651	17.20	4.77	10.42	275	0.89	10.27	270	50.02	1.55	12.05	662	141
5	6.89	657	18.05	5.72	13.63	302	1.11	24.18	304	56.23	3.66	21.18	399	141
6	7.62	933	17.98	5.72	8.98	366	1.96	20.77	393	53.93	1.01	20.81	587	147
7	7.54	795	15.98	4.20	8.08	435	0.81	7.64	304	46.81	3.42	21.18	408	136
8	7.00	966	15.94	4.94	10.18	673	1.02	11.12	397	48.02	3.64	20.08	500	154
9	7.61	644	16.08	7.35	7.79	310	1.11	20.42	320	59.74	2.04	18.56	424	172
10	7.66	626	16.48	6.91	8.29	315	2.02	13.38	342	53.72	2.32	30.26	315	78
11	7.46	643	15.75	5.99	11.10	310	1.10	13.99	319	53.72	1.78	18.16	440	110
12	7.52	678	16.13	5.73	12.41	311	1.00	13.56	296	54.93	1.67	13.31	874	186
13	6.75	684	16.97	6.68	15.62	338	1.24	31.92	334	61.74	3.94	23.40	527	186
14	7.48	960	16.90	6.68	10.97	402	2.20	21.81	431	59.21	1.59	23.00	775	194
15	7.40	822	14.91	5.15	10.06	471	0.91	10.08	334	51.40	3.69	23.40	539	179
16	6.86	993	14.87	5.90	12.17	709	1.15	14.67	436	52.72	3.92	22.19	660	203
17	7.47	671	15.01	8.31	9.78	346	1.24	26.95	352	65.59	2.20	20.51	559	227
18	7.52	653	17.56	7.87	10.28	352	2.26	17.67	376	58.99	2.50	33.44	416	103

Table 10: Results of the physical-chemical and microbiological analysis in P_RIVER 2.

Sampling	pH	Conductivity	Temperature	Dissolved Oxygen	Turbidity	STD	Phosphate	Nitrate	Total hardness	Alkalinity	BOD	COD	Total Coliforms	Fecal Coliforms
	-	μS/cm	ºC	mg/L	NTU	mg/L	mg/L	mg/L	mg $CaCO_3$ /L	mg $CaCO_3$/L	mg O_2/L	mg/L	ufc/100 mL	ufc/100 mL
1	7.90	721	18.95	7.39	4.19	197	0.94	14.71	350	65.28	2.27	20.15	988	314
2	7.94	700	19.40	6.89	4.55	201	1.71	9.64	374	58.71	2.58	32.86	734	143
3	7.74	720	18.59	5.82	6.58	197	0.93	10.07	349	58.71	1.98	19.72	1025	201
4	7.81	761	19.01	5.52	7.53	198	0.85	9.76	324	60.02	1.86	14.46	2038	340
5	7.02	768	19.94	6.62	9.85	218	1.06	22.99	365	67.47	4.39	25.41	1229	340
6	7.76	1091	19.86	6.62	6.49	264	1.87	19.74	471	64.71	1.71	24.97	1806	355
7	7.68	929	17.66	4.85	5.83	314	0.77	7.26	365	56.17	4.11	25.41	1256	328
8	7.13	1129	17.62	5.71	7.36	486	0.97	10.57	476	57.61	4.36	24.10	1538	372
9	7.75	752	17.77	8.50	5.63	224	1.05	19.41	384	71.68	2.45	22.27	1304	414
10	7.80	732	18.21	8.00	5.99	228	1.92	12.72	410	64.46	2.78	36.31	969	188
11	7.60	752	17.40	6.92	8.02	224	1.04	13.29	383	64.46	2.14	21.79	1353	266
12	7.66	792	17.83	6.63	8.96	225	0.95	12.89	356	65.91	2.01	15.98	2690	449
13	6.87	799	18.76	7.72	11.29	244	1.18	30.34	400	74.08	4.73	28.08	1622	449
14	7.61	1123	18.68	7.72	7.93	291	2.09	20.73	517	71.05	1.91	27.60	2384	469
15	7.54	961	16.47	5.96	7.27	340	0.86	9.58	400	61.67	4.43	28.08	1657	433
16	6.99	1160	16.43	6.82	8.79	512	1.09	13.95	523	63.26	4.70	26.63	2030	490
17	7.61	784	16.58	9.61	7.07	250	1.18	25.62	422	78.70	2.64	24.61	1721	547
18	7.66	763	19.40	9.10	7.42	254	2.15	16.80	450.56	70.78	3.00	40.12	1279	248

Table 11: Results of the physical-chemical and microbiological analysis in P_RIVER 3.

Sampling	pH	Conductivity	Temperature	Dissolved Oxygen	Turbidity	STD	Phosphate	Nitrate	Total hardness	Alkalinity	BOD	COD	Total Coliforms	Fecal Coliforms
	-	μS/cm	ºC	mg/L	NTU	mg/L	mg/L	mg/L	mg $CaCO_3$ /L	mg $CaCO_3$/L	mg O_2/L	mg/L	ufc/100 mL	ufc/100 mL
1	6.71	613	16.11	6.28	3.56	168	0.80	12.50	298	55.49	1.93	17.13	839	267
2	6.75	595	16.49	5.86	3.87	171	1.46	8.19	318	49.90	2.19	27.93	624	121
3	6.58	612	15.80	4.94	5.59	168	0.79	8.56	296	49.90	1.69	16.76	871	171
4	6.64	647	16.16	4.69	6.4	169	0.72	8.30	275	51.02	1.58	12.29	1732	289
5	6.70	652	16.95	5.62	8.37	185	0.90	19.54	310	57.35	3.73	21.60	1044	289
6	6.59	928	16.88	5.62	5.52	225	1.59	16.78	400	55.00	1.41	21.23	1535	302
7	6.53	790	15.01	4.13	4.96	267	0.65	6.17	310	47.74	3.49	21.60	1067	279
8	6.66	959	14.97	4.86	6.25	413	0.83	8.98	405	48.97	3.71	20.48	1307	316
9	6.59	640	15.10	7.22	4.79	190	0.89	16.50	327	60.93	2.08	18.93	1108	352
10	6.63	622	15.48	6.80	5.09	194	1.63	10.82	349	54.79	2.36	30.86	823	160
11	6.46	639	14.79	5.88	6.82	190	0.89	11.30	325	54.79	1.82	18.52	1150	226
12	6.51	674	15.15	5.63	7.62	191	0.81	10.95	302	56.02	1.71	13.58	2287	382
13	6.57	679	15.94	6.56	9.59	208	1.01	25.79	340	62.97	4.02	23.87	1378	382
14	6.47	954	15.88	6.56	6.74	247	1.78	17.62	440	60.39	1.62	23.46	2026	399
15	6.41	817	14.00	5.07	6.18	289	0.73	8.15	340	52.42	3.77	23.87	1409	368
16	6.41	986	13.97	5.80	7.48	436	0.93	11.86	444	53.77	4.00	22.63	1726	417
17	6.47	666	14.10	8.16	6.01	213	1.00	21.78	359	66.90	2.24	20.92	1463	465
18	6.51	649	16.49	7.74	6.31	216	1.83	14.28	383	60.16	2.55	34.10	1087	211

Table 12: Results of the physical-chemical and microbiological analysis in P_RIVER 4.

Sampling	pH	Conductivity	Temperature	Dissolved Oxygen	Turbidity	STD	Phosphate	Nitrate	Total hardness	Alkalinity	BOD	COD	Total Coliforms	Fecal Coliforms
	-	µS/cm	ºC	mg/L	NTU	mg/L	mg/L	mg/L	mg $CaCO_3$ /L	mg $CaCO_3$/L	mg O_2/L	mg/L	ufc/100 mL	ufc/100 mL
1	7.68	570	16.32	5.94	6.83	321	1.01	15.87	266	49.67	1.73	15.33	333	84
2	7.73	554	16.70	5.54	7.41	328	1.85	10.40	284	44.67	1.96	25.00	286	38
3	7.53	570	16.00	4.68	10.72	321	1.00	10.87	265	44.67	1.51	15.00	340	54
4	7.60	602	16.37	4.44	12.26	323	0.92	10.53	246	45.67	1.42	11.00	528	91
5	6.83	607	17.17	5.32	16.04	355	1.14	24.80	277	51.33	3.34	19.33	378	91
6	7.55	863	17.10	5.32	10.57	430	2.01	21.30	358	49.23	1.51	19.00	485	95
7	7.47	735	15.20	3.90	9.50	511	0.83	7.83	277	42.73	3.14	19.33	383	87
8	6.94	893	15.17	4.59	11.98	791	1.05	11.40	362	43.83	3.22	18.33	435	99
9	7.54	595	15.30	6.83	9.17	364	1.13	20.94	292	54.53	1.86	16.94	392	110
10	7.59	579	15.68	6.43	9.75	371	2.07	13.73	312	49.04	2.12	27.63	330	50
11	7.39	595	14.98	5.57	13.06	364	1.12	14.34	291	49.04	1.63	16.58	401	71
12	7.46	627	15.35	5.33	14.60	366	1.03	13.90	270	50.14	1.53	12.16	649	120
13	6.69	632	16.15	6.21	18.38	398	1.28	32.74	305	56.36	3.60	21.36	451	120
14	7.41	888	16.08	6.21	12.91	473	2.25	22.37	393	54.05	1.45	21.00	592	125
15	7.33	760	14.18	4.79	11.84	554	0.93	10.34	305	46.92	3.38	21.36	457	115
16	6.80	918	14.15	5.48	14.32	834	1.18	15.05	398	48.13	3.47	20.26	526	131
17	7.40	620	14.28	7.72	11.51	408	1.27	27.65	321	59.88	2.01	18.72	469	146
18	7.45	604	16.70	7.32	12.09	414	2.32	18.12	343	53.85	2.28	30.53	387	66

Table 13. Results of the physical-chemical and microbiological analysis in P_RIVER 5.

Sampling	pH	Conductivity	Temperature	Dissolved Oxygen	Turbidity	STD	Phosphate	Nitrate	Total hardness	Alkalinity	BOD	COD	Total Coliforms	Fecal Coliforms
	-	µS/cm	ºC	mg/L	NTU	mg/L	mg/L	mg/L	mg $CaCO_3$ /L	mg $CaCO_3$/L	mg O_2/L	mg/L	ufc/100 mL	ufc/100 mL
1	7.16	590	18.96	6.15	7.07	333	1.05	16.42	276	51.41	1.79	15.87	189	52.00
2	7.20	573	17.28	5.73	7.67	339	1.91	10.76	294	46.23	2.03	25.88	141	24.00
3	7.02	590	18.63	4.84	11.09	333	1.04	11.25	275	46.23	1.56	15.53	197	33.00
4	7.08	623	21.08	4.60	12.69	334	0.95	10.90	255	47.27	1.47	11.39	391	56.00
5	6.36	629	19.84	5.51	16.60	367	1.18	25.67	287	53.13	3.46	20.01	236	56.00
6	7.03	894	20.80	5.51	10.94	445	2.08	22.05	371	50.95	1.76	19.67	346	59.00
7	6.96	761	19.87	4.04	9.83	529	0.86	8.11	287	44.23	2.67	20.01	241	54.00
8	6.46	924	20.87	4.75	12.40	819	1.09	11.80	375	45.37	2.89	18.98	295	61.00
9	7.03	616	17.90	7.07	9.49	377	1.17	21.68	303	56.44	1.93	17.54	250	69.00
10	7.07	599	16.23	6.66	10.09	384	2.14	14.21	323	50.76	2.19	28.59	186	31.00
11	6.89	616	17.57	5.76	13.51	377	1.16	14.85	302	50.76	1.68	17.16	260	44.00
12	6.95	649	20.02	5.52	15.11	379	1.06	14.39	280	51.90	1.58	12.58	516	74.00
13	6.23	654	18.78	6.43	19.02	412	1.32	33.88	315	58.34	3.73	22.11	311	74.00
14	6.90	919	19.75	6.43	13.36	490	2.33	23.15	407	55.95	1.50	21.73	457	78.00
15	6.83	787	18.82	4.96	12.25	574	0.96	10.70	315	48.56	2.89	22.11	318	72.00
16	6.33	950	19.82	5.68	14.82	864	1.22	15.57	412	49.81	2.56	20.97	389	81.00
17	6.90	642	16.85	7.99	11.91	422	1.32	28.61	332	61.97	2.11	19.38	330	91.00
18	6.94	625	17.28	7.58	12.51	429	2.40	18.76	355	55.74	2.05	31.59	245	41.00

Figure 2 shows the mean values obtained through the three indices for July to November 2018. The values are between 59 and 73. It is observed that July presents high values and October low values. Once the samples were analyzed, the quality index was determined via three methods, as described, for each sampling point (Table 14). The results show two types of quality and water, acceptable (A) and slightly contaminated (LC), predominating the LC classification in the three indices for type A.

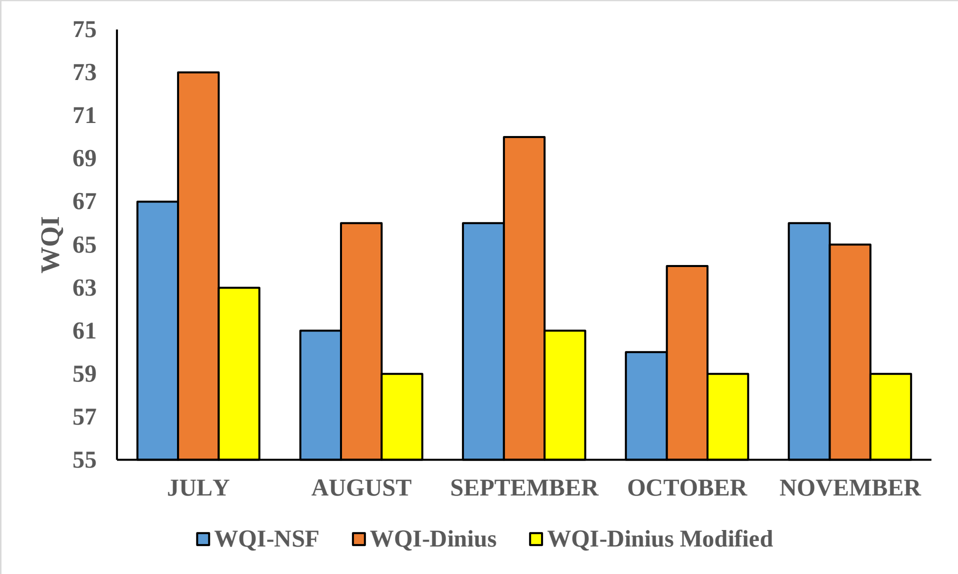

Figure 2: Values for WQI-NSF, WQI-Dinius and WQI-Dinius Modified.

Table 14: Results of WQI index for the Guano River.

SAMPLE	WQI-NSF	WQI-Dinius	WQI-Dinius Modified
Sampling 1	A	A	LC
Sampling 2	LC	A	LC
Sampling 3	LC	A	LC
Sampling 4	LC	A	LC
Sampling 5	LC	LC	LC
Sampling 6	LC	A	LC
Sampling 7	LC	LC	LC
Sampling 8	LC	LC	LC
Sampling 9	A	LC	LC
Sampling 10	LC	A	LC
Sampling 11	LC	A	LC
Sampling 12	LC	LC	LC
Sampling 13	LC	LC	LC
Sampling 14	LC	LC	LC
Sampling 15	LC	LC	LC
Sampling 16	LC	LC	LC
Sampling 17	LC	LC	LC
Sampling 18	LC	LC	LC

4. Discussion

According to the results, the Guano River is a small micro-basin, with slopes ranging from medium-rough to gentle. It also shows the results of the slopes in the sections studied since the river slopes range from medium-rough to soft. In addition, it is observed that the flow at the sampling points varies depending on human activities and natural conditions. In the upper part of the river (P_RIVER 1), the flow is small; at point P_RIVER 2, it increases a little due to the effect of the runoff of the sector. From point P_RIVER 3 the flow decreases, because there are irrigation canals (Castillo-López *et al.,* 2021; Mendoza *et al.,* 2021; Quevedo, 2020). P_RIVER 4 and P_RIVER 5 show an increase in the flow due to the presence of a spring that again provides water to the river (Chidichimo *et al.,* 2018). Moreover, the water quality results also depend on anthropic and natural conditions. In other matters, the water quality results also depend on the anthropic and natural conditions.

From a geomorphological point of view, it is evident that the slope influences the water quality because the effect of the slope on the rivers is essential; it allows the self-purification of the water with high slopes (Marimón-Bolívar, Jiménez, Toussaint-Jiménez, & Domínguez, 2021; Šaulys, Survile, & Stankevičiene, 2019; Toussaint-Jimenez, Marimon-Bolivar, & Dominguez, 2020).

This is perceptible in the water quality in the upper part of the river, where there are medium-rough slopes, allowing the presence of surface runoff, oxygenation of the water, and the dissolution of pollutants. The slope is gentle in the middle and lower part of the river, minimizing self-purification conditions. In addition, 88% of the river area is affected by agricultural activity, extending from 3000 to 2480 masl. The actions of towns (San Andres and Guano) are notoriously detrimental to the water quality by wastewater discharges directly into the riverbed.

Furthermore, Guano's artisan activities, such as leather and textile garment making, produce organic contaminants, including detergents, dyes, and heavy metals. Furthermore, non-technical agriculture has deteriorated the water quality indicators. This includes the riparian forests, which have disappeared almost entirely from the river banks, causing erosion and drag of the materials (Quevedo, 2020). In this context, the water quality assessment was carried out at the five sampling points of the fundamental cause; the values shown are the average of the 5 points. The qualitative evaluation of the water quality of the Guano River is: WQI-NSF values acceptable (A) in 2 samples and slightly contaminated (LC) in the rest of the samples. WQI-Dinius values seven samples as good (A) and 11 as slightly soiled (LC). In the case of the modified WQI, the evaluation is somewhat contaminated (LC) in all the samples. That is to say; water treatment is necessary to improve its condition so that it should not affect the quality of the crops.

5. Conclusions

The three indices reveal that the water is slightly contaminated and must be treated before use. The WQI-Dinius Modified gives lower values concerning the other two indices, as it shows the effects of flow and slope in determining water quality. When there is less flow and the water is contaminated in areas of human activity, such as areas with wastewater discharge. In this context, the water Quality with WQI-NSF and WQI-Dinius has been used and validated in several rivers worldwide. Therefore, the results obtained with these indices for the Guano River are considered valid, showing that the river is slightly contaminated.

The study of the water quality of the Guano River allowed us to see the approximation to reality of the WQI-Dinius modified since when comparing them with WQI-NSF and WQI-

Dinius, the results are lower. Still, the qualitative assessment is similar regarding the water quality along the river. In the same way, it was possible to assess how the slope and flow parameters affect the value of the WQI-Dinius Modified since it was noticed that there is a more significant contamination in the areas with slope and low flow, other areas with higher flow and greater slope. In the lower part of the river, the water quality improves due to the greater volume of water and the presence of springs, which allows the dilution of pollutants and oxygenation of the water.

Although the index shows somewhat different values, it should be studied in greater detail, with a more significant number of physical-chemical data, for several years and in other rivers with similar characteristics. In the same way, the sampling of the parameters should be carried out in the dry season, where there is less flow. The effect of the flow and the slope on the self-purification of the river water would probably be observed better: This is because the slope and the flow are new parameters in the WQI that need further study for the method to be reliable. In addition, the results in rivers already studied must be validated to verify if this can contribute to improving this type of water quality study.

Interest conflict

The funders had no role in the study design; in the collection, analysis or interpretation of data; in the writing of the manuscript or in the decision to publish the results.

Authors' contributions

Following the internationally established taxonomy for assigning credits to authors of scientific articles (https://casrai.org/credit/). The authors declare their contributions in the following matrix:

	Guananga, N.	Mendoza, B.	Guananga, F.	Bejar, J.	Carbonel, C.	Escobar, S.	Guerrero, A.
Conceptualization	X	X					
Formal Analysis	X	X			X		
Investigation	X	X	X	X	X	X	X
Methodology	X	X					
Resources	X		X	X			
Validation	X				X	X	X
Writing-review & editing	X	X	X	X	X	X	X

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