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Evaluation of the quality the waters of the Yamanigüey river using the Montoya methodology

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Abstract: Water, as time passes, becomes scarcer since its consumption is increasing due to the population and industrial increase in recent years. The objective of the research consisted in evaluating the quality of the waters the Yamanigüey River in the period November 2019 - March 2020 according to the methodology proposed by Montoya et al., (1997). Twelve water samples were taken in the river to analyze the physicochemical and bacteriological characteristics of the water and then apply the Water Quality Index. As the main result, it was obtained that the waters of the Yamanigüey River according to the methodology of Montoya et al., (1997) are classified as uncontaminated and acceptable.

Keywords: Water quality index (WQI), River, Yamanigüey, Montoya methodology.

1. Introduction

The deterioration of quality the surface waters due to the increase in anthropogenic activities has been a topic of much attention in recent years. These are subject to various changes resulting from the actions of man, which alter the quality of their waters, which causes different levels of contamination in them (Sabater et al., 2009; João-Benetti et al., 2012; Liévano-León, 2013). For several decades, different WQI have been used to know quickly and precisely the behavior the quality of different bodies of water, and thus take immediate measures. These aim to simplify the positive or negative characteristics of any water source into a numerical expression (Martínez de Bascaran, 1976; Prat et al., 1986). Many have been the WQI that have been applied internationally for the study of surface waters; among them, the methodology proposed by Montoya et al., (1997) stands out.

In Cuba, due to the importance of water resources for social and economic development, it is necessary to search for new water sources with the required quality for drinking water purification. In the world and in Cuba, several investigations have been carried out with a view to evaluating the quality of existing river waters in the mountain area (Toledo-Medrano & Amurrio-Derpic, 2006; Dunán-Avila, 2019; Calvo-Brenes & Mora-Molina, 2015; Córdova-Batista, 2017; Dunán-Avila et al., 2020; Rubio-Caballero, 2017; Bracho-Fernández & Fernández-Rodríguez, 2017; Dunán-Avila et al., 2021; Fernández-Rodríguez et al., 2018; Crespo-Lambert, 2018; Dunán-Avila et al., 2022). This work aims to evaluate the water quality of the Yamanigüey River in the period November 2019 - March 2020 through the methodology proposed by Montoya et al., (1997), as this methodology is one of the most complete to analyze the quality of different water bodies.

2. Materials and Methods

2.1. Location of the study area

The Yamanigüey River is located in the Sagua-Moa-Baracoa mountain range, in the municipality of Moa, in the province of Holguín, Cuba (Fig. 1). The Yamanigüey basin constitutes one of the most important surface water reserves in the region and is source of the river approximately at coordinates 20º32'23.7" N and 74°46'18.0"W at an altitude of 200 meters above mean sea level, with an extension of 15.87 km^2 and flows into the Yamanigüey Bay. Rainfall has an annual value (period 2010-2019) ranging from 1469.9 - 3014.40 mm, so it is considered one of the highest rainfall in the country. The abundance of rainfall, combined with the mountainous relief in the study area and the characteristics of the climate, favors the existence of a well-developed hydrographic network, mainly of the dendritic type, which runs from south to north. According to

Viltres-Milán, (2010) the average annual temperature ranges between 22.6 ºC – 30.5 ºC. Geologically, the municipality of Moa is located in the Mayarí - Baracoa ophiolitic complex, which is located at the eastern end of the island of Cuba. It is possible to distinguish different overthrust mantles, in which slickensides (fault mirrors) and flake tectonics of different thicknesses can be appreciated (IGP, 2011). There are also extensive weathering crusts, which allow the development of Nickel and Cobalt mining in the region. The study area is located in the "Alejandro de Humboldt" National Park (inscribed in 2000 on the World Heritage List under Natural Criteria IX and X), in the eastern sector of the municipality of Moa (UNESCO, 2021) (Heritage, 2021). As its soils are within the protected area, they are not used for any activity that would cause damage to the ecosystem.

2.2. Sampling and physicochemical analysis of water

Twelve surface water samples were taken from the Yamanigüey River. The taking, preservation and analysis of the samples were carried out respecting the international criteria recommended by the standardized methods in APHA (2017) and they were located on a digital map using the QGIS 3.9.0 program (Fig.1). Surface water samples were taken in duplicate in 500 mL plastic containers. For the determination of total coliforms and fecal coliforms, the samples were taken in Whirl-pak plastic bags. The pH and electrical conductivity contents were determined by the electrometric method, the chlorides by the volumetric method, the dissolved solids by the gravimetric method, the turbidity by the turbidimetric method, total coliforms and fecal coliforms by the technique of multiple fermentation tubes, the apparent color through the visual comparison method and the BOD_5 through the BOD determination method (5 days at 20 ºC). The physicochemical analyzes were carried out in the Laboratory Projects Unit of the Nickel Research Center, Moa, Holguín, Cuba; which has 14 laboratory tests accredited and validated by the Cuban Standard CS: ISO/IEC-17025 of 2006 (General requirements for the technical competence of testing and calibration laboratories), for the analysis of water and wastewater. The determinations were made in duplicate to corroborate the results obtained during the laboratory stage.

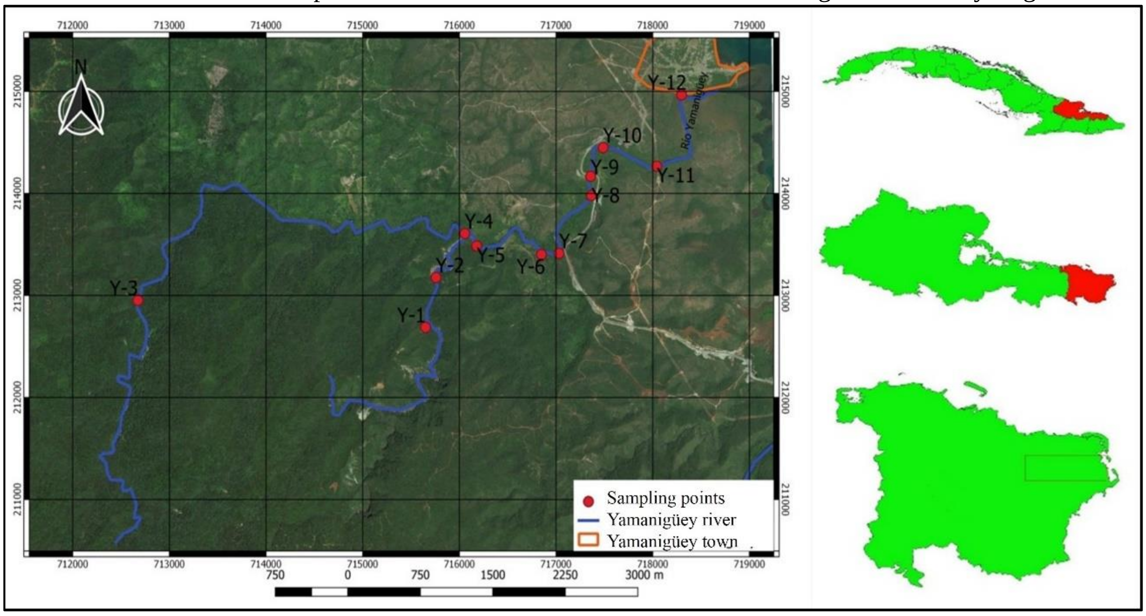

Figure 1 Graphic representation of the geographical location map and the sampling points.

2.3. Methodology for the determination the water quality of the Yamanigüey River through the WQI of Montoya et al., (1997)

The degree of contamination of the water is measured in terms of the index, defined as the degree of contamination existing in the sampled water, expressed as a percentage of pure water. Thus, for totally contaminated water it will have a quality index close to or equal to 0 and for water with excellent conditions of 100. Therefore, the index is an average percentage of the effect caused by the different levels of each of the measured variables in a body of water. This water quality index is the only one that has legal connotations for drinking water in Central America and the most widely used to analyze different bodies of water. It is made up of 18 variables classified into four categories:

Amount of organic matter: determined by the percentage of saturation of dissolved oxygen (DO) and the biochemical oxygen demand (BOD_5).

Bacteriological matter present: determined by total coliforms (TC) and fecal coliforms (FC).

Physical characteristics: determined by color (COL) and turbidity (TUR).

Organic matter: determined by alkalinity (ALKY), total hardness (TH), chlorides (Cl^-), electrical conductivity (EC), hydrogen ion concentration (pH), grease and oils (OG), total suspended solids (TSS), total dissolved solids (TDS), nutrients: nitrogen in nitrates ($N\text{-}NO_3$), ammonia nitrogen ($NH_3\text{-}N$), phosphates (PO_4) and detergents (SAAM).

Some tests are more representative of water quality than others, certain specific weights are assigned to the 18 different designated variables, represented by W, these specific weights are in accordance with the nature of the body of water under study, so the formula that provides the water quality index is:

$$WQI = \sum_{i=1}^{n}(Li * Wi) / \sum_{i=1}^{n} Wi \tag{1}$$

Where:
WQI = Water quality index, 0 = <I = <100,
Ii = Subscript function of parameter i, 0 = <I = <100,
Wi = Weight of importance of the parameter (Weighting Factor) i, 0 = <Wi = <5,
n = Number of variables used.

The subscript functional equations (Table 1) for each of the 18 variables used to calculate the index are shown below:

Table 1 Functions of the WQI sub-indices of Montoya et al., (1997)

Parameter	Equation	Weighing
Dissolved oxygen	$I = \frac{(100)(DO)}{14.492} - 0.384T + 0.064T^2$	5.0
BOD_5	$I = 120(BOD_5)^{0.673}$	5.0
Total coliforms	$I = 97.5(TC)^{0.270}$	3.0
Fecal coliforms	$I = 97.5(5 * FC)^{0.270}$	4.0
Conductivity	$I = 540(EC)^{-0.379}$	1.0
Chlorides	$I = (Cl^-)^{0.223}$	0.5
Total hardness	$I = 10^{1.974-(0.00174*TH)}$	1.0
Alkalinity	$I = 105\ (ALKY)^{-0.185}$	0.5
pH < 7 pH = 7 pH > 7	$I = 10^{0.2336*(pH)+0.440pH}$ $I = 100$ $I = 10^{[4.22-0.293\ (pH)]}$	1.0 1.0 1.0
Fats and oils	$I = 87.25\ (OG)^{0.298}$	2.0
Total suspended solids	$I = 266.5\ (TSS)^{-0.37}$	1.0
Total dissolved solids	$I = 109.1 - 0.0175\ (TDS)$	0.5
Detergents	$I = 100 - 16.68\ (SAAM) + 0.161\ (SAAM)^2$	3.0
Phosphates	$I = 34.215\ (PO_4)^{-0.460}$	2.0
Nitrogen in nitrates	$I = 62.2\ (N - NO_3)^{-0.343}$	2.0
Ammonia nitrogen	$I = 45.8\ (NH_3 - N)^{0.343}$	2.0
Color (Pt-Co)	$I = 123\ (COL)^{-0.295}$	1.0
Turbidity or cloudiness	$I = 108\ (TUR)^{-0.178}$	0.5

After having calculated the quality index by the methodology of Montoya et al., (1997), these results are classified, as shown in the following table:

Table 2 Classification of water quality using the methodology of Montoya et al., (1997)

WQI	General criteria
85 - 100	Uncontaminated
70 - 84	Acceptable
50 - 69	Little polluted
30 - 49	Contaminated
0 - 29	Highly polluted

For calculate the water quality by the methodology of Montoya et al., (1997), ten parameters were used (electrical conductivity, pH, chloride, total hardness, total dissolved solids, color, turbidity, total coliforms, fecal coliforms and BOD_5) of the 18 proposed by the methodology, since it does not require that all the parameters must be taken to perform a water quality analysis (Fernández & Solano, 2013).

3. Results and Discussion

3.1. Evaluation of the quality of the waters the Yamanigüey river through the methodology of Montoya et al., (1997)

The WQI calculation by the methodology under study (Fig.2) showed that 6 of the 12 samples analyzed (Y-1, Y-2, Y-3, Y-4, Y-5, Y-6) are classified as uncontaminated, with WQI results ranging from 94 – 92 %, while the remaining 6 samples (Y-7, Y-8, Y-9, Y-10, Y-11, Y-12) are classified as water acceptable, with WQI values between 84 – 70 %.

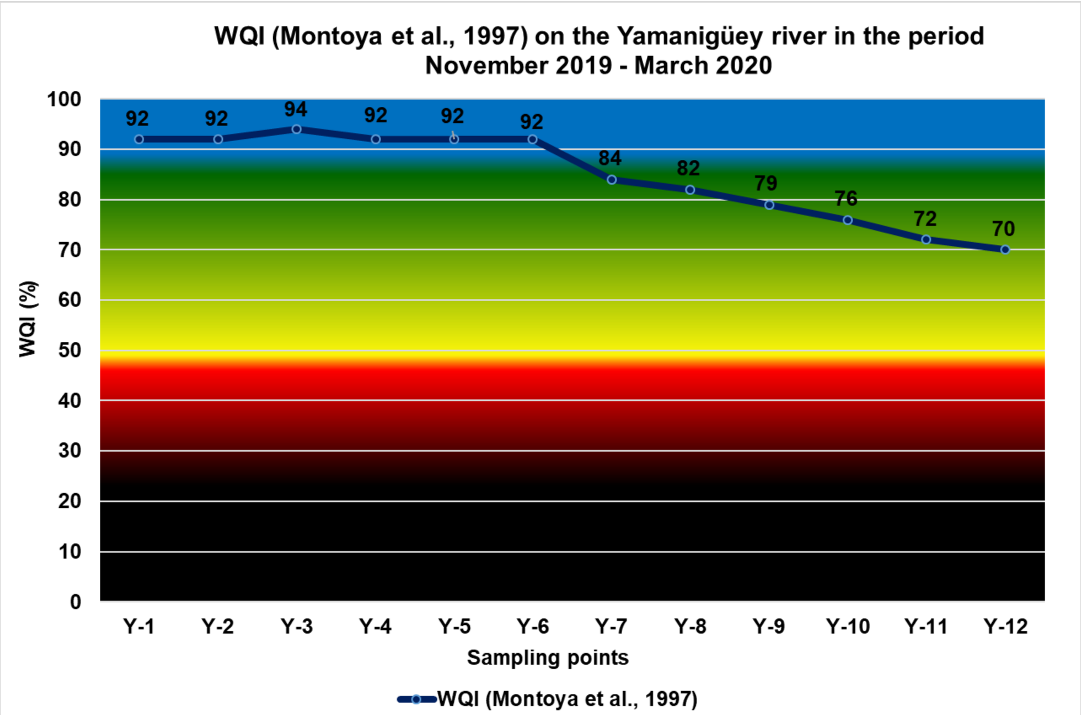

Figure 2 The WQI results by the methodology of Montoya et al., (1997) on the Yamanigüey River.

Crespo-Lambert, (2018) carried out an investigation with the objective of evaluating the quality of the supply waters of the Yamanigüey town through the methodology of Montoya et al., (1997), taking one water sample in the river under study near the catchment point of water from the Yamanigüey town (approximately in the same place where the author of the investigation took the sample Y-6). The author classifies the water from that point as acceptable because it has a WQI value of 84 %. Dunán-Avila, (2019) carried out an evaluation of the quality of the waters the Yamanigüey river using the water quality index of the National Sanitation Foundation (WQI-NSF), classifying the waters as good quality (samples Y-1, up to Y-7) and medium quality (samples Y-8 to Y-12). When carrying out a comparative analysis of the result obtained by Crespo-Lambert, (2018) with the sample Y-1 of his investigation and the sample Y-6 corresponding to the present investigation, it is appreciated that the river has had a gradual recovery in the period of 1 year, going from an WQI of acceptable quality to one of uncontaminated quality. Comparing the results obtained by Dunán-Avila, (2019) and those obtained in this research, it is observed that from the sampling point Y-7 to Y-12 the water quality index decreases due to different evaluated methodologies, due to the negative impact that man has on rivers.

The man, in his daily actions, performs actions on the riverbeds that would take him a long time to recover to obtain an excellent quality. In the field work carried out, it was possible to verify that in the first 6 samples of collected water, no index of their action in the area was witnessed ("Alejandro de Humboldt" National Park) and therefore the results of the WQI range between 94 – 92 %, which are classified as water not contaminated (Fig. 3); while from sampling points Y-7 to Y-12 (the remaining 6 water samples) it was appreciable in the river and in its surroundings garbage dumps, pig pens with drains towards the river, use of its waters for recreation and car washes, which made it possible that the quality index as we get closer to the coast (the area where the highest concentration of inhabitants is located in the study area) begins to decrease the quality of the water and consequently the WQI decreases with values ranging between 84 – 70 % (water with acceptable quality). A considerable increase in Cl^- concentrations, TDS and electrical conductivity is also evident from samples Y-10 to Y-12 (Table 3). The rise of Cl^- in river water can be associated with the release of wastes in general. In addition, there is an increase in Cl^- at these sampling points due to the marine intrusion in the area and the location of the sampling points, which are closer to the sea, resulting in a higher ion exchange between the river water and the seawater. The increase of TDS in the river water is due to an increment of chemicals in the water; and therefore, as the existing chemicals, Cl^- and TDS rise, the electrical conductivity of the water increases because it is proportional to the above parameters, therefore, its quality decreases.

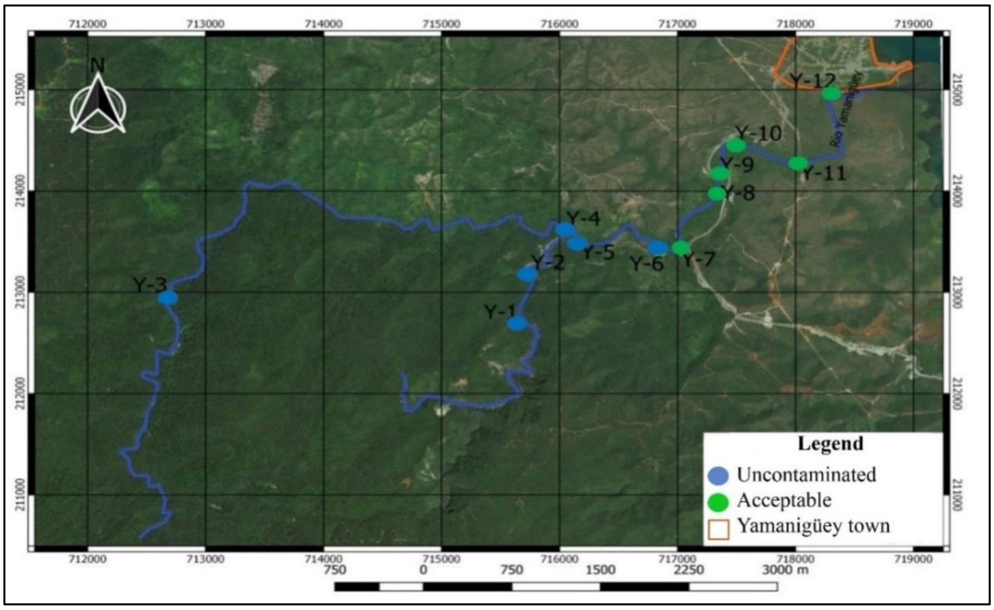

Figure 3 Map showing the water quality in the sampling points according to the WQI calculation by the methodology of Montoya et al., (1997).

The results of the physicochemical, bacteriological characteristics and WQI in the Yamanigüey River are shown below according to the Montoya et al., (1997) methodology and the color assigned to the result of the water quality index according to the classification proposed by said methodology (Table 3).

Table 3 Results of the physicochemical and bacteriological analyzes and the water quality index (WQI) in the Yamanigüey river by the methodology of Montoya et al., (1997)

Code	Electrical conductivity (µs/cm)	pH	Cl^- (mg/L)	Total hardness (mg.eq/L)	TDS (mg/L)	Color (Pt/Co)	Turbidity (NTU)	Total coliforms (NMP/100mL)	Fecal coliforms (NMP/100mL)	BOD_5 (mg/L)	WQI (%)
Y-1	143,00	7,17	11,00	1,14	60,00	11,00	0,70	16,00	1,80	0,41	92
Y-2	109,70	6,95	8,95	0,84	64,00	15,00	0,80	9,20	2,00	0,45	92
Y-3	108,00	7,98	26,00	3,46	67,00	12,00	0,90	2,20	1,10	0,47	94
Y-4	126,60	7,08	9,42	1,08	66,00	10,00	1,00	16,00	2,20	0,50	92
Y-5	132,40	7,01	8,00	1,08	58,00	10,00	0,90	16,00	2,20	0,56	92
Y-6	146,00	7,56	10,00	1,22	60,00	11,20	0,80	16,00	2,20	0,58	92
Y-7	138,10	7,37	9,89	1,12	66,00	12,50	0,90	16,00	1,70	0,60	84
Y-8	151,00	7,62	16,99	1,46	69,00	7,00	2,00	16,00	2,20	2,65	82
Y-9	138,20	7,29	9,65	1,12	72,00	12,50	1,00	16,00	2,80	3,72	79
Y-10	286,00	7,48	49,45	1,40	174,00	22,50	1,00	16,00	16,40	4,75	76
Y-11	294,01	6,51	48,14	8,13	122,00	15,00	1,00	16,00	16,8	7,00	72
Y-12	301,05	6,53	64,77	10,60	273,00	15,00	1,80	16,00	75,4	7,00	70

When performing the statistical assessment for the calculation of the water quality index by the methodology of Montoya et al., (1997), the minimum WQI value was 70 % belonging to the sample Y-12. The main factors that affected the decrease in the water quality index were fecal coliforms, dissolved oxygen and BOD_5. The maximum WQI value was 94 % corresponding to sample Y-3. The main characteristics that influenced this value were the low existence of fecal coliforms, electrical conductivity, BOD_5 and the turbidity of the water. The median represents the value of the central position variable of the WQI values (92 %) and the average of the WQI values evaluated is 85 %, corresponding to uncontaminated water according to the classification proposed by the studied methodology.

4. Conclusion

Since several decades, there has been a rise in the study of different water bodies using water quality indices (WQI). These are a powerful tool that provides the possibility to quickly and accurately calculate the quality of any water body. They also, make it possible to evaluate and prevent, correct and control at source, factors related to water resources that affect or may affect the health of the population and the balance of the ecosystem, determine the possibility of use and evaluate water quality trends, both at the national level and by region or locality. The implementation of new methodologies that involve more than two parameters for the assessment of water quality is becoming increasingly important. Water quality indexes include several parameters, mostly physicochemical and in some cases microbiological, which allow reducing the information to a simple expression.

This work evaluates the quality of the waters of the Yamanigüey River using the methodology proposed by Montoya et al. (1997), which is considered one of the most complete and integrated, and for being one of the only ones with legal connotations for drinking water in Central America. The 50 % of the samples evaluated to analyze the quality of the waters the Yamanigüey river according to the methodology proposed by Montoya et al., (1997) are classified as uncontaminated (samples Y-1 to Y-6) and the remaining 50 % are classified in acceptable waters according to their quality (samples Y-7 to Y-12). It is important to highlight the influence that man has on the basin under study and its ability to recover itself.

5. Acknowledgements

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