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REVISTA INGENIO

Determination of the WQI Index to Evaluate the Water Quality of the Monjas River Located in Quito

Determinación del Índice de Calidad del Agua para Evaluar la Calidad del Agua del Río Monjas Ubicado en Quito

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RESUMEN
El estudio de la calidad del agua es importante a lo largo del tiempo debido a que es un elemento indispensable para el ser humano, pues ha sido vital para su supervivencia, expansión territorial y desarrollo socioeconómico. El agua del río Monjas presentan problemas de contaminación principalmente por actividades humanas como la agricultura, la crianza de animales y las descargas de aguas grises que alteran sus propiedades químicas, biológicas y físicas. El propósito de esta investigación es evaluar si las condiciones del agua son óptimas para uso agrícola, aplicando la metodología del Índice de Calidad de Agua (ICA) que requiere un estudio de laboratorio de coliformes fecales, oxígeno disuelto, pH, demanda biológica de oxígeno, nitratos, fosfatos, sólidos disueltos, turbidez y temperatura. Se tomaron muestras en seis puntos de muestreo a lo largo del cauce cuyos resultados fueron comparados con los resultados con la normativa ambiental TULSMA y la FAO. Se obtuvieron valores más altos para los coliformes fecales y la demanda bioquímica de oxígeno, que superaron los límites máximos permisibles con respecto al resto de parámetros examinados. En este estudio el índice ICA fluctuó en un rango entre 26 y 50, clasificando la calidad de agua del río Monjas como mala, por lo que podría no ser apta para uso agrícola por la contaminación que podría ocasionar en los cultivos. Los motivos principales de este resultado podrían explicarse por la presencia de materia fecal de origen humano y animal, fertilizantes, plaguicidas y residuos domiciliarios.

PALABRAS CLAVE
Sistema meteorológico, Asistente del hogar, Raspberry Pi, IoT.

ABSTRACT
The study of water quality is important over time because it is an essential element for human beings, it has been vital for their survival, territorial expansion, and socioeconomic development. The water of the Monjas river present contamination issues, mainly due to human activities such as agriculture, animal husbandry, and gray water discharges that alter their chemical, biological, and physical properties. The purpose of this research is to evaluate whether the water conditions are suitable for agricultural use, applying the Water Quality Index (WQI) methodology, which requires a study in the laboratory for fecal coliforms, dissolved oxygen, pH, biological demand for oxygen, nitrates, phosphates, dissolved solids, turbidity, and temperature. Samples were taken at six sampling points along the riverbed. Results were compared with the parameters described by TULSMA (Texto Unificado de la Legislación Secundaria de Ministerio de Ambiente), and FAO (The Food and Agriculture Organization of the United Nations) environmental regulations. Higher values were obtained for fecal coliforms, and biochemical oxygen demand that exceeded the maximum permissible limits with respect to the rest of the parameters examined. In this study, the WQI ranged from 26 to 50, classifying the water quality of the Monjas river as unsuitable. It implies that it is not appropriate for agricultural use due to the contamination that it could cause to the crops. The main reasons for this could rely on the presence of fecal matter of human, and animal origin, fertilizers, pesticides, and household waste.

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1. INTRODUCTION

The water is strongly related to the development of humanity. Thus, the first civilizations located their settlements near areas with abundant water, since it was the key to their survival, territorial expansion, and socioeconomic development [1]. Moreover, since ancient times, it has been relevant to acquire knowledge on monitoring, and control of water quality for agricultural use, and human consumption. To evaluate the status of water, there are currently different methodologies that differ in the parameters that are analyzed and how they are calculated [2].

Water resources both in Ecuador and around the world satisfy several basic needs for all human beings. This is the reason because water is exposed to strict control measures. Moreover, according to Guastay [3], in Ecuador, 70% of electrical energy comes from hydraulic sources. Therefore, adequate, and sustainable water management is of the utmost importance.

The population growth together with the dizzying pace of social, technological, and industrial advances, have generated a critical need for freshwater for various activities worldwide [1]. Therefore, the design of methods and mechanisms to evaluate water quality is necessary nowadays. The Water Quality Index (WQI) is one of these tools to evaluate it. It is a tool for assessing the state of water resources. R. K. Horton [4] was one of the first to develop this methodology. It combines into a single value some physical, chemical, and biological factors.

The WQI is an elementary instrument in the development of public policies, production activities, and the evaluation of water resources. Fernández and Solano [5] state that the WQI is represented by an exclusive value, a specific color, and a range of values. In Ecuador, the use of the WQI method has not been sufficiently disseminated. Two projects have been carried out, one in rivers that flow into the Sangay National Park in 2013 [6], and other for the determination and evaluation of the quality of the water in the Chibunga river in 2014 [7].

From what was mentioned above, there is not any project in Quito city. It has an area of 4,235.2 km^2, in addition to having approximately 15.5% of the national population. It is estimated that by 2022, the population will grow to 2.8 million people, and it will occupy the 68.7% of urban areas. The most important basin in the city is the Guayllabamba basin, formed by the Machángara, Monjas, and San Pedro rivers, that are considered important effluents within the Distrito Metropolitano de Quito (DMQ).

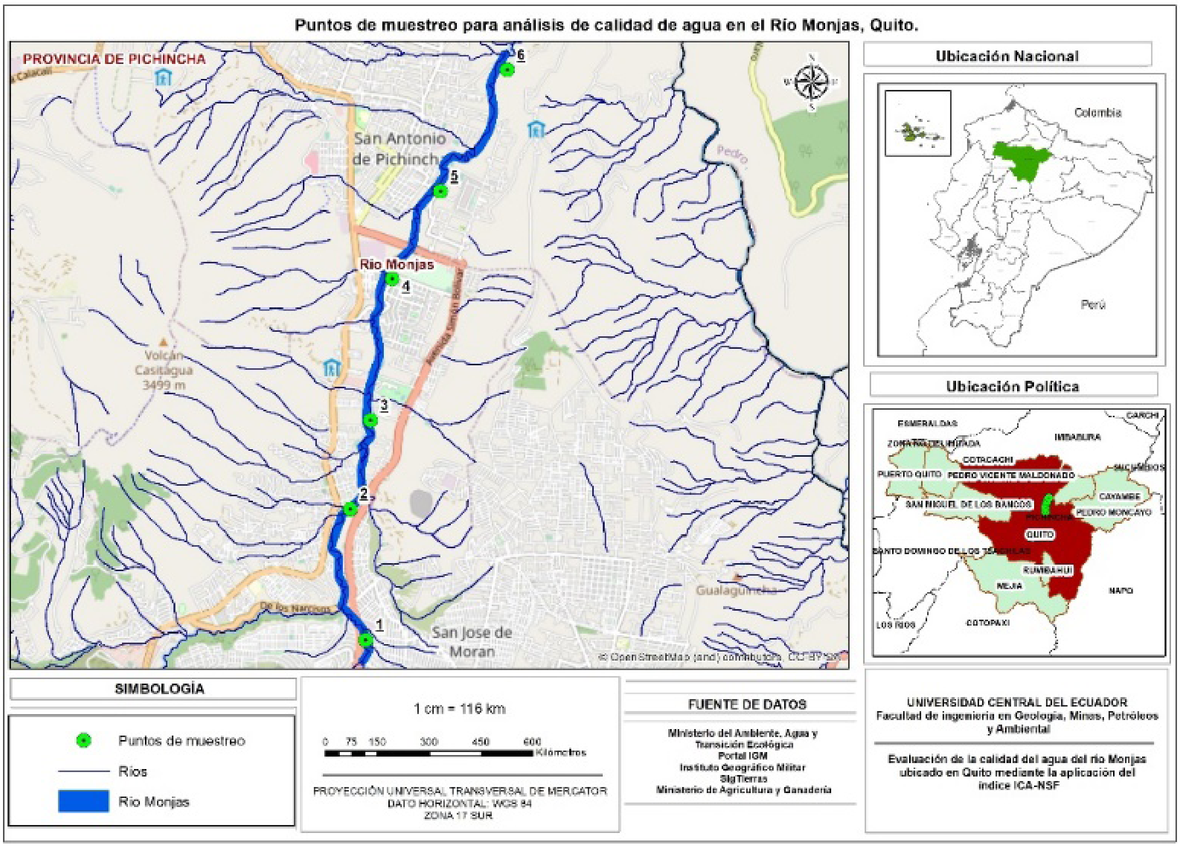
Rivers in Quito city is seriously affected by the contamination, being Monjas river one of the most affected, causing damage and instability in water supply for the city. According to a study by Campaña et al. [8], it has been determined that the critical contamination the rivers in Quito has caused that the water is not suitable for agricultural use, since 81% is contaminated by sewage.

In the last years, there has been a population growth in the sectors of Pomasqui and San Antonio de Pichincha. This has caused an increase in waste generated that is thrown into streams and wastewater effluents. This affects both the natural state streams such as rivers. It turns them into an infectious focus, generating major environmental and health problems. Poor territorial planning has also caused these sectors to be seriously affected by the risk of landslides due to both the instability of the soil and the growth of the Monjas river caused by the rains. These problems have slowed down the economic development in the neighborhoods in that sector [8].

1.1 Locations of study

This study took place in the Monjas River located in the city of Quito, during the month of December 2021. It covers an approximate area of 17.61 hectares, with an altitude of 2,342 meters [8]. It empties from the Guayllabamba river and runs throughout the city of Quito crossing sectors such as San Antonio, Pomasqui, Cotocollao, Carcelén, Cochabamba, La Pampa, and El Condado [15], as depicted in Figura 1.

Figure 1.
Map of strategic points for water samples collection



2. METHODS

In Figure 1, six strategic places were identified for taking surface water samples. They are San José de Morán (1), and Pomasquí (2), located in the parishes of Calderón. Quishuar (3), and La Pampa(4), located in the parishes of Pomasqui. Chaguar (5) and, La Providencia (6), located in the parishes of San Antonio. Table 1 shows the Universal Transverse Mercator (UTM) coordinates for the selected places or sampling points.

Table 1.
UTM coordinates of sampling locations

Table 1. UTM coordinates of sampling locations.

Places	*Coordinates*	
1	783 741.501 E	9 991 670.214 N
2	783 503.145 E	9 993 672.450 N
3	783 813.015 E	9 995 031.110 N
4	784 146.721 E	9 997 200.198 N
5	784 885.641 E	9 998 535.022 N
6	785 910.595 E	10 000 394.241 N

At point 1, the passage of a stream whose purpose is to irrigate crops was evidenced. Its waters flow into the Monjas river, carrying with it residues from agricultural activity. A large amount of organic fertilizer was witnessed in the vicinity of the river, belonging to the owners of crops, but also crops on the banks of the hydrographic basin. In addition, the inhabitants of the sector expressed concern since the river gives off bad odors and generates discomfort.

At point 2, there are many green areas contaminated by plastic waste such as bags and bottles. In its surroundings there are tourist sites, mainly the “Granja del Tío Mario” whose crops have an irrigation system that depends directly on the Monjas river. In addition, at this point the breeding of horses, goats, sheep, and cattle predominates, so large tracts of land and the banks of the river are heavily contaminated by excrement.

At point 3, the river is similarly contaminated by plastic waste, tires, and glass. In addition, there are agricultural and livestock activities in its surroundings. The same ones that generate organic waste such as animal excrements.

At point 4, there is a large amount of domestic waste, mainly organic, such as fruit peels, vegetables, and animal excrement, which generate a fetid odor that causes discomfort among its residents.

At point 5, it was evidenced that part of its waters is used for crops, Moreover, on the banks of the river domestic, waste from anthropogenic activities was found.

At point 6, there are around it places that influence the generation of waste and contamination such as Textile Vicuña, the Ruins of Catequilla, housing complexes and several quarries of stone material were found. At this point, the river separates a rural area from an urban one, where land for agriculture, nurseries and residences can be found. On the other hand, on the riverbank, a large amount of construction debris and plastic waste was visualized. In addition, its smell resembles decomposing sludge. However, even though it corresponds to a dry territory, some native vegetation grows around it.

In this research, the water quality of the Monjas river has been evaluated through the application of the WQI index and the analysis of the following parameters: fecal coliforms, dissolved oxygen (DO), pH, five-day biochemical oxygen demand (BOD_5), nitrates, phosphates, dissolved solids, turbidity and change of temperature. This evaluation will allow to compare the results of each parameter with the FAO and the Environmental Quality Standard for Effluent Discharge of the Ministry of the Environment of Ecuador in order to know the current state of the river and to determine if its waters are suitable for agriculture and irrigation of crops.

To calculate the WQI, the methodology proposed by Brown (1970) is used, which is based on a multiplicative weighted function of the specific weights assigned to each evaluated parameter to evaluate the water; This function is expressed mathematically as follows:

$$WQI_a = \sum_{I=1}^{9} (Sub_I * w_i) \qquad (1)$$

Which:
Sub_i= variable subscript i,
W_i= subscript weighted weight i.

To determine the *Sub_i* values of each parameter, the curves developed by NSF International Consumer and by Fernández and Solano [5] were used. While to classify the WQI, the ranges shown in Tables 2, and Table 3 were used. The Wi values are standard values and were taking from [32].

Table 2.
Relative weights for each WQI parameter

i	Parameter	Unit	W_i
1	Fecal Coliform	#/100ml	0,15
2	pH	units	0,12
3	BOD_5	ppm	0,10
4	Nitrates	ppm	0,10
5	Phosphates	ppm	0,10
6	Temperature	°C	0,10
7	Turbidity	NTU o FTU	0,08
8	T.D.S.	mg/L	0,08
9	Dissolved Oxygen	%saturation	0,17
n	9		

Table 3.
Qualitative classification "WQI

Quality of water	Color	WQI
Excellent		91 a 100
Good		71 a 90
Regular		51 a 70
Unsuitable		26 a 50
Very unsuitable		0 a 25

The methods used to analyze the water from the Monjas river are detailed below:

2.1 Determination of nitrates by colorimetry and cadmium reduction (APHA 4500 -E)

The *APHA 4500 -E* is an analytical chemical method that uses cadmium granules processed with copper sulfate and wrapped in a glass column to reduce nitrate (NO_3^-) to nitrite (NO_2^-) (National Environmental Methods Index, n.d.). The materials used in this procedure were: a reduction column with enough Cu-Cd granules to reach 18.5 cm in length, and a colorimetric equipment (543 nm) or a filter photometer (540 nm) [11].

The main instruments required are a reduction column and a colorimetric equipment, spectrophotometer or a filter photometer [11].

The procedure begins with the treatment of the sample, adjusting the pH to a value between 7 and 9. Next, 2 ml of reagent (100 ml of water, 85% phosphoric acid and 10 g of sulfonamide) is added, which colors a false red to the analyte, and 15 minutes after reduction, the absorbance is measured at 543 nm using distilled water as blank [21]. Standard nitrate reagents are prepared, diluting volumes of 0.5; 1.0; 2.0; 5.0, and 100 milliliters in different volumetric flasks with a capacity of 100 ml. Finally, the calculation of the nitrate concentration is obtained by means of a calibration curve, by plotting the absorbance of the standards as a function of the nitrate concentration (National Environmental Methods Index, n.d.). Sample concentrations were identified directly from the standard curve. It is important to consider that there are certain interferences in the result of the method, for example, suspended matter that restricts the flow of samples, oil and grease that coats the column, among others [11].

2.2 Detection of phosphates using the ascorbic acid method (APHA 4500-P -E)

In this method, ammonium molybdate together with antimony and potassium tartrate react in an acid medium with orthophosphate to form compounds that are reduced to molybdenum blue, intensely colored by ascorbic acid [27].

The materials used in this procedure were: acid-washed glassware and colorimetric equipment with an infrared phototube (880 nm) or a red filter photometer (880 nm) [11].

The procedure begins with a treatment that consists of pipetting 50 ml into a sterilized test tube with 0.05 ml of phenolphthalein indicator. If it turns red, a 5N sulfuric acid solution is added dropwise to remove the color [27]. After treatment, 8 ml of a combination of reagents is added (50 ml of 5N sulfuric acid, 5 ml of 0.009M potassium antimony tartrate solution, 15 ml of 0.03M ammonium molybdate tetrahydrate solution and 30 ml of 0.1M acid solution) and mix thoroughly (American Public Health Association, n.d.). It is necessary to correct the turbidity of the sample in the case of highly colored water. In the measurement and calculation process, the individual calibration curves were prepared from a series of standards. Next, the absorbance is plotted as a function of the phosphorus concentration, obtaining a linear graph (American Public Health Association, n.d.). At least one phosphorus standard is tested with each set of samples. Finally, the amount of phosphates is acquired by stoichiometry after calculating phosphorus, as shown in equation (2).

$$\text{mg } {}^{P}/_{l} = \frac{\text{mg } {}^{P}/_{58\,(\text{final volume aprox.})} \times 1000}{\text{ml of sample}} \qquad (2)$$

2.3 Determination of total dissolved solids (TDS) using the method MEAGP – 37 (APHA 2540 - C)

Wilder and Costa [29] indicated that to obtain real data for the TDS parameter, the MEAGP - 37 APHA 2540 C method is used, which allows determining values with a minimum error, thus avoiding human errors when handling equipment and materials or imprecision. of these. The materials to determine TDS were filtration equipment that has a deposit and a thick filtered disc (40 to 60 µm), a crucible, a suction flask, an analytical balance, a funnel with a membrane filter, and a drying oven.

In this methodology, it begins by heating the residue-free evaporation dish at 180 °C ± 2 °C for 1 hour in an oven and then inserting it into a desiccator until further use. With an analytical balance, the weight of the evaporation plate or better known as a crucible is recorded. Subsequently, the appropriate sample volume was chosen with the purpose of obtaining the amount of dry residue that is in the range between 2.5 and 200 mg.

Using a magnetic stirrer, the sample was homogenized and then pipetted onto a glass fiber filter. For complete drainage, rinse with 30 mL H_2O and continue suction for 3 minutes immediately after filtration is complete. Add the total filtrate to a respective evaporation plate that was previously measured by its weight on the analytical balance and by means of the steam bath, evaporate all the liquid. Dry in the oven at 180 ± 2< °C for one hour. Finally, place in a desiccator until reaching room temperature and weigh the dried sample for further analysis [29]. Once the weight of the dry sample is obtained, the TDS is calculated with the following equation (3):

$$mg\ T.D.S./l = \frac{\{((PSC + plate,\ mg) - plate\ weight,\ mg) \cdot\ 10^3\}}{(sample\ volumen,\ ml)} \quad (3)$$

2.4 Determination of turbidity by the method MEAG – 53 (APHA 2130 – A)

The MEAG -53 APHA 2130 – A method is carried out by comparing the intensity of the light scattered by the water sample under defined conditions and that scattered by a reference standard solution under the same conditions [20]. This methodology is based on the fact that if the sample presents a higher intensity of scattered light, it has high turbidity values.

Within the methodology, the authors Zhihui et al. [31] indicate that turbidity be determined *in situ* to avoid any type of interference and, if this is not possible, samples should be stored for no more than 24 hours in a dark environment.

To start with the turbidity measurement, the turbidimeter was calibrated following the manufacturer's or laboratory personnel's instructions. In this methodology there are two types of measurements: To measure turbidity of less than 40 NTU (Nephelometric Turbidity Unit), first the sample of water must be carefully shaken so that the air bubbles disappear, once these bubbles are no longer observed, the water is added to the turbidimeter tube. Then immerse the tube in an ultrasonic bath for approximately 1 to 2 seconds to completely remove bubbles. Finally, the turbidity value measured by the apparatus is observed. To measure a turbidity of less than 40 NTU, the sample is diluted with distilled water until it reaches a value of 30 or 40 NTU and the turbidity of the original sample is calculated based on the dilution factor, that is, if there were five volumes. of distilled water added to a volume of sample and this manifested a turbidity of 30 NTU, then the original sample was 180 NTU [20].

2.5 Determination of pH by the method MEAG-15 (APHA 4500 B)

The MEAG-15 APHA 4500 method is based on the process of determining the activity of hydrogen ions in an aqueous solution by measuring with a potentiometer that uses a reference electrode together with a standard hydrogen electrode. The pH of the sample is determined by extrapolation [11].

In view of the problem of their use and the potential for contamination of the hydrogen electrode, electrodes made of glass are often used. The pH presents a strong linear relationship with the electromotive force (emf) originated in the electrode system, this linear relationship can be described by drawing the mean of the electromotive force against different buffer solutions, which have different pH values [31].

First, the potentiometric equipment is calibrated following the manufacturer's instructions, removing the electrodes from the storage solution. Establish the equilibrium between the two electrodes by stirring the sample in order to ensure the homogeneity of the solution; Stir slowly to decrease carbon dioxide transport, taking into account that for buffered samples or those with high ionic strength, condition the electrodes after the cleaning process, introducing them into the sample for 1 min. Dry, immerse in a fresh portion, and read the pH. When working with poorly buffered and dilute solutions, it is necessary to equilibrate the electrodes by immersing between three or four sample portions [31].

2.6 Determination of by the method MEAG-08 (APHA 5210 - D)

The MEAG-08 APHA 5210 D method is based on respirometric procedures, which directly determine the oxygen consumed by the different microorganisms existing in an environment rich in air or oxygen found in a closed container at constant temperature and agitation (American Public Health Association, n.d.).

According to Guzman and Perea [17], respirometry measures oxygen consumption continuously over time. They are useful for evaluating the biodegradation of specific chemicals; the treatability of organic industrial waste; the effect of known amounts of toxic compounds on the oxygen uptake reaction of a test wastewater or organic chemical.

To start the measurement, the equipment is calibrated following the manufacturer's instructions. Next, the sample is prepared, which goes through a process of homogenization, pH adjustment, dechlorination (total elimination of chlorine). If the sample contains toxic substances, a treatment will have to be carried out to eliminate said substances and make an adjustment. of temperature, it should be at 1°C. Then, a solution of the sample is carried out with distilled water, adding adequate quantity that brings the sample to 80% of the desired final volume. The prepared sample goes through nutrient and mineral addition processes for a subsequent inhibition of nitrification. Finally, the samples are incubated at 20°C or another suitable temperature [13].

2.7 Determination of fecal coliforms 9215 enzyme substrate

The MEAG-60 APHA 9215 E method is based on the use of bacteria and their respective color difference, which produces shine. The formation of the set of fecal coliforms thus defined is based on the fermentation of lactose, which produces and forms aldehydes. There are some significant alterations in the degree of generation and maintenance of metallic luminosity among coliform strains. On the other hand, the dissimilarity in the choice of the correct indicator is not considered critical to change its importance for public health [30].

Criterion for defining the characteristics and sample size: The sample selection criteria will be governed by the number of bacteria needed, the sample size will be limited only by the level of proliferation of other contaminants of non-coliform origin and turbidity in Water. For regulatory purposes, 100 ml is the official sample size. The water is evaluated, filtering three different volumes that can be diluted or undiluted, depending on the desired bacterial density. "When less than 10 mL of sample (diluted or undiluted) must be filtered, add approximately 10 ml of sterile dilution water to the funnel prior to filtration or pipet the sample volume into a sterile dilution bottle and then filter the entire sample. dilution. This increase in the volume of water helps the uniform dispersion of the bacterial suspension over the entire effective filtering surface" [30].

Sample filtration: With sterile material such as membrane filters, tweezers, and holders, place the sample on the previously sterilized high porosity plate. Carefully place the necessary funnel over the cavity that can contain the substance and fix it in the corresponding place. Under partial vacuum conditions, the sample is filtered. Even with the filter in place and with the use of distilled water, proceed to wash the inside of the funnel with approximately 30 ml, thus avoiding losses and alterations. Alternatively, rinse the funnel with a stream of sterile dilution water from a squeeze bottle. Contamination produced by entrainment is eliminated thanks to rinsing. At the end of the entire filtration and washing process, disconnect the vacuum, and the funnel is unlocked and removed as well as the membrane filter, which are removed with sterile tongs and placed in the middle, it is done with rotating movements and circular so that no trace of air remains inside [30].

Coliform Counting and Verification: To determine colony counts, which are given on filters, use a low power wide-field dissecting binocular microscope or other optical device, preferably with a fluorescent white light, which is directed to provide optimum display of brightness. The typical set of coliform bacteria is a deep pink color that has a metallic-like surface sheen. Count both typical and atypical coliform colonies. Occasionally, typical bright colonies may be produced by non-coliform organisms and atypical colonies (deep pink colonies) are identified as coliforms. Preferably check all typical and atypical coliform colony types. Depending on the need and the type of sample, laboratories can incorporate stricter measures that allow the evaluation of water quality [30].

Finally, the following equation (4) is applied to calculate coliforms, specifically density

$$Coliform \frac{total}{100ml} = \frac{colony\ count\ of\ coliforms\ x100}{filtered\ sample\ (ml)} \quad (4)$$

2.8 Determination of dissolved oxygen by using a membrane electrode (4500-O-G)

According to laboratory analysis, for the respective continuous analysis of Dissolved Oxygen (DO), membrane electrodes are very useful, which are used in cultures of various bacteria, including the BOD_5 test and are excellent for evaluating and determine water with polluting loads, as well as highly colored and residual effluents [31].

Specifically, those so-called membrane electrodes are used, which must be sensitive to the type of oxygen, either galvanic or polarographic, which are made up of two solid metal electrodes. This type of electrodes has a high temperature coefficient, this generated by different changes and alterations in the permeability of the membrane [11].

The procedure begins with the respective calibration of the membrane with sodium sulfite and cobalt chloride, making sure that the marker indicates zero in DO. For the measurement of DO, the water samples are placed in beakers and, by using the membrane electrodes, the level of Dissolved Oxygen that the problem water has is determined, providing the appropriate amount of sample on the surface of the membrane, so as not to exceed the margin of error [11].

Water quality diagnosis with WQI

For the calculation of the WQI index, Equation 1 is required, corresponding to the methodology described by Sánchez (2018). The *Wi* components that correspond to the weight units for each water quality parameter are identified, which are shown in Table 2.

The Sub_i parameter is obtained from the standard graphs described in Figures 2. Interpolating the abscissa axis that corresponds to the concentration of the parameter, with the ordinate axis that indicates the value.

Subsequently, the product W_i* Sub_i is obtained for fecal coliforms, pH, BOD_5, nitrates, phosphates, temperature, turbidity, total dissolved solids, and dissolved oxygen to finally perform the sum of the nine parameters analyzed, whose result corresponds to the WQI value. This same process is carried out for the six sampling points.

The following example details the WQI determination procedure for the first sampling point:

- The weight unit for the first parameter is verified, for example, fecal coliforms (FC), which has a value of W_i=0.15, according to the classification shown in Table 2.

- For the calculation of the value of Sub_i, there are two possible resolution cases:

  Case 1: In the biochemical oxygen demand process (BOD_5), the Sub_3 value is identified from Figure 3. First, the value of the measurement of the parameter is located on the "x" axis of the graph., BOD_5=28ppm, it is interpolated with the "y" axis obtaining the value of the subscript of the parameter, Sub_3=5.46.

  Case 2: The value of Sub_i is identified from Figure 4. Regarding fecal coliforms (FC), there is a value of FC= 549 300 NMP⁄(100 ml), so interpolation is not carried out, since it meets the conditions proposed by the author that are located in the notes section at the bottom of the image, which indicate that for a FC value greater than 10^5, the Sub_i result corresponds to 3.

- Then, the following multiplication is performed: W_1*Sub_1(0.15*3), whose result was 0.45.

- The process is repeated for the remaining 8 water quality parameters from point 1.

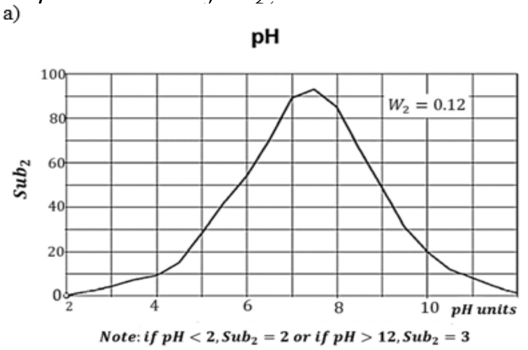
- Once the products (W_1*Sub_1) for the nine parameters, they are replaced in Equation 1, finally obtaining the sum of all the values resulting from said operation, as indicated below:

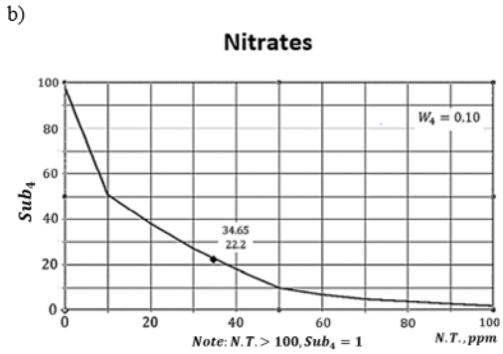
$$WQI_{(sampling\ point\ \#1)} = \sum_{i=1}^{9} (Sub_i * W_i)$$

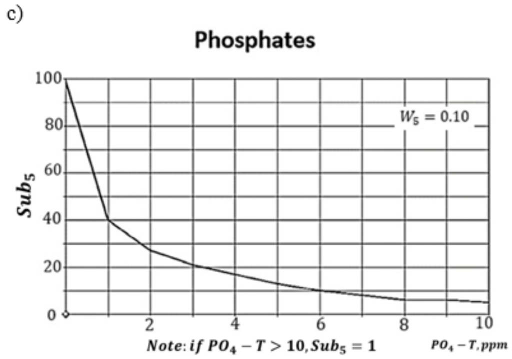
$$WQI_{(sampling\ point\ \#1)} = 40{,}44$$

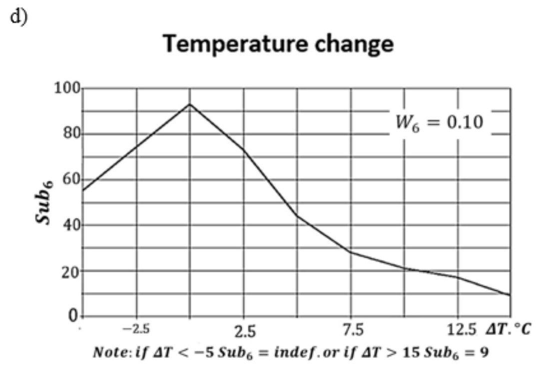
Finally, the value obtained from the WQI is qualitatively classified from the range of values proposed in Table 3. In this case, point 1 located in Calderón has unsuitable water quality.

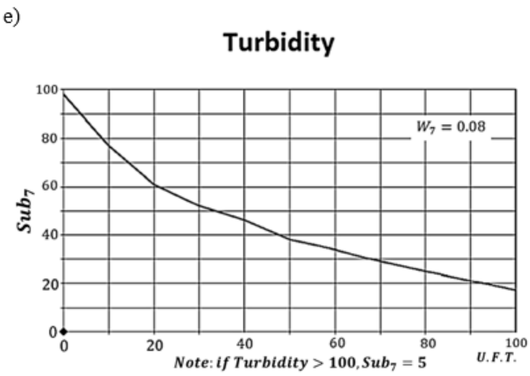
Figure 2.
Evaluation of water quality according to the parameters of WQI

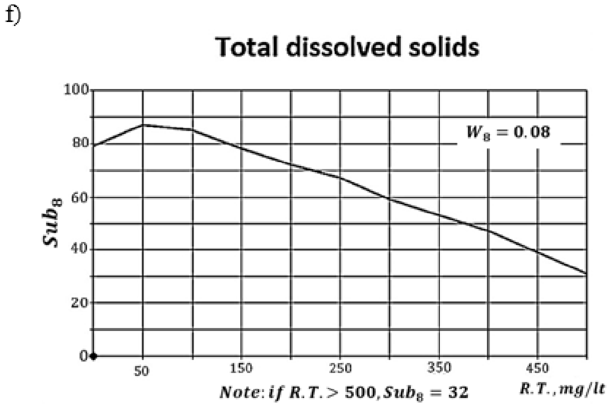


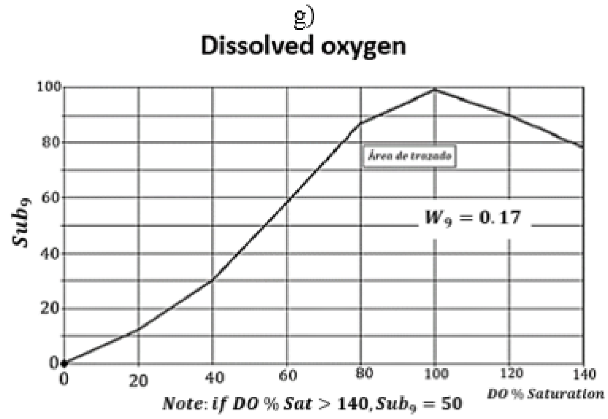












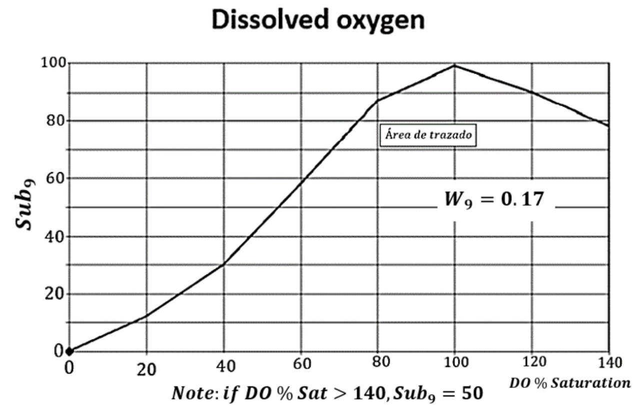


Figure 3.
Evaluation of for BOD_5 parameter according to WQI

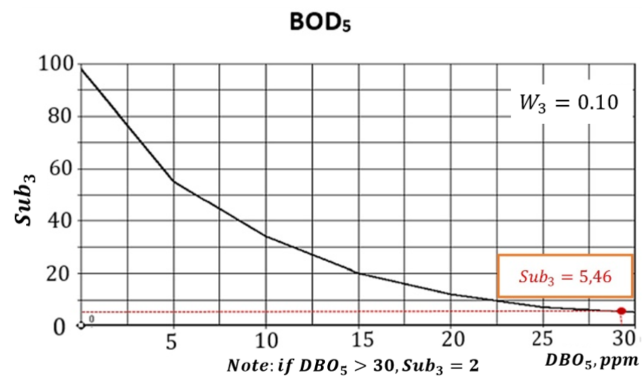
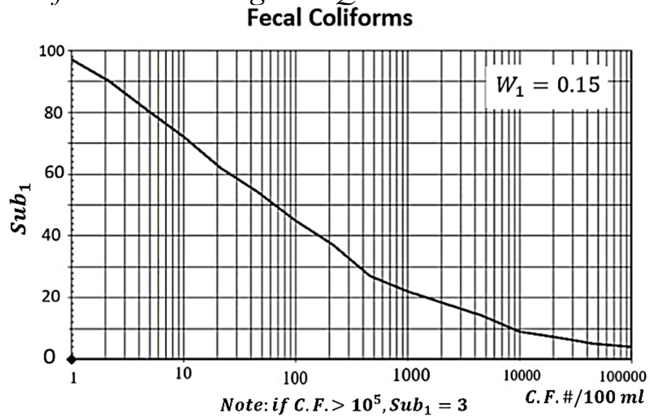


Figure 4.
Evaluation of for the parameter Fecal Coliforms according to WQI



3. RESULTS

In this research project, an analysis of the quality of the water samples from the Monjas river was carried out. The laboratory parameters measured in the water samples taken from the 6 sampling points are presented in Table 4.

Within the fecal coliforms found in the collected samples, the mean was 1.10E+06 ± DE 1.49E+06 NMP/100 ml. There is an extreme value at point 5 corresponding to Chaguar with a quantity of fecal coliforms that reaches 4.14E+06 NMP/100 ml. On the other hand, at point 2 the lowest levels were found with 456 900 NMP/100 ml. In relation to dissolved oxygen, the lowest saturation percentage was detected at point 2 as well, and the highest at point 6 with values of 19.0%, and 74.3% respectively. This laboratory parameter presented a mean of 41.95 ± SD 19.49. In relation to pH, the mean was 7.82 ± SD 0.06. The value with the highest frequency was a pH of 7.87, which corresponds to the sample from point 2, followed by a pH of 7.86 from point 2, and a pH of 7.85 from points 3 and 4. In general, the values pH values were found in a range of 7.71 to 7.87, within accepted limits of normality (between 6.5 and 8.4) [9].

Table 4.
Determination of laboratory parameters for WQI

Parameters	Fecal Coliforms (NMP/100 ml)	Dissolved oxygen (% saturation)	pH	BOD_5 (mg/l)	Nitrates (mg/l)	Phosphates (mg/l)	Dissolved solids (mg/l)	Turbidity (NTU)	Temperature (°C)
Point 1	549 300	40,5	7,86	28	<0,3	7,27	296	<5	18
Point 2	456 900	19,0	7,87	35	<0,3	5,98	264	6	18
Point 3	501 959	31,67	7,85	31	<0,3	6,67	279	5,47	18,08
Point 4	467 600	32,7	7,85	32	<0,3	6,67	283	< 5	17,8
Point 5	4147310	53,5	7,78	26	<0,3	6,12	267	< 5	18
Point 6	478 600	74,3	7,71	20	<0,3	5,57	250	<5	20

Regarding the biochemical oxygen demand, the highest value was identified at point 2, while the lowest value was found at point 6 (San Antonio). In addition, the values of this parameter fluctuated between 20 mg/l and 35 mg/l with a mean of 28.67 ± SD 5.28 g/dl. In relation to nitrates, the mean of the measured values was less than 0.3 mg/l at all sampling points; the mean level of phosphates identified in these samples was 6.38 ± SD 0.61 mg/l. With measured values of 5.57 mg/l and 7.27 mg/l, respectively, the lowest phosphate levels were measured at point 6, and the highest at point 1. The mean dissolved solids measured in the samples was 273.17 ± SD 16.19 mg/l. The lowest value was determined at point 6, and the maximum value at point 1 with 250 mg/l and 296 mg/l respectively. Furthermore, turbidity varied between < 5 NTU and 6 NTU in the samples obtained. The sampling point with the highest turbidity was point 2 with a value of 6 NTU, while the one with the lowest turbidity was found at points 1, 4, 5 and 6 with an NTU value of less than 5. Finally, the mean temperature at the sampling points was 18.31 ± SD 0.83 ºC. The range of this parameter oscillated between 17.8ºC and 20 ºC; the lowest corresponded to point 4, while the highest was identified at point 6.

Next, the physical-chemical parameters measured in the water samples and the limits defined by the Ministry of the Environment of Ecuador (MAE) and the Food and Agriculture Organization of the United Nations (FAO) (Table 5) are compared within of environmental quality standards and water use for anthropological activities. The values corresponding to fecal coliforms exceeded the maximum recommended limit, in addition, the dissolved oxygen saturation percentage was lower than stipulated. The rest of the parameters were adjusted to the limits considered for its consumption as a water resource for irrigation.

Table 5.

Comparison of the minimum and maximum water quality limits defined by the FAO and the MAE

Parameters	Minimum limit	Maximum limit	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
Fecal Coliforms (NMP/100 ml)	0§	600§	549 300	456 900	501 959	467 600	4147310	478 600
Dissolved Oxygen (% saturation)	≥80§	100§	40,5	19,0	31,67	32,7	53,5	74,3
pH	6,5§	8,4§	7,86	7,87	7,85	7.85	7,78	7,71
BOD_5 (mg/l)	0§	2,0§	28	35	31,00	32	26	20
Nitrates (mg/l)	0§	10,0§	<0,3	<0,3	<0,3	<0,3	<0,3	<0,3
Phosphates (mg/l)	0†	15,0†	7,27	5,98	6,67	6,67	6,12	5,57
Dissolved Oxygen (DO) (mg/l)	0§	1000§	296	264	279	283	267	250
Turbidity (NTU)	0§	100§	<5	6	5,47	< 5	< 5	<5
Temperature (ºC)	-	-	18	18	18,08	17,8	18	20

- No data.
† Limits defined by FAO (1).
§ Limits defined by Environmental Quality Standard for Effluent Discharge of the Ministry of the Environment of Ecuador (2).

Table 6 (Exhibit Table 6) shows the WQI result values for the study in the Monjas river. The mean of the WQI is 42 with a range between 36.38 and 49.09. The lowest value of WQI corresponded to point 4, while the highest was found at point 6. According to the obtained values in this study, the water quality is unsuitable.

The results obtained from each parameter were compared with the Environmental Quality and Effluent Discharge regulations of the Ministry of the Environment of Ecuador and the FAO for agricultural use, where it was determined that the waters of the Monjas river are not suitable for irrigating crops without a previous treatment. Since the analyzes of the laboratory samples and the values obtained from the WQI index were between 26 and 50, which corresponds to an unsuitable water quality. It could cause contamination in the crops due to water contaminated by fecal matter from human and animal origin, fertilizers, pesticides, and household waste.

According to the data obtained, the average pH is 7.82. This value is accepted in the water regulation index for agricultural and irrigation purposes. However, it is important to mention that point 2 turned out to be the maximum pH value with 7.87, which tends to be closer to becoming a basic pH. According to Caho and López [2], the progressive increase of this parameter throughout the sampled points is due to mine drainage, wastewater discharges, and atmospheric sedimentation caused by industries located near the Monjas river.

For the temperature parameter, it was identified that Point 6 had a value of 20 ºC, being the maximum of the sampled points, this increase in temperature is attributed to the residual water from the production processes of the “Vicuña” textile company. In addition, a strong smell of drainage was detected which, according to Valencia et al. [28], generally temperatures that are above 15 ºC influence the intensification of the smell and taste of the water. In addition, it enhances the development of microorganisms.

The BOD_5 varies between 20 mg/L and 31 mg/L, however, these exceed the limits defined by the Standard for Environmental Quality and Effluent Discharge. Park and Lee [14] states that BOD_5 is an indicator of the organic matter contained, this includes solids from anthropogenic activity, the plant and animal kingdom. The Monjas river has a high organic matter content and significantly at point 3. This leads to the river presenting pollution problems related to anthropogenic, livestock and agricultural activity that takes place near the river.

In the case of dissolved oxygen (DO), Rubio et al. [25] pointed out that the levels of this parameter depend on the time it is exposed to in the sun, since plants capture CO_2 during the day, converting it into oxygen. On the other hand, authors such as Hernández et al. [18] report that the DO depends on the depth, that is, that at a greater depth its concentration decreases and in turn the environmental conditions affect the amount of dissolved oxygen that at higher temperatures there will be lower concentrations. In the results of the DO analysis (Table 5) it was observed that the lowest percentage of saturation was at point 2 with a value of 19.0 % and at point 6 reaching a maximum value of 74,3%.

In general, the DO values at the six points were below the permissible limit, which is greater than 80%, a value set by the TULSMA environmental regulations. The low DO content in the cause is due to anthropic activities (deforestation, agriculture, sports, among others) practiced on the banks of the Monjas river [2]. Therefore, when analyzing this parameter, it is inferred that there is no natural life along the river, and it is not suitable for agricultural use.

Regarding the phosphate parameter, the results show that its concentration has a negative trend as the sampling points go north, which means that in the most populated areas such as point 1, point 2, and point 3 show a higher concentration of phosphates. Although none of the six sampling points exceeded the permissible limit (Table 5). According to Aldana and Zacarias [24] the presence of chemicals such as detergents and fertilizers. In addition to anthropic activities such as agriculture and domestic and/or industrial discharges, they contribute to the existence of phosphates in the Monjas river. In addition, as stated by Caho and López [2], the growth of plant organisms is considerably lower when dissolved oxygen has low concentrations, consequently, phosphorus levels increase in the water as evidenced in Table 4.

Total dissolved solids values range from 250 mg/L to 296 mg/L, with the points with the highest concentration of this parameter being points 1 and point 4. Based on Gutiérrez [6], the high concentrations of dissolved solids are caused due to the transport of anthropogenic pollutants caused mainly by the existing erosion on the banks of the Monjas river and the dumping of solid waste.

Turbidity, according to Clesceri, Greenberg and Trussell (1992), refers to the low transparency present in water due to the presence of suspended particles. When referring to this factor in agricultural activities and irrigation, it is compared with the permissible limit of freshwater turbidity, which, according to the Standard for Environmental Quality and Effluent Discharge, cites the turbidity value corresponding to anthropogenic activities with a maximum permissible limit of 100 NTU, so when analyzing the values obtained from the 6 sampling points, an average of 5.25 NTU was obtained, being within the permissible range.

The presence of Nitrates in the Monjas river is constant (<0.3 mg/L) this value is within the permissible limits of the Environmental Quality and Effluent Discharge Standard, a key factor to consider is that according to Litter et al. (2009). It is more common to find nitrates in groundwater sources compared to surface waters, varying according to the area of influence of anthropogenic activities.

For fecal coliforms (FC), ecuadorian legislation shows that the permitted value of FC in agricultural activities is between 0 and 600 NMP/1000ml of water [9]. In this investigation, a general mean of 1.10E+06 ± SD 1.49E+06 NMP/100 ml was observed, a minimum value of 456 900 NMP/100 ml at point 2 and at point 5 had a maximum range of 4.14E+06 MPN/100 ml. These values exceed the limits established by the TULSMA environmental regulations. This is due to the fact that in several points of the Monjas river agricultural activities and the raising of horses, goats, sheep, and cattle predominate where there are large tracts of land and on the banks of the river it is heavily contaminated by their fecal matter [2]. In addition, there is water runoff from blind wells and latrines of the inhabitants of the populations settled on its banks, which directly contribute these microbiological contaminants, which means that their waters cannot be used in agricultural activities [10].

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4. CONCLUSIONS

The study of water quality in rivers is of the utmost importance because the necessary water resources are taken from their tributaries to carry out various productive activities. In addition, the WQI is more sensitive to the different quality variations that a body of water presents. Therefore, it is an effective instrument in decision-making in order to avoid threats to aquatic life or its use.

The Monjas river presented an average WQI of 42, which represents a deplorable quality of its waters. It is important to indicate that from these data there was a slight downward trend in the upper parts of the tributary and according to what was observed, its level of contamination is due to everything to activities such as: agriculture, livestock, industry, and domestic activities that generate solid waste on the banks of the river.

The measured quantities of fecal coliforms and BOD_5 exceed the permissible limits established by the "FAO" environmental legislation and the "Environmental Quality Standard for Effluent Discharge: Water Resources of the Ministry of the Environment of Ecuador". Waters with high BOD_5 values present reduced levels of DO, since the percentage of oxygen decreases when it is assimilated by bacteria, endangering the sustainability of aquatic life. On the other hand, coliform bacteria cause diseases, with symptoms such as gastrointestinal upset and among others such as flu, fever, abdominal cramps, and diarrhea. In general terms and according to the results of this study, its waters are not optimal for agricultural use and human consumption.

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Appendix

Table 6.
WQI index of each sampling point of the Monjas River

Point	Location	WQI index	Water quality	Color
1	Calderón-San José de Moran	40.44	Unsuitable	
2	Calderón-Pomasqui	36.38		
3	Pomasqui-Quishuar	41.83		
4	Pomasqui la Pampa	39.36		
5	San Antonio Chaguar	44.87		
6	San Antonio-Providencia	49.09		
Total		42.00		