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Evaluation of the impact of anthropogenic activities on surface water quality using a water quality index and environmental assessment

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Abstract: The article presents an assessment of the effects of anthropogenic activities on the quality of water in four streams flowing through a camp based on a combined assessment of environmental impacts and the water quality index. The quantitative and qualitative assessment of environmental impact was made after identifying the anthropogenic activities carried out in the camp. The water quality index (*WQI*) was calculated after monitoring seventeen physicochemical and microbiological variables and the Montoya index was applied. The samples were collected during 48 sampling campaigns, organised over the period of six months in eight stations. Two stations were located in each stream, one before and one after it passed through the camp. The results indicated that streams 1, 3, and 4 show a slight deterioration in water quality, affected by anthropogenic activities carried out in the said camp; meanwhile, stream 2 shows an increasing deterioration in water quality. The water quality of the streams before passing through the camp was determined to be between "uncontaminated" and "acceptable", while after passing through the camp it was classified between "acceptable" and "slightly contaminated". The results indicated a non-significant difference between the downstream and upstream *WQI* values for streams 1, 3, and 4; while stream 2 did show a significant difference in the *WQI* between upstream and downstream; indicating that anthropogenic activities alter the quality of the water.

Keywords: anthropogenic activities, environmental impact assessment, principal component analysis (PCA), surface water quality, water quality index (*WQI*)

INTRODUCTION

Surface water sources are the axis of human development, as they supply water for the different socioeconomic activities carried out in human settlements; however, paradoxically, many of these activities cause alteration and deterioration of the quality of water sources [El-Alfy *et al.* 2019; Rao *et al.* 2020]. Therefore, the development of human activities without due regard for environmental criteria is affecting human health and the state of aquatic systems, in some cases causing irreversible changes [Gopchak *et al.* 2020; Karavan *et al.* 2013]. The marked deterioration of surface water bodies makes its evaluation a priority in order to control and mitigate the level of risk that will be decisive for the complexity and costs of treating water for human consumption [Japitana *et al.* 2019; Kelmendi *et al.* 2018].

The quality of surface water deteriorates due to various activities such as agriculture, livestock farming, aquaculture, forestry, domestic and industrial activities, which can result in a deterioration of the quality and quantity of water that affects not only the aquatic ecosystem but also the availability of safe water for human consumption [Anyona *et al.* 2014; Ayobahan *et al.* 2014].

The most common method of evaluating water quality is by comparing the measurements of physical, chemical, and bacteriological parameters with the ranges established by guidelines or water quality standards [García-Ávila *et al.* 2018; Zhushi Etemi *et al.* 2020]. Another method of determining water quality is through the application of quality indices [Fayaji *et al.* 2019].

The water quality index (*WQI*) serves as a simple tool for evaluating the fundamental water resource in public policy decision-making processes and in monitoring its impacts [Sedeño-Díaz, López-López 2007; Son *et al.* 2020]. Researchers define *WQI* as a simple expression, which is the result of a combination of a number of parameters that serve as an indication of water quality [Abdul-Hameed 2020; Bouslah *et al.* 2017]. The assessment of water quality can be understood as the evaluation of its chemical, physical, and biological features in relation to its natural quality, human impact, and potential uses [Ayobahan *et al.* 2014; Son *et al.* 2020]. To simplify the interpretation of the data obtained from monitoring, there are water quality indices that reduce a large number of parameters to a simple expression that is easy to interpret by technicians, environmental managers, and the general public [Gari *et al.* 2018; Kamboj, Kamboj 2019].

The *WQI*s enable the evaluation of the general quality of the water using previously established standards. At the same time, they make it possible to predict if the quality of the water represents a potential risk for human consumption, and to determine whether it can be used as irrigation water for agriculture and livestock, for the aquatic life, and for recreational and aesthetic purposes [Ayobahan *et al.* 2014; Gari *et al.* 2018].

Increasing levels of anthropogenic disturbance in water quality underscored the need for this study [Garcia *et al.* 2021]. The objective of the study was to determine the effects of anthropogenic activities carried out in a camp on the quality of water in four streams that flow through this camp. It identified the activities carried out in the camp. An analysis of physical, chemical, and biological parameters that provide relevant information in the generation of water quality indices (*WQIs*) was carried out, which will make a useful contribution to the formulation of future policies for the management of water resources.

MATERIALS AND METHODS

STUDY AREA

The study was carried out in four streams that flow through a camp belonging to a hydroelectric project, located in the Sevilla de Oro sector, Azuay province, Ecuador. In the lower part of the camp is the Paute River, while near this camp is the Sangay National Park, which consists of riparian forests and tropical humid forests. The camp is located at the coordinates 2°34'48.3" S, and 78°30'12.4" W. Figure 1 shows the location of the camp and the four streams, as well as the location of the monitoring stations. The four streams flow near some activities developed within the camp. All these streams are tributaries of the Paute River. Stream 1 supplies water for human consumption after treatment and all streams contribute to the conservation of the flora and fauna in the camp.

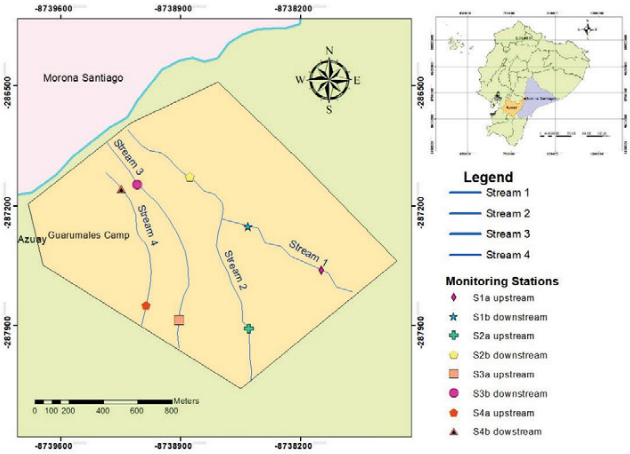

Fig. 1. Location of the camp, the streams, and monitored stations that make up the study area; source: own elaboration

In the camp there are carpentry, industrial mechanics, and automotive workshops necessary for the proper operation of the hydroelectric plants that are close to the study area; likewise, there are offices and houses inhabited by the people responsible for the planning, operation, and maintenance of the different facilities.

IDENTIFICATION AND ASSESSMENT OF ANTHROPOGENIC ACTIVITIES AND THEIR THEIR IMPACT ON WATER QUALITY

The qualitative assessment of impacts was performed after identifying the anthropogenic activities carried out in the camp that have an impact on water quality [Aiswarya, Sruthi 2016]. To assess the relationship between the activities carried out in the camp and the quality of surface water, an impact matrix was prepared, in which the four streams were identified as the affected medium.

The activities carried out in the camp were divided into six groups. To measure the environmental impact in qualitative terms, the variable labelled "Total impact" was used to measure the change in water quality resulting from anthropogenic activities [Morgan 2012]. The methodology proposed by Custodio and Pantoja [2012] allows for the qualitative measurement of environmental impacts through the calculation and analysis of the "Total impact". The impact was obtained from the degree of incidence of the alteration produced and characterisation of the effect using variables for the evaluation, such as perturbation (P), importance (I), occurrence (O), extension (E), duration (D), and reversibility (R). Total impact (TI) was calculated using Equation (1), a matrix was proposed that evaluates the total impact, assigning weights to each variable of 1, 2, and 3 for low, medium, and high respectively.

$$TI = C(P + I + O + E + D + R) \qquad (1)$$

where: C = the character of the impact.

The range of impact importance values is as follows: negative impact: severe: $TI \leq -15$; moderate: $-15 < TI \leq -9$; compatible: $-9 < TI < 0$. Positive impact: high: $TI \geq 15$; medium: $9 \leq TI < 15$; low: $0 \leq TI < 9$.

SAMPLING

The monitoring was carried out over six months considering the distinctive climatic seasons in Ecuador (winter and summer). It was monitored during the rainy months (April, May, and June) and those with the lowest rainfall (July, August, and September). Eight sampling stations were identified in total; one station before the camp and another one after passing through the camp for each stream. The samples were taken manually, in the total number of eight samples per month, of which four were collected upstream from the camp (one in each stream) and four downstream from the camp (one in each stream). The parameters measured included temperature (*T*), dissolved oxygen (*DO*), biochemical oxygen demand (*BOD*), total coliforms (*TC*), faecal coliforms (*FC*), real colour (*RC*), turbidity (Turb), alkalinity (Alk), total hardness (*TH*), chlorides (Cl^-), electrical conductivity (*EC*), concentration of hydrogen ions (pH), total suspended solids (*TSS*), total dissolved solids (*TDS*), nitrates nitrogen (NO_3-N), ammoniacal nitrogen (NH_3-N), phosphates (PO_4^{3-}). Using a previously calibrated HORIBA model U52G-10 multiparameter, on-site parameters such as *T*, *DO*, pH, *EC*, and *TDS* were measured in each of the stations. The analysis of the other parameters was carried out in the Laboratory of Water Quality Analysis of the University of Cuenca. All the samples were kept in acid-washed 2 dm^3 high-density polyethylene (HDPE) bottles and transported to the laboratory at a temperature <4°C. The analytical methods used to determine the physicochemical and microbiological parameters complied with the procedures and methodologies recommended by APHA [2005].

WATER QUALITY INDEX

Water quality was evaluated using the multiplicative weighted index proposed by Montoya *et al.* [1997]. These researchers proposed the ICA as a tool for determining the quality of surface waters in the State of Jalisco-Mexico. This index considers nine uses of water, among which public supply stands out. Montoya *et al.* [1997] propose a qualification of water quality between values from 0 to 100, where values close to 100 indicate good quality, while values close to 0 indicate poor water quality. This *WQI* is made up of eighteen variables classified into four categories.

1. Amount of organic matter: dissolved oxygen (*DO*), and biochemical oxygen demand (*BOD*);
2. Bacteriological matter: total coliforms (*TC*) and faecal coliforms (*FC*);
3. Physical characteristics: real colour (*RC*) and turbidity (Turb);
4. Inorganic matter: alkalinity (Alk), total hardness (*TH*), chlorides (Cl^-), electrical conductivity (*EC*), pH, fats and oils (FO), total suspended solids (*TSS*), total dissolved solids (*TDS*), nutrients: nitrates nitrogen (NO_3-N), ammoniacal nitrogen (NH_3-N), phosphates (PO_4^{3-}), and detergents (SAAM).

The *WQI* calculation is based on the following formula:

$$WQI = \frac{\sum_{i=1}^{n} I_i \cdot W_i}{\sum_{i=1}^{n} W_i} \tag{2}$$

where: *WQI* = the water quality index, a number from 0 to 100, I_i = the quality subindex of parameter *I*, W_i = the weight of parameter *i*; *n* = the number of variables used.

The equations for the subscripts and the weights of the different parameters are presented in Table 1. To determine the subscripts, quality functions (function curves) were used, with a range from zero to 100 on the ordinate and the different levels of the variables on the abscissa. Curves were constructed for each variable with the purpose of transforming variables from a dimensional scale ($mg \cdot dm^{-3}$, $\mu g \cdot dm^{-3}$, percentages, etc.) to a dimensionless scale that allows for their aggregation.

Table 1. Subindices and weights of the parameters for the calculation of the water quality index

Parameter	Subindex I_i	Weight W_i
Real colour	$I_{RC} = 123\ (RC)^{-0.295}$	1.0
Turbidity	$I_{\text{Turb}} = 108\ (\text{Turb})^{-0.178}$	0.5
Electric conductivity	$I_{EC} = 540\ (EC)^{-0.379}$	1.0
Total suspended solids	$I_{TSS} = 266.5\ (TSS)^{-0.37}$	1.0
Total dissolved solids	$I_{TDS} = 109.1 - 0.0175\ (TDS)$	0.5
Hydrogen potential	a) $I_{\text{pH}} = 10^{0.2335\text{pH}+0.44}$ pH < 7 b) $I_{\text{pH}} = 100$ pH = 7 c) $I_{\text{pH}} = 10^{4.22-0.293\text{pH}}$ pH > 7	1.0
Alkalinity	$I_{\text{Alk}} = 105\ (\text{Alk})^{-0.185}$	0.5
Total hardness	$I_{TH} = 10^{1.974-[0.00174\ (TH)]}$	1.0
Total phosphates	$I_{\text{PO}_4^{3-}} = 34.215\ (\text{PO}_4^{3-})^{-0.46}$	2.0
Chlorides	$I_{\text{Cl}^-} = 121\ (\text{Cl})^{-0.223}$	0.5
Nitrate nitrogen	$I_{\text{NO}_3-\text{N}} = 62.2\ (\text{NO}_3 - \text{N})^{-0.343}$	2.0
Ammoniacal nitrogen	$I_{\text{NH}_3-\text{N}} = 45.8\ (\text{NH}_3 - \text{N})^{-0.343}$	2.0
Dissolved oxygen	$I_{DO} = \frac{100(DO)}{14.492 - 0.384T + 0.054T^2}$	5.0
Biochemical oxygen demand	$I_{BOD} = 120(BOD)^{-0.673}$	5.0
Total coliforms	$I_{TC} = 97.5(TC)^{-0.27}$	3.0
Faecal coliforms (*E. coli*)	$I_{FC} = 97.5\ [5(FC)]^{-0.27}$	4.0
Fats and oils	$\text{I}_{\text{FO}} = 87.25\ (\text{FO})^{-0.298}$	2.0
Detergents	$I_{\text{SAAM}} = 100 - 16.8\ (\text{SAAM}) + 0.161\ (\text{SAAM})^2$	3.0

Explanation: *T* = temperature.
Source: own elaboration.

Table 2 shows the *WQI* classification range according to the general criteria and the colours assigned in each case on the basis of corresponding calculations.

Table 2. Classification range of water quality index (*WQI*) according to general criteria

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

Source: own elaboration.

DATA ANALYSIS

The data analysis consisted of applying the *t*-Student test to compare the mean *WQI* scores. A significance level of 0.05 was applied in this study. The *t*-Student test determined if there is a difference between the upstream and downstream *WQI* values. In order to study the existence of spatial variation in the variables evaluated in each of the streams, the principal component analysis (PCA) test was performed. PCA is a multivariate analysis method that allows for the synthesis of information collected in a study [Nascimento *et al.* 2019]. This analysis tool has been used to analyse environmental data sets, which are generally complex, due to a large number of variables involved and the strong relationship between them. The PCA was applied based on the data set of the monthly mean values of the 16 physical, chemical, and microbiological parameters of water quality. The statistical program R studio 3.2.0 was used for this purpose.

RESULTS

IDENTIFICATION AND ASSESSMENT OF THE ENVIRONMENTAL IMPACT

The identification of the anthropogenic activity possibly impacting on the water quality of the four streams, in turn, enabled the recognition of the respective impacts or effects that this activity leaves on the streams. Table 3 shows the activities that generate polluting elements and cause alterations in the physical, chemical, and biological state of the water bodies of the streams. Thus, wastewater treatment activity leads to the contamination with nitrogen and phosphorus, elements that cause eutrophy and alteration of the chemical state in the waters of the stream 2. This is due to the fact that the effluent from the wastewater treatment plant (WWTP) had an average value of 1.23 and 0.76 mg·dm^{-3} of nitrates and phosphates respectively. Meanwhile, stream 2 upstream had average values of 0.4 and 0.1 mg·dm^{-3} of nitrates and phosphates, respectively, while stream 2 downstream had average values of 0.53 and 0.43 mg·dm^{-3} of nitrates and phosphates respectively. There is evidence of an influence of the effluent of the WWTP in stream 2. In general, the effects caused in the streams, as a consequence of these activities, are the alteration of the chemical state and turbidity, impacts that degrade the quality of the water.

Table 3 shows the impact assessment matrix, in which the activities that generate impact in each of the four streams were identified. The character of all activities on the surface water quality was recognised as a "negative" impact because it was estimated that there is a deterioration in the analysed environmental condition. According to the interpretation of the results obtained, it can be concluded that the activities on stream 1 generate an "irrelevant" impact, while the "circulation and vehicle maintenance" are the most significant influences. The impact generated by the activities in stream 2 turned out to be "moderate", which is mainly because the treated wastewater is

Table 3. Matrix of environmental impact assessment due to anthropogenic activities carried out in the camp on the streams

Impact charac-teristics	Stream 1			Stream 2				Stream 3				Stream 4		
	vehicle circulation and maintenance	domestic activities	labour activities	vehicle circulation and maintenance	domestic activities	wastewater treatment	labour activities	vehicle circulation and maintenance	domestic activities	supply and food	workshop maintenance	vehicle circulation and maintenance	domestic activities	workshop maintenance
Character	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1
Perturbation	1	1	1	1	1	2	2	1	1	1	2	1	1	2
Importance	1	1	1	1	1	2	1	1	1	1	2	1	1	2
Occurrence	2	1	2	1	2	3	2	1	1	2	2	1	1	2
Extension	3	1	2	3	1	2	1	1	1	2	2	1	1	2
Duration	2	1	1	2	1	2	1	2	1	1	1	2	2	1
Reversibility	1	1	1	1	1	2	1	1	1	1	1	1	1	1
Total impact	–10	–6	–8	–9	–7	–13	–8	–7	–7	–8	–10	–7	–7	–10

Source: own study.

discharged into this stream. Regarding streams 3 and 4, its total impact was recognised as "irrelevant", these streams are mostly affected by "maintenance of machines and equipment in workshops".

The results show that in stream 2, the total impact is moderate with a tendency to become severe. In streams 1, 3, and 4, moderate and compatible impacts were obtained. The results obtained show that various anthropogenic activities are taking place in the camp, which results in changes in the quality of the water in the streams. These activities produce waste that is mainly released into stream 2. Moderate impacts indicate that recovery requires time and it is advisable to apply corrective measures. The severe impact requires the application of intensive preventive or corrective measures to restore the chemical and ecological states of the waters of the streams to acceptable levels.

WATER QUALITY INDEX

The evaluation of water quality using the Montoya index has made it possible to integrate the physical-chemical and biological parameters, and to qualify the type of water in the four streams, both upstream and downstream of the camp. The results allowed for classifying it as medium quality water, allowing the majority of uses with this water, such as human consumption after treatment, aquaculture production, irrigation water, preservation of aquatic life, and recreation by secondary contact. Figure 2a shows that in stream 1 there is no evidence that the anthropogenic activities of the camp are actually affecting the water quality; in the month of May, *WQI* downstream was higher than upstream, while in April, July, and September, *WQI* was higher upstream compared to downstream; in June and August, there was no difference in the *WQI* value.

Figure 2b illustrates how anthropogenic activities effectively affect the water quality of stream 2, since *WQI* during winter and summer was lower downstream, and higher upstream. Therefore, it can be affirmed that the change in water quality is due to the anthropogenic activities carried out in the camp, especially because the effluent from the WWTP is discharged into this creek. According to Figure 2c, there is no clear evidence that the activities carried out in the camp are affecting the water quality of stream 3, since, in the months of April, June, July, and September, *WQI*s are practically similar. Figure 2d also provides no clear evidence that the activities carried out in the camp are affecting the water quality of stream 4, since, in five of the six months monitored, *WQI* remains practically unchanged.

When averaging *WQI* for each stream, little variation was found between downstream and upstream values for streams 1, 3, and 4 as shown in Figure 3; since their values varied between 83.12 and 88.48, which, according to the general criteria of the Montoya *WQI* set forth in Table 2, is classified between an "acceptable" and "not contaminated" water quality. Regarding stream 2, the value of 88.39 upstream interpreted as "not contaminated" was established; meanwhile, the value of 70.11 downstream was established and interpreted as "acceptable", tending to "slightly contaminated" (Tab. 4). The spatial variability between upstream and downstream of the physicochemical and microbiological parameters was relevant in stream 2, especially the variables of total suspended solids, electrical conductivity,

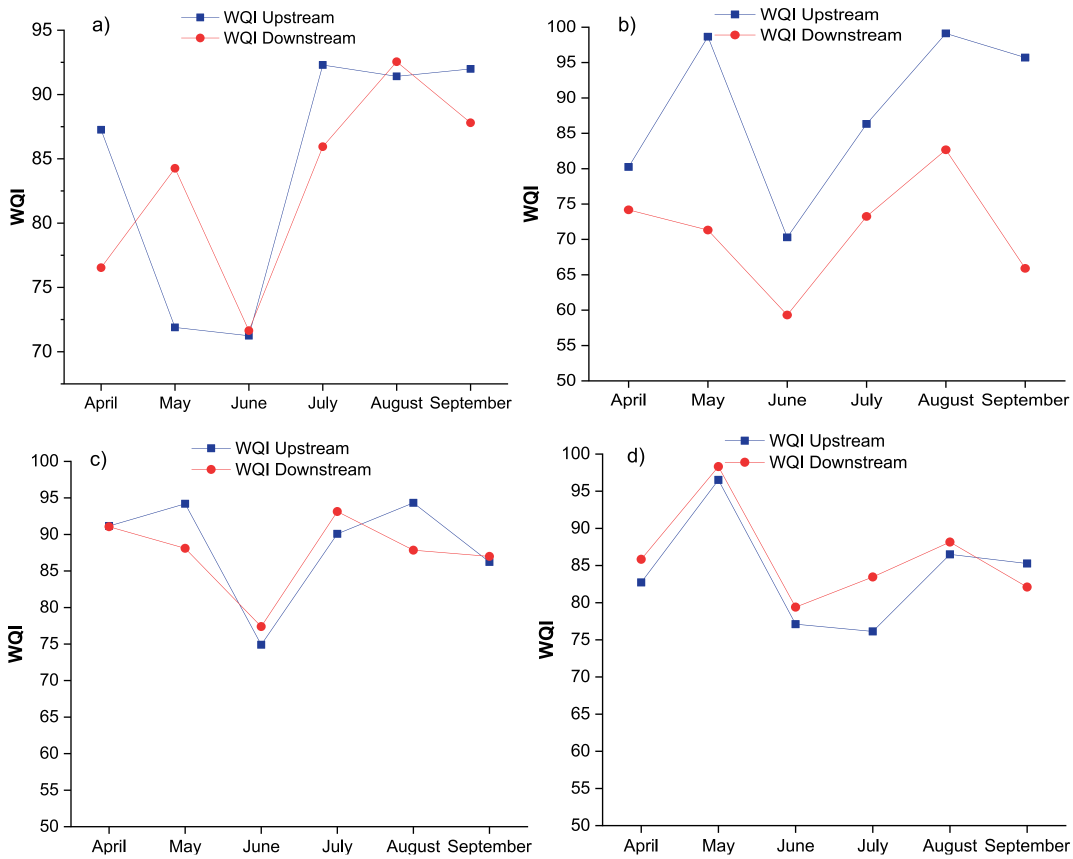

Fig. 2. Temporal variation of water quality index (*WQI*) for the upstream and downstream monitoring months: a) stream 1, b) stream 2, c) stream 3, d) stream 4; source: own study

ammoniacal nitrogen (NH_3-N), temperature, true colour, phosphates, turbidity, total hardness, coliform total and faecal, which increased; while the dissolved oxygen decreased. This deterioration in water quality is attributed to the influence of the water discharge from the WWTP which, when mixed with this stream, modifies its properties negatively, reducing its quality. Meanwhile, the levels of total suspended solids, total coliforms, and real colour were relatively higher during the winter season, which means that they were influenced by rainfall. The decrease in water quality in stream 2 due to the operation of the WWPT reflects the lack of efficiency in the operation of the WWPT. Thus, for example, stream 2 upstream, during the monitoring time had an average value of 8.64 mg·dm^{-3} of *BOD*; meanwhile, the WWTP effluent had an average value of 11.37 mg·dm^{-3} .

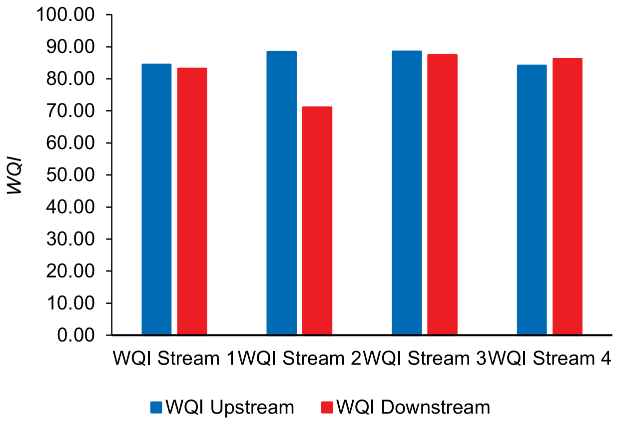

Fig. 3. Average of the water quality index (*WQI*) in the streams; source: own study

Table 5. Statistical differences of water quality index in results upstream and downstream of the camp

Variable	Result
Stream 1	no significant difference (p = 0.5651)
Stream 2	significant difference (p = 0.0130)
Stream 3	no significant difference (p = 0.7820)
Stream 4	no significant difference (p = 0.6062)

Source: own study.

related to each other. Likewise, the variables *TC* and *RC* are related. The presence of conductivity is due to the content of ionisable compounds, probably due to mineralisation in soils close to these streams. On the other hand, turbidity could be related to erosive processes, whose origin could be due to natural dynamics or anthropic activities, causing runoff to carry away suspended solids and colloids. When the above was presented, it caused a statistical correlation between conductivity and turbidity. The colour is due to plant or organic extracts, which are colloidal. On the other hand, coliforms can be found both in faeces and in the environment, for example, in waters with decomposing plant matter. The aforementioned causes a correlation between colour and coliforms. On the other hand, PC2 includes the variables *TSS* and *TDS*, which showed a similar positive correlation.

In Figure 4b it is observed that the CP1 of stream 1 downstream determines that *FC* and *TC* are interrelated. Meanwhile, PC2 includes the *EC* and Cl^-, allowing evidence of a strong correlation between Cl^- and *TSS*; just as it was presented upstream, which indicates that there are soluble and insoluble mineral salts in both points.

Table 4. Classification criteria of water quality index for each stream

Station	Stream 1	Stream 2	Stream 3	Stream 4
Upstream	acceptable	uncontaminated	uncontaminated	acceptable
Downstream	acceptable	acceptable	uncontaminated	uncontaminated

Source: own study.

The *WQI* values of the four streams before and after crossing the camp were compared using the *t*-test (p <0.05), and the results were presented in Table 5. The *t*-Student test shows that in stream 2 there is a significant difference in the upstream and downstream and water *WQI* values with a *p*-value of 0.0130. Meanwhile, there is no significant difference between downstream and upstream in streams 1, 3, and 4.

PRINCIPAL COMPONENT ANALYSIS

Figure 4 presents the principal component analysis (PCA) of the physicochemical and microbiological variables. The PCA carried out for the physicochemical and microbiological variables for each monitored point indicates that in all cases components 1 and 2 cover between 57 and 74% of the variability, which is a representative value for the analysis.

In Figure 4a, the PC1 of stream 1 upstream is displayed, describing above all the variables of Turb and *EC*, which are

When analysing Figure 4c, the PCA corresponds to stream 2 upstream, it was observed that PC1 includes pH, *DO*, and *EC*; presenting a strong correlation between these three variables. PC2 includes *RC*, NH_3-N, and NO_3-N; the first two parameters indicate a positive relationship with PO_4^{3-} and Turb, indicating the presence of nutrients that increase these parameters and in turn decrease pH. This last variable evidently shows a negative correlation with the previous variables.

When analysing Figure 4d, the PCA corresponds to stream 2 downstream, PC1 describes NH_3-N, *RC* and *TSS*, related to each other and particularly to Cl^-. All these variables have a negative relationship with the *DO*, which attributes at this point the presence of domestic contamination. The PC2, in turn, includes the variables *BOD*, PO_4^{3-} and pH; the *BOD* indicated an important correlation with the *FC* and *TC*, indicators of organic and faecal contamination. On the other hand, PO_4^{3-}, and pH correlate positively with each other, and with Turb; unlike upstream, indicating the influence of detergents and phosphate

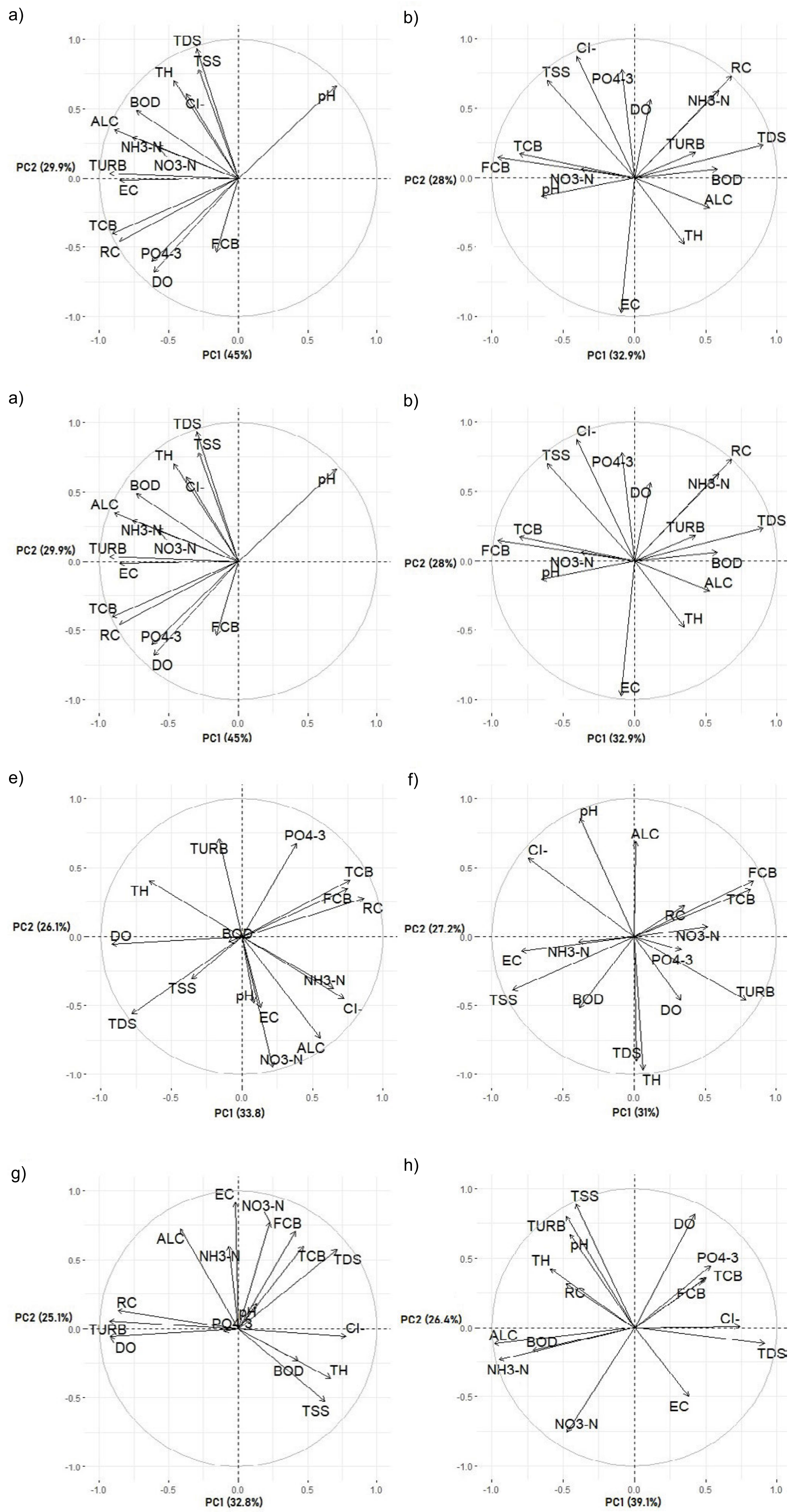

Fig. 4. Principal component analysis of water quality variables: a) stream 1 upstream, b) stream 1 downstream, c) stream 2 upstream, d) stream 2 downstream, e) stream 3 upstream, f) stream 3 downstream, g) stream 4 upstream, h) stream 4 downstream; source: own study

substances that would cause these variables to increase. Analysis of Figures 4c and 4d shows that that the discharge of the effluent from the WWTP alters the quality of the water in stream 2.

In Figure 4e, the PCA of stream 3 is presented. Upstream, PC1 explains the variables *DO*, *RC*, and *TC*, the parameter *DO* indicates an important correlation with the *TDS* and *TH*; while the *RC*, *TC*, and *FC* were correlated with each other; furthermore, it was demonstrated that the *DO* has an inverse correlation with *TC* and *FC*. PC2 includes NO_3-N, Alk, Turb, and PO_4^{3-}; NO_3-N has an inverse correlation with Turb.

Meanwhile, in Figure 4f it can be seen that downstream PC1 of stream 3 includes *EC*, *TSS*, *FC*, and *TC*; *TSS* was associated with *EC*, while *FC* and *TC* were also correlated with each other. PC2 describes *TH* and *TDS*, noting a strong correlation between them. Figure 4e upstream and Figure 4f indicates that the *TDS*, *TSS*, and *TH* parameters are related to the presence of soluble and insoluble mineral salts in the water.

In the PCA of stream 4 (Fig. 4g) upstream, PC1 includes the parameters Turb, *DO,* and *RC*, which are positively correlated with each other; but those parameters have an inverse correlation with the chlorides; in this case, the *DO* has no relationship with *TC* and *FC*. PC2 includes *EC* and NO_3-N that are mutually related due to the amount of dissolved ions that increases the concentration of both parameters.

Meanwhile, in Figure 4h downstream of stream 4, PC1 describes the variables Alk, NH_3-N, and TDS; Alk and NH_3-N have a positive correlation with each other but maintain an inverse relationship with *TDS*. *TDS* also had an important relationship with chlorides, due to the inorganic salts of chlorides that affect *TDS*. PC2 includes *TSS*, *DO*, and Turb, in this component the strongest correlations observed were *TSS* with Turb, and pH, while the most important negative correlations correspond to *DO* with NO_3-N, indicating algae proliferation that consumes oxygen from the water.

In summary, the PCAs carried out for streams 1, 3, and 4, indicate that natural geological conditions, the presence of soluble and insoluble mineral salts have an influence on the physicochemical parameters and organic plant and animal matter. Regarding stream 2 (downstream), the wastewater presented indicators of contamination on this stream.

Once the environmental impacts on the four streams have been evaluated and after calculating the water quality indices, it is evident that the streams are affected by anthropogenic activities. The changes in the physicochemical and microbiological parameters that are mainly driven by anthropogenic activities cause a negative impact on the stream bed. Therefore, there is a need to protect the water resource from streams. The control of anthropogenic activities, educating the inhabitants of the camp and raising public awareness about environmental integrity are recommended. Regarding fats and oils, there is no evidence of a danger to streams, as the workshops have roofs and their floors are waterproof. Additionally there is a good management plan for these products in case of spillage.

A slight variation was observed in the calculated values of *WQI* upstream and downstream for streams 1, 3, and 4. Meanwhile, a notable variation was evident in stream 2 (Fig. 3). Therefore, this progressive increase in *WQI* values along the streams suggests an effect of anthropogenic activities ranging from organic contamination, discharge of poorly treated effluents, and other human activities. Therefore, the water quality in streams 1, 3, and 4 ranged from "uncontaminated" upstream to "acceptable" downstream; meanwhile, in stream 2 it ranged from "uncontaminated" upstream to "slightly contaminated" downstream.

DISCUSSION

This research, like the studies carried out by Briciu *et al.* [2020], Hasan *et al.* [2020] and Naubi *et al.* [2016] showed that the water quality in rivers downstream is of lower quality compared to upstream. To demonstrate this, all the aforementioned authors used the water quality index (*WQI*). The spatial variability of the *WQI* of the present study showed a similarity to the study carried out by Briciu *et al.* [2020], where a calculation of the *WQI* was also made, both upstream and downstream of the Suceava city, and a modified additive type *WQI* was applied. The results indicated that the main cause of the deterioration of the stream water quality in the metropolitan area is the wastewater from the WWTP.

Likewise, Hasan *et al.* [2020] determined different water quality indices both upstream and downstream to evaluate the spatio-temporal variations of the Dhaleshwari River, for which he used the weighted arithmetic water quality index method. In this study, the lowest values on the downstream side were also determined, revealing that the effluent from the central effluent treatment plant of the industrial park significantly affects the *WQI*. On the other hand, Naubi *et al.* [2016] in their study, calculated the *WQI* for eight sections of the Skudai basin, for which they use the *WQI* formula developed by the Department of Environment Malaysia. *WQI* values decreased in the direction of river flow (from top to bottom), the decrease in water quality is due to agricultural practices, economic development, and other human activities in the Skudai River basin.

Ewaid and Abed [2017] calculated water quality indices to determine the water quality of the Al-Gharraf River, using the weighted arithmetic index. The *WQI* values obtained showed poor water quality, which may be due to several natural phenomena and anthropogenic activities that occur along the river, and which coincides with the results obtained in the present study. Likewise, Son *et al.* [2020] analysed the water quality of the Cau River in Vietnam, for which they used five different quality indices. These researchers found that the index's average values, upstream, ranged from 66.36 to 83.31, while downstream the values of the indices varied between 61.83 and 62.89. These indices showed more serious contamination downstream of the river.

In the present study, little variation between downstream and upstream was found for streams 1, 3, and 4; the index values varied between 83.12 and 88.48. Regarding stream 2, a value of 88.39 upstream was obtained; meanwhile, a value of 70.11 was obtained downstream. It should be emphasised that the index applied in this study has a classification range from 0 to 100, as presented in Table 2.

The results of the environmental impact assessment and the water quality index reflected that the anthropogenic activities responsible for the variations of the water quality in the streams were mainly related to organic pollution and domestic effluents (*DO*, *BOD*, Turb).

It needs be highlighted that the environmental impact assessment and *WQI* are effective tools for understanding the dynamics between anthropogenic influences and the state of water quality.

CONCLUSIONS

This study suggests a water quality evaluation combined with a water quality index based on environmental monitoring and the assessment of environmental impacts based on the identification of activities that cause impacts on the quality of water bodies.

The impacts identified in each stream were evaluated, determining that streams 1, 3, and 4 were impacted in an "irrelevant" manner. The impact generated by the activities carried out in the camp on stream 2 turned out to be "moderate", tending to "severe"; these categories resulted from the direct and indirect influence of water treatment and other activities on these streams.

The Montoya water quality index confirmed the deterioration in the water quality in stream 2, which is affected by the activities carried out in the camp and which cause variations in the physicochemical and microbiological parameters registered in the said bodies of water.

The Principal Component Analysis carried out with the physical, chemical, and microbiological variables allowed for synthesising the information in such a way that the relationship between these parameters was evidenced both upstream and downstream of the camp. This analysis, through correlations, made it possible to evaluate the variation in water quality, emphasising once again the influence of anthropogenic contamination on stream 2 and the influence of natural conditions on streams 1, 3, and 4. It is evident that the streams that flow through this camp, especially stream 2, are affected by anthropogenic activities, therefore, the control of anthropogenic activities, the protection of the streams and greater education and awareness of the inhabitants regarding environmental integrity are recommended.

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