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RESEARCH ARTICLE OPEN ACCESS

LOSS OF WATER QUALITY OF AN URBAN RIVER IN CUSCO: SAPHY CASE

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ABSTRACT

Water quality is the set of chemical, physical and biological characteristics that make the river suitable for different uses such as: maintenance of ecosystems to human consumption. The objective was to determine the loss of quality of the Saphyriver that crosses the city of Cusco through the historic center; Physicochemical and biological parameters were used through standardized methods for the analysis of drinking and waste water, the sources of deterioration were identified. For the laboratory analysis, the methodology of the National Water Authority was followed. The results were compared with the Environmental Quality Standards for water-ECA, approved by the Ministry of the Environment; dissolved oxygen was found to be suboptimal and biological oxygen demand exceeds ECA by 8.6 times; the same occurs with turbidity and thermotolerant coliforms that show high concentrations with respect to ECA-water; the river becomes alkaline and the main sources of deterioration are agricultural and livestock activities, household wastewater, solid waste and dumped debris.

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INTRODUCTION

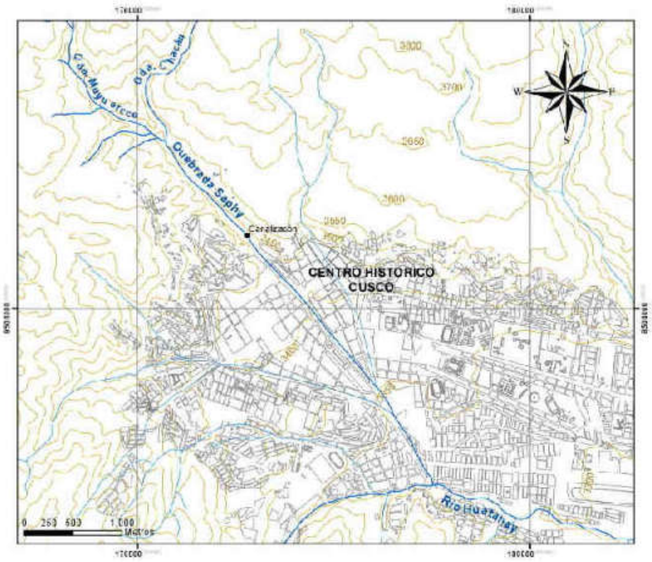
Water quality indices constitute a functional tool in the planning of hydrographic basins in terms of quality; they are used in the classification of water uses, in sustainable development, in environmental management, in resource management and scientific research. The countries of South America have adapted these quality indices to the environmental conditions of their ecosystems for the assessment and evaluation of surface water quality (Orozco et al., 2005). According to Damo &Icka (2013), the physical-chemical indices are based on a combination of physical-chemical parameters that provide information on the nature of the chemical characteristics of the water and its physical properties, providing a global vision of the quality of river water and giving information on its influence on aquatic life. Currently, the river is considered an essential resource that requires the maximum attention of the public sectors because it is essential for the preservation of life and is exposed to deterioration, sometimes irreversible, generated by an irresponsible and intensive use of the resource, in this regard, Valdés *et al*., (2012) comment that, in the assessment and evaluation of water quality, various methodologies have been used, including the comparison of physical, chemical and bacteriological variables with current regulations.

Physical-Chemical Indicators: Water quality refers to the conditions in which the water is found with respect to physical, chemical and biological characteristics in its natural state or when altered by human beings (Monroy, 2011); the problems derived from the contamination of bodies of water, such as: the reduction of the supply of fresh water, health risks, the uselessness of the water for various uses, the negative impact on aquatic life, are some of the effects associated with the water quality (Food and Agriculture Organization of the United Nations-FAO, 2013); therefore, water quality is a variable term depending on the use made of the resource. In Peru, water quality is regulated by the Ministry of the Environment, which approved through Supreme Decree N°. 004-MINAM, the National Environmental Quality Standards for Water (ECA-water), which are set according to the categories that receive water bodies as mentioned in the Water Resources Law (Law N°. 29338). According to MINAM (2016), the ECA-water is the measure that establishes the level of concentration or the degree of elements, substances or physical, chemical or biological parameters, present in the water, in its condition as a receiving body, which does not represent significant risk to human health or the environment. In most developing countries, the microbiological risk is quite marked, mainly associated with inadequate sanitation, which is ratified in Agenda 21 of the United Nations Conference on Environment and Development, which states that approximately 80% of all diseases and more than a third of deaths are caused by the consumption of contaminated water (CEPIS, 2002). On the other hand, the deterioration of the water resource is also associated mainly with discharges of domestic, industrial and agricultural and livestock production wastewater and activities such as land, river and maritime transport of dangerous substances or oil, water from mining extraction and solid waste disposed of in sanitary landfills or directly in them (IDEAM, 2005).

For the Latin American case, the development and application of these indices has been more booming in Mexico, developing various indices. The INDIC-SEDUE index was the first to be applied in Mexico, in Jalisco, and was commonly used in the former Secretariat of Urban Development and Ecology in the Department of Prevention and Control of Environmental Pollution of the Sub-delegation of Ecology of the SEDUE-Delegation. Jalisco (Montoya, *et al*., 1997). In Peru, two indicators have been applied: the ICA-NSF and a model developed in Cuba by García, Beato and Gutiérrez, in which, in addition to the ICA-NSF parameters, electrical conductivity, chlorides and ammoniacal nitrogen are considered (OEA, 2004). The selection of parameters or variables depends largely on the objectives of the study, as well as the use to be given to the results. On the other hand, in the context of the use of physical-chemical and biological parameters, it is pertinent to consider water contamination; according to the Water Charter, Council of Europe (1968), water pollution is the modification, generally caused by man, of the quality of water making it unsuitable or dangerous for human consumption, industry, agriculture, fishing and recreational activities, as well as for domestic animals and natural life. There are currently several indicators of water pollution; according to Samboni*et al*., (2011), they were developed from physicochemical, microbiological and limnological studies carried out in the oil industry for river conditions in Colombia. They use the variables of BOD_5, total coliforms and percentage of oxygen saturation: the first two reflect various sources of organic contamination and the third expresses the body's environmental response to this type of pollution. Currently, the vast majority of surface water bodies present an alteration in their own quality (Thi, 2011; Pedraza, 2016) due to all the discharges they receive from domestic and industrial activities, which influencein health and in socioeconomic aspects of the adjacent populations (Flores, 2013). However, one of the difficulties in planning water bodies in basins has been the limited applicability of water quality indices in decision-making processes (Damo &Icka, 2013).

METHODS

Study Area. The study is limited to a water course of importance in the urban area of the city of Cusco: The Saphy river micro-basin that crosses the historic center of the city and runs from northwest to southwest; it is located northwest of the city and results from the confluence of the Chacán and Muyuorcco rivers, as shown in Figure 1.



Source: Prepared based on cartographic information, 2021

Figure 1. Saphy River crosses the Historic Center of the city of Cusco

The sampling stations (Table 1 and Figure 3) were chosen according to Maldonado *et al*., (1998); Rodríguez *et al*., (1997) and Romero *et al*., (2000) and prior observation considering changes in the water ecosystem (OAS, 2004), changes in slope, union with tributaries, wastewater discharges, point and non-point sources of pollution, hydrological context, use of the resource, physical accessibility, synoptic investigation (Rickert, 1993 and Alexander *et al*., 2001), temporality (Tyson *et al*., 1989). The samples were taken in two seasons, the rainy season (December-march) and the dry season (april-october).

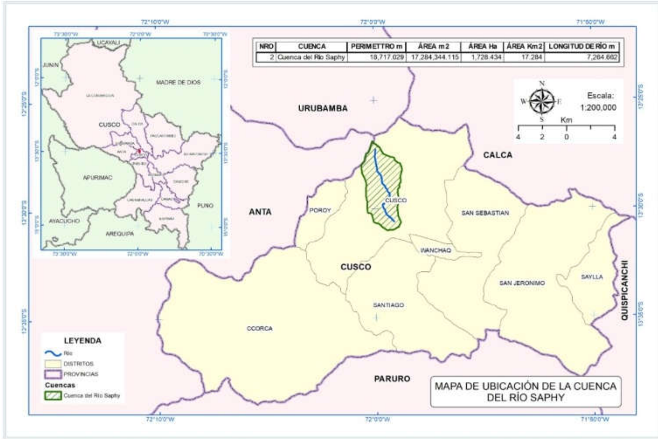


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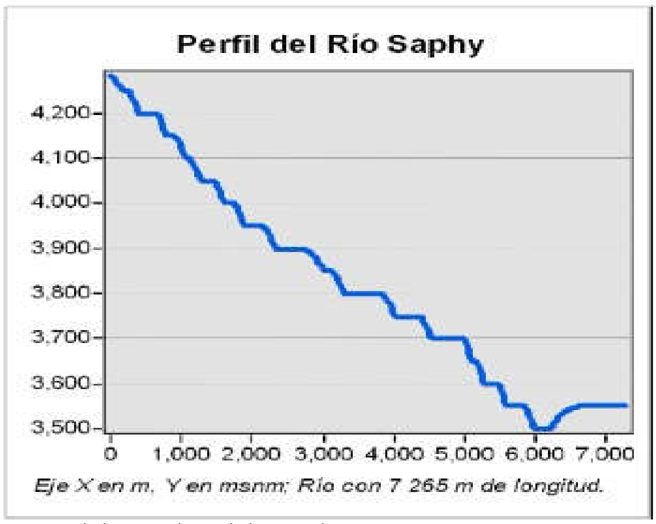
Figure 2. Location map of the study area: Saphy River

Table 1. Saphy river sampling stations

Sampling station	Altitude (m.a.s.l.)
1: Salkantay	3 987
2: T´inkoq	504
3: Unión	3 490



Note: X axis in m. and Y axis in m.a.s.l.

Figure 3. Longitudinal profile of the river Saphy

On-Site Sampling. Some parameters were measured "in situ" using a Hach HQ 40d equipmentmultiparameters. Samples were taken at each sampling station, placing the probeto measure the parameters: temperature, pH and dissolved oxygen as a percentage of saturation; in the case of dissolved oxygen, the samples were taken in Winkler flasks and fixed to determine the concentration in the laboratory following the modified Winkler methodology and the other variables have been analyzed in the SEDA Cusco laboratory. To obtain the BOD_5 value, the sample collected in the field was fixed in order to maintain dissolved oxygen and then incubated in the laboratory.

Laboratory Analysis. The physicochemical and bacteriological parameters were determined by the standardized methods for the analysis of drinking and waste water, described in Standard Methods for the Examination of Water & Waste Water (American Public Health Association, 2017). At each sampling station, a water sample was taken for subsequent analysis in the laboratory, following the ANA methodology (2016). The parameters determined in the laboratory, as well as the methodology used, are shown in tables 1 and 2.

wastewater; substantially from the Muyu Orcco tributary that collects these waters from human settlements that drain directly into the Saphy and Muyu Orcco rivers. In turn, these BOD concentrations recorded in the micro-basin, suggest that wastewater discharges are high. Therefore, the magnitude of the effects and/or impacts are severe on the receiving body.

Table 2. Parameters analyzed in the field

Parameter	Unit	Method
pH		multiparameter equipment
Temperature	°C	multiparameter equipment
Electric conductivity	uS/cm	multiparameter equipment

Table 3. Parameters analyzed in the laboratory

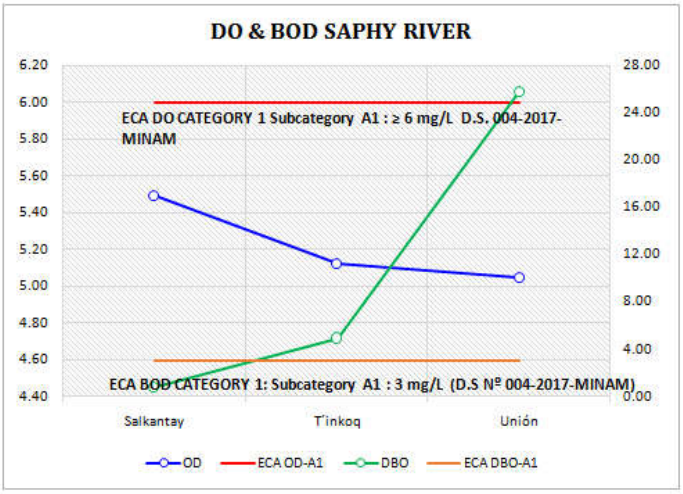
Parameter	Unit	Method
Phosphates	mg/L	Quick Method
Nitrates	mg/L	Quick Method HACH 355
Total dissolved solids	mg/L	Standard method 23nd edition 2017 2540-C
Turbidity	NTU	Direct reading
Dissolved oxygen (DO)	mg/L	Standard method 23nd edition 2017 4500-O C
Biochemical Oxygen Demand (BOD_5)	mg/L	Standard method 23nd edition 2017 5210-B
Total coliforms	NMP/ 100 mL	Standard method 23nd edition 2017 9221-B
Thermotolerant coliforms	NMP/ 100 mL	Standard method 23nd edition 2017 9221-E

RESULTS

Evaluation of the Physical-Chemical and Microbiological Parameters in the Saphy River

Table 4. Average Values of Physical-Chemical and Microbiological Indicators for the Saphy River

Sampling station	DO (mg/L)	DBO (mg/L)	Thermotolerant coliforms (NMP/100ml)	Temperature (°C)	pH	Total dissolved solids (mg/L)	Turbidity (NTU)	Nitrates (mg/L)	Phosphates (mg/L)
Salkantay	5.49	0.80	6.67E+01	8.73	7.61	265.33	3.14	0.64	0.54
T´inkoq	5.13	4.97	8.59E+02	11.60	7.85	1577.33	5.45	0.86	0.48
Union	5.05	25.87	12.3E+06	11.77	8.12	1178.67	28.70	0.74	1.13



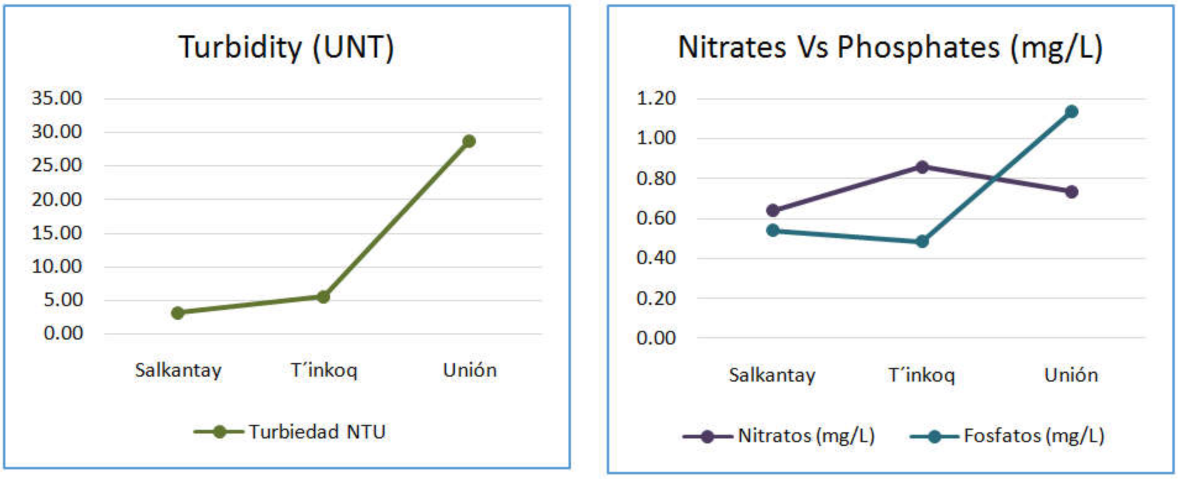
Source. Prepared based on information from Table 4

Figure 4. Saphy River, average DO and BOD concentrations compared to the respective ECA-Water

As usually happens when a water course is affected by organic contamination, the DO decreases and the BOD increases along the course of the river; however, the concentration of DO remains relatively high, due to the slope of the river and because there are infrastructure constructions called "pressure breaker" that includes waterfalls, which enables reoxygenation. When comparing the values found in these two indicators with the ECA-DO and ECA-BOD, respectively, it is observed that the DO is below the optimum and the BOD exceeds the established ECA-water by more than 8.6 times. This implies a loss of water quality due to contamination of domestic

It is pertinent to point out that the decrease in DO is a contamination indicator that is a function of the presence of oxidizable organic matter, aerobic organisms and germs, vehicle oils, greases and hydrocarbons, detergents, etc. It can be seen that the turbidity increases by more than six times in sampling station three compared to station one; this increase is mainly due to the geomorphological characteristics that allow a dragging of sediments and erosive processes whose genesis is given by the natural dynamics of the area, resulting in the loss of capacity to habor organisms of aquatic diversity, also by increasing turbidity, suspended particles absorb heat from the sun and thereby increase the temperature of the water, which in turn reduces dissolved oxygen levels. Also, because the particles scatter light, they impede photosynthetic activity.

previously mentioned is clearly related to the presence of contamination provided by the urban center located on the right bank of the micro-basin, in the last section of the Saphy River.



Source. Prepared based on information from Table 4

Figure 5. Average values of turbidity, phosphates and nitrates for the Saphy River

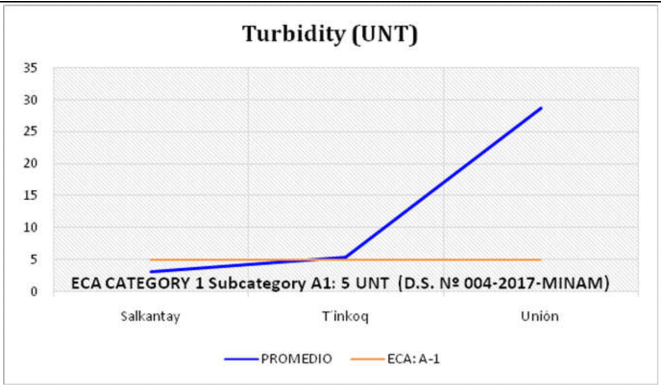


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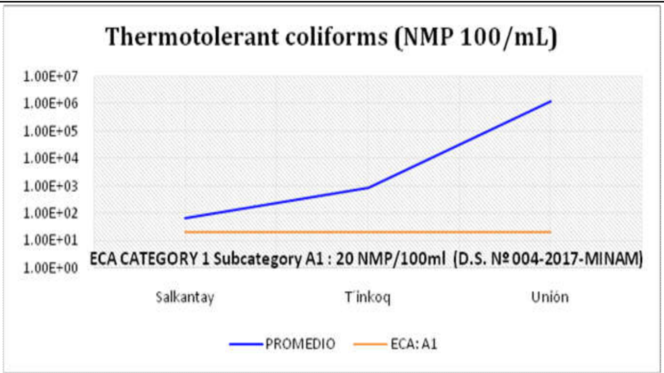
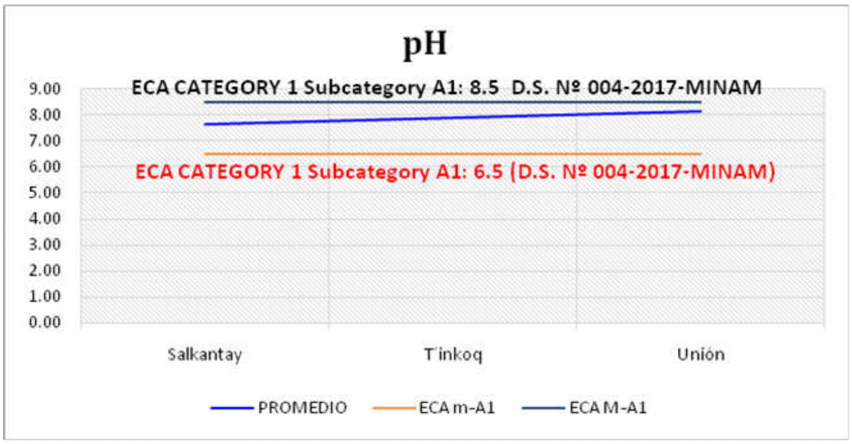
Figure 6. Turbidity compared to ECA-water. Saphy River



Source. Prepared based on information from Table 4

Figure 7. Fecal coliform concentration compared to ECA-water. Saphy River

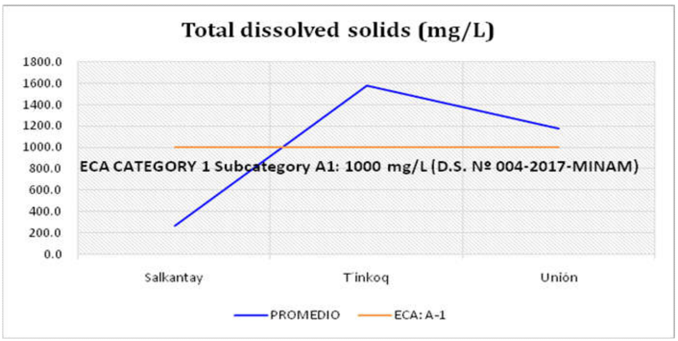


Source.Prepared based on information from Table 4

Figure 8. pH values compared to ECA-water. Saphy River

On the other hand, phosphates are increased substantially due to the high content of detergents that carry household wastewater, as well as due to agricultural practices in which fertilizers are used. When comparing the turbidity present in the water of the Saphy river with the ECA-water approved by MINAM, it can be seen that from sampling station two it exceeds these quality standards, especially at station three due to the contribution of wastewater from population settlements in this last section of the river. Fecal coliforms are greatly increased by the presence of sewage that is discharged directly into the river, becoming a real and effective source of infection. The

When the concentrations of coliforms are compared with the ECA-water, in all stations they are higher than this index, particularly in stations two and three. The alkalinization of the water is evident and, in general terms, the increase in total dissolved solids, signifying the loss of the quality of the Saphyriver from sampling station two. When comparing the values found for pH and dissolved solids with ECA-water, both values are higher, especially total dissolved solids; indicating loss of water quality. It should be noted that the pH fluctuates considerably with the time of day and the depth of the water because the pH is closely related to the concentration of carbon dioxide.



Source. Prepared based on information from Table 4

Figure 9. Concentration of total dissolved solids (TDS) compared to ECA-water. Saphy River

In stations two and three, the TDS values are higher than the ECA-water, which implies the loss of quality from sampling station two.

Main Sources of Deterioration of the Saphy River

There are three main sources that affect the quality of the water in the Saphy river:

- **a.** Agricultural and livestock activity, with its processes of deforestation, intensive use of the soil and furrows in favor of the slope, and overgrazing. Processes that generate erosion, discharge of agrochemicals, total solids and others.
- **b.** Wastewater without prior treatment discharged by all population settlements, constitutes the source of fecal coliforms, total solids, phosphates, chlorides, ammonia, detergents and nitrates.
- **c.** Solid waste, mainly those consisting of cans, plastic containers, glass, etc. that are not degradable, generate the greatest disturbances in the habitats and affect the aesthetics of the channel and waters of the basin.

The organic discharges contained in the residual waters coming from the towns, especially in the last section, substantially alter the natural quality of the river; however, the concentration of dissolved oxygen is relatively high, due to the significant turbulence, high oxygenation due to the presence of natural waterfalls or infrastructure built for this purpose that lead to a high self-purification capacity, which is why BOD levels are relatively low (See Figure 10).

Figure 10. The Saphy River in the last section receives wastewater and has waterfall aerators that re-oxygenate the water

One of the causal factors of contamination is the poor sewage or drainage system, consisting of a network of pipes that collect everything from domestic excreta, rainwater, runoff water, etc. Contamination is complicated by the lack of collectors in marginal human settlements that cause domestic wastewater to be discharged directly into the river.

DISCUSSION

Fernández and Solano (2005), when carrying out studies on river quality indices in Pamplona, state that all quality indices must include at least three of the following parameters: OD; BOD or COD; NH_4; PO_4; NO_3; pH and total solids and that all are of interest; when carrying out studies on the loss of water quality in the Saphyriver, it is necessary to apply not only three parameters, but also thermotolerant coliforms, turbidity, and temperature; these factors strongly indicate the loss of water quality due to contamination. The behavior of the DO in the Saphyriver agrees with that proposed by Bain & Stevenson (1999), as long as there are slopes and waterfalls that re-oxygenate the river and the temperature remains below 15 °C, the water course could continue to harbor still healthy ecosystems; this is the particular case of the Saphyriver, not only referring to the slope but also to the contribution of tributaries with a high content of dissolved oxygen. The measurement of physical, chemical and bacteriological parameters of water is used in numerous researchs for the evaluation of its quality (Maggioni*et al*., 2012; Rautenberg*et al*., 2014; Cochero*et al*., 2016) who at study the quality of the waters of the Suquia River in Córdova, indicate that the changes are insignificant due to the flow of said river. In the present study, the evaluation using the same parameters indicates a loss of quality, evidenced through the parameters OD, BOD, pH and thermo-tolerant coliforms. According to Aznar (2000), to manage the quality of water, whether for its discharge, purification treatment, potabilization or any other use, it is unpredictable to determine physical-chemical parameters through standardized methods in order to know if these parameters are within the interval established by current legislation. In the case of the Saphy urban river in Cusco, the values found have been compared with the official ECA-water determined by MINAM; hence, it is concluded that the river has lost its quality when entering the urban center. In 2001, Machado carried out a physical-chemical and biological characterization of the Tapias and Tasas river basins in the Department of Caldas (Colombia), determining that the evolution of the physical-chemical and biological characteristics is related to the presence of pesticide inputs, agrochemicals and detergents causing a loss of quality for human use; in the case of the Saphyriver in Cusco, the loss of its quality is substantially due to the contributions of household wastewater, solid waste and debris. Our results coincide with León, 2014 and Zhen, 2009, who maintain that a water quality index basically consists of a simple expression related to the degree of contamination, based on a more or less complex combination of a number of parameters, which serve as a measure of water quality; which allows to know in a general way the state or "health" of the aquatic system of a body of water; indeed, our field studies in the Saphyriver and the laboratory results determine a loss of quality or "health" of the river from its beginnings to the last segment of the river; because the indicators are evident of the loss of water quality.

CONCLUSIONS

The results of the laboratory analyze referring to fecal coliforms show that the values exceed the permissible standards provided by the WHO/PAHO, even for body contact activities such as recreation; particularly in sampling station three, located in the last section, since the wastewater effluents flow directly into the studied river. The pH, for the Saphyriver, is alkaline due to the allochthonous or exogenous contribution of rocks, minerals and sediments rich in carbonates, sulfates and chlorides and the endogenous contribution of wastewater with a high content of alkaline substances such as detergents and domestic wastewater. Detergents are not only a source of polyphosphates and could generate the proliferation of algae and other aquatic vegetation, but they could also harm the purification process at the San Jerónimo wastewater treatment plant, by preventing flocculation, as well as producing foams. From an ecological perspective, a river is a dynamic and complex ecosystem characterized by the presence of fresh water in movement that travels distances in favor of gravity through a bed or channel. Along its path, it establishes interactions and ecological connectivity (connectivity is an ecological attribute that means the continuity or spatial connection of ecosystems without interruptions, in which exchanges of materials, energy and genetic material between species are favored; in the field of in socio-ecosystems, ecological connectivity implies interconnected physical, biological, social and economic processes) in the three dimensional axes in which it travels: longitudinal, transversal and vertical. In the water courses studied, these interconnections are clearly appreciated and, in addition, a river is an ecosystem with marked temporal variability, as Gonzales *et al*. (2014). The presence of nitrates is an indication of recent organic contamination or predominant reductive processes, coming from various sources, including wastewater, use of fertilizers in agriculture and from livestock excreta in the micro-basin. In most cases, the variables most used for the physical-chemical assessment of water from indicators are temperature, pH, DO, BOD_5, nitrates, phosphates and total suspended solids, parameters that are convincing for determining the loss of the quality of a water course.

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