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Assessment of surface water quality using the water quality index (WQI) in a river located in northern Minas Gerais (Brazil)

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A B S T R A C T

Water is an indispensable natural resource for the survival of living beings, as well as for performing anthropic activities. However, in urban areas, watercourses are directly affected by impacting activities, making these resources increasingly scarce and degraded. In this sense, the aim of this research is to analyze the Water Quality Index (WQI) of the Cintra River, which is located to Montes Claros, Minas Gerais, Brazil southeastern, to indicate the current state of conservation of watercourse. For that, water samples were collected to physical-chemical and microbiological analysis based on four distinct points of Cintra River. The WQI analyzed indicated that the watercourse has a good degree of preservation only in the nascent area. In the other points analyzed, the WQI indicated a reasonable or poor state of preservation. These results indicated that the wastewater discharge and the irregular disposal of solid wastes are the most significant impacting human activities that contribute to degradation of the Cintra River. In addition, other factors, as the removal of vegetation present on the banks of the Cintra River, are contributed to its degradation. In conclusion, the current state of conservation of this river harms ecological processes and aquatic organisms. In addition, it may represent serious public health problems, since waterborne diseases can affect the population

Keywords: water quality, effluent, pollution, environmental impact.

Avaliação da qualidade da água superficial usando o índice de qualidade da água (WQI) em um rio localizado no norte de Minas Gerais (Brasil)

R E S U M O

A água é um recurso natural indispensável para os seres vivos, bem como para a realização das atividades antrópicas. Entretanto, em áreas urbanas os cursos hídricos são diretamente afetados por atividades impactantes, tornando esses recursos cada vez mais escassos e degradados. Nesse contexto, o objetivo desta pesquisa foi analisar o Índice de Qualidade de Água (IQA) do rio Cintra, que está localizado em Montes Claros, Minas Gerais, Brasil, a fim de indicar o estado atual de conservação desse curso hídrico. Por isso, foram coletadas amostras de água para análises físico-químicas e microbiológicas em quatro pontos distintos do rio Cintra. O IQA analisado indicou que o curso de água tem um bom grau de preservação apenas na área nascente. Nos demais pontos analisados, o IQA indicou um estado de preservação razoável a ruim. Esses resultados indicaram que o lançamento de efluentes e a disposição irregular de resíduos sólidos são as atividades impactantes mais significativas que contribuem para a degradação do rio Cintra. Além disso, outros fatores, como a supressão da vegetação presente nas margens do rio Cintra, contribuem para sua deterioração. Em conclusão, o atual estado de conservação deste rio prejudica os processos ecológicos e organismos aquáticos. Além disso, pode representar sérios problemas de saúde pública, uma vez que doenças de veiculação hídrica podem afetar a população.

Palavras-Chaves: qualidade da água, efluente, poluição, impacto ambiental.

1. Introduction

Water is an indispensable natural resource for the survival of living beings and for the performance of human activities (Litynska, Astrelin & Tolstopalova, 2017). The preservation of water resources in adequate quantities and qualities provides a precondition for economic development and ecological integrity (Wu et al., 2018).

Water has become a strategic resource worldwide, due to several factors including population growth, urban expansion, industrial growth, agriculture, livestock and the production of electricity (Santos et al., 2017). Water resources have gradually become a restricting factor for regional socio-economic and environmental development (Wei et al., 2018). With the rapid and continuous progress of urbanization, industrialization and modernization, problems related to water demand and the growing scarcity of water resources have become even more worrying (Wei et al., 2018). The solution of these problems, therefore, depends not only on the availability of water, but also on its correct management and planning (Biswas, 2005).

In this context, the water course framework is a management instrument established by legislation and is defined by the most prevalent use restrictions, current or intended. In Brazil, Resolution No. 357 of March 17, 2005 of the National Environmental Council (CONAMA), as well as Resolution No. 91 of November 5, 2008 of the National Water Resources Council (CERH), define criteria for watercourses based not necessarily on their current state, but also on the quality levels they should have to meet the needs of the community (BRASIL, 2005; BRASIL, 2008).

Fresh water is classified into five classes: special class, class 1, class 2, class 3 and class 4. The waters of the special class are intended for human consumption, with filtration and disinfection; preservation of the natural balance of aquatic communities; and the preservation of aquatic environments in protected areas of integral protection (BRASIL, 2005).

Class 1 includes waters intended for human consumption after a simplified treatment; protection of aquatic communities and recreation of primary contact; irrigation of vegetables that are eaten raw and fruits that develop close to the soil and that are eaten raw without film removal; and the protection of aquatic communities in Indigenous lands (BRASIL, 2005). The Class 2 covers waters which may be destined for supply for human consumption after conventional treatment; protection of aquatic communities; recreation of primary contact; to the irrigation of vegetables, fruit and park plants, gardens, sports and leisure fields, with which the public can come into direct contact; and aquaculture and fishing activity (BRASIL, 2005).

Class 3 corresponds to waters which may be destined for supply for human consumption after conventional or advanced treatment; irrigation of tree, cereal and forage crops; amateur fishing; secondary contact recreation; and to the consumption by animals. Water belonging to Class 4 may be used for navigation; to landscape harmony; and less demanding uses (BRASIL, 2005).

Although the most common uses are associated with human consumption, watercourses have been progressively degrading the quality of their waters, generating several problems (Santos et al., 2017). In urban areas, population growth and inappropriate use are the main processes that make this resource increasingly scarce (Cunha, Lucena & Sousa, 2017; Singo et al., 2020). The changes that occur in the characteristics of the river basin and that in some way alter the balance and the dynamics of the water resources are associated to the existing pollution in the territory (Gude et al., 2017; Hassan et al., 2017). Surface waters can be directly affected, receiving the most diverse types of domestic, agricultural and industrial effluents, in addition to the loss of riparian forest and silting (Gude et al., 2017; Liu et al. 2017; Hassan et al., 2017).

As in many Brazilian cities, in Montes Claros, Minas Gerais, Brazil, there was no adequate planning, and the disordered urban development affects the watercourses present in the city, which, in their majority, suffer the impacts caused by anthropic action. The management of natural resources and the control of river pollution pose notable challenges for the local government. According to Alves et al. (2019), currently, the problem of water quality and water resource management has become one of the most serious obstacles faced by public authorities, as well as by society. Thus, the main challenge is to develop sustainable management that ensures an adequate supply of quality water and at the same time prevents the degradation of associated aquatic ecosystems (Durán-Sánchez, García & Rama, 2018).

It is necessary to ensure the water quality of surface water resources and create public policies for their sustainable use. Thus, it is necessary to carry out studies that analyze the current degree of conservation of rivers, serving as a subsidy and tool for local government decisions.

In this sense, the water quality index (WQI) is considered a fundamental information for the analysis of water quality and conservation degree of water resources, being an important subsidy for their management. The WQI was proposed in 1970 by the National Sanitation Foundation (NSF), in the United States of America (USA). Generally, WQI is a dimensionless number which combines multiple water quality factors into a single number by normalizing values to subjective rating curves and enabling easy interpretation of monitoring data (Garcia et al., 2017). In Brazil, the WQI has been adapted and is used by several environmental agencies as a tool for pollution control and resource management.

In this sense, the aim of this research is to analyze the Water Quality Index (WQI) of the Cintra River, which is located to Montes Claros, Minas Gerais, Brazil southeastern, to indicate the current state of conservation of watercourse.

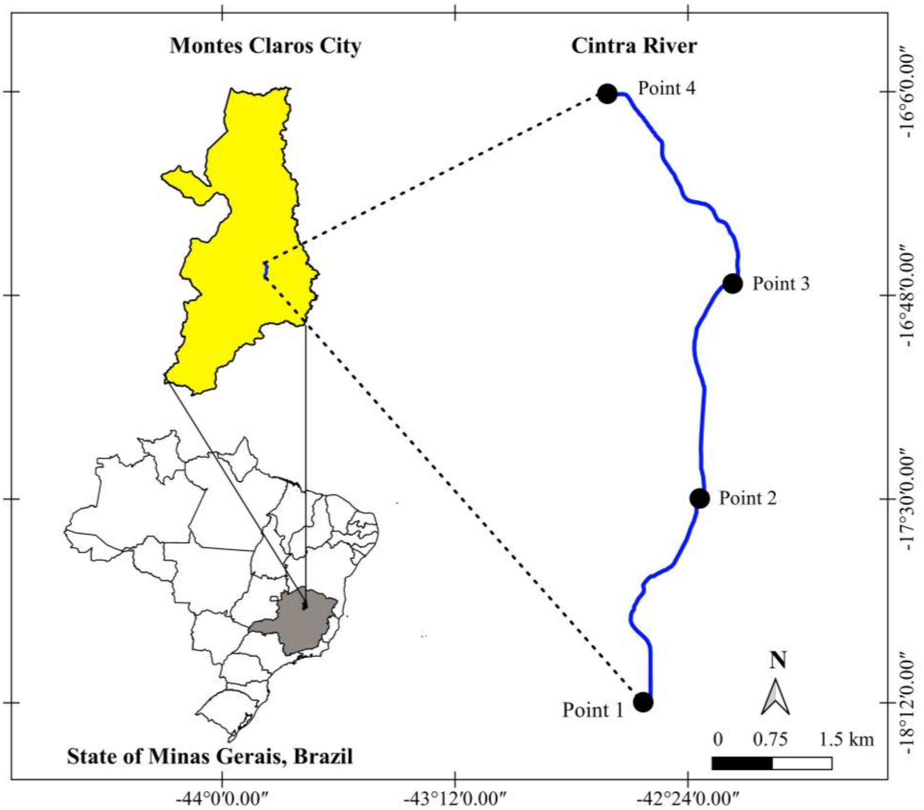
2. Methods

2.1 Sample Collection and Laboratory Analysis

The Cintra River, the object of study of this paper, is a watercourse of great importance for the city of Montes Claros, Minas Gerais, Brazil southeastern. The Cintra River has its hydrographic basin located in the urban area of the city.

The watercourse has an extension of approximately 7000 m, and is not classified in water quality classes, as established in CONAMA Resolution Nº. 357/2005 (BRASIL, 2005). The water from this river is used for domestic activities in the spring area. In point 2, at Figure 1, water is used by residents to irrigate some plants on the banks of the river. In points 3 and 4 water is used for the consumption of animals, mainly horses, that are raised by local residents of the area (Figure 1).

Figure 1. Location of the four sample points of the Cintra River.



The Cintra River is one of the tributaries of the Vieira River that flows into the Verde Grande River, a direct tributary of the São Francisco River. The São Francisco River, is the 5th largest watercourse in Brazil, and has great economic, social and environmental importance for the country.

To perform the WQI analysis, water samples were collected at four distinct sample points of the Cintra River. The sampling sites were defined at points equidistant along the river, being: spring (16°44'21.65" S, 43°51'9.47" W), two intermediate points (16°43'20.32" S , 43°50'52.46" W and 16°42'15.65" S, 43°50'42.54" W) and river mouth (16°41'18.51" S, 43°51'20.25" W), as presented in Figure 1. The distance between the sampling points was approximately 2300 meters. Geographic locations of the sampling points were recorded using a portable GPS system (Garmin - eTrex 12, Brazil).

The samples were collected in polyethylene bottles and kept under refrigeration in the thermal box until the analysis, according to APHA (2012) criteria. The time of water sample collection and analysis was less than 24 hours.

The analysis of temperature (T), hydrogen potential (pH), dissolved oxygen (DO), biochemical oxygen demand (BOD), total coliforms (TC), total nitrogen (TN), total phosphorus (TP), total solids (TS) and turbidity (TH), which compose the parameters required to calculate the water quality index, were performed as described (APHA, 2012). The parameters and methodologies adopted for the analysis are presented in Table 1. After the analysis of the Cintra River water samples, the WQI was calculated.

Table 1 – Parameters and methodology for water quality index analysis

Parameters Analyzed	Methodology Adopted
DO and BOD	The analysis of dissolved oxygen was performed at the time of collection. In order to calculate the biochemical oxygen demand, water samples were incubated in an oven at 20ºC for 5 days, after which the oxygen dissolved in them was analyzed and the initial dissolved oxygen was subtracted from the dissolved oxygen after 5 days. The analyzes were performed with a portable dissolved oxygen meter (Instrutherm MO-900, Brazil).
T	The temperature of the water was analyzed at the time of sampling, using a digital thermometer (JProlab TE07, Brazil).
TC	The culture medium, Rapid HiColiform broth, was prepared, which was submitted to the sterilization process, autoclave. Subsequently, the dilutions of 10.0 mL, 1.0 mL and 0.1 mL of the water sample were added to the broth. The result of the analysis was verified after 24 hours, verifying if there was change of color and formation of gases in the tubes (total Coliforms) and taken to the light Ultraviolet to analyze if fluorescence formation occurred (indicating presence of *Escherichia coli*).
TS	150 mL of the water sample was added in an Erlenmeyer flask, which was brought to the oven at 105 °C for drying. The calculation was done by removing the difference found in the sample before and after drying in the oven. For greater reliability of the results, the analysis was done in triplicate.
TH	Turbidity analysis was performed using a portable turbidimeter (Quimis W279p, Brazil).
TP	Samples were analyzed through colorimetric reactions using specific reagents (Alfakit 1555, Brazil).
TN	Samples were analyzed through colorimetric reactions using specific reagents (Alfakit 1555, Brazil).
pH	For pH analysis, the samples were analyzed using the bench digital potentiometer (Hanna HI 8424, Brazil).

DO: dissolved oxygen; BOD: biochemical oxygen demand; T: temperature; TC: total coliforms; TS: total solids; TH: turbidity; TP: total phosphorus; TN: total nitrogen; pH: hydrogen potential

2.2 Water Quality Index (WQI)

The determination of WQI was conducted according the methodology used by the Environmental Company of the State of São Paulo (CETESB, 2016). Nine parameters of water quality were analyzed. The WQI was calculated according to Equation 1, with index values varying from 1 to 100. According to Sperling (2014), in the calculation of WQI presented by NSF, the sum of the weights of the variables must be equal to 1.

$$WQI = \prod_{1}^{9} qi^{wi} \qquad (1)$$

On what: WQI: water quality index, between 0 and 100; qi: quality of the ith parameter, between 0 and 100, obtained from the respective average curve of quality variation, as a function of its concentration or measurement; wi: weight corresponding to the ith parameter, between 0 and 1, attributed as a function of its importance for the overall quality; n: number of variables that enter the WQI calculation.

The results of the Water Quality Index were classified in color bands as provided in Table 2, following the established parameters (CETESB, 2016).

Table 2. Classification of the modified water quality index (WQI), according to CETESB (2016).

Classification	Color	WQI Classification
Excellent		$90 < WQI \leq 100$
Good		$70 < WQI \leq 90$
Reasonable		$50 < WQI \leq 70$
Bad		$25 < WQI \leq 50$
Very Bad		$0 < WQI \leq 25$

3. Results and Discussion

According to the Resolution No. 91/2008 (BRASIL, 2008), until the authority has information necessary for the definition provided and establishes the corresponding class, class 2 may be adopted for surface fresh waters (BRASIL, 2008). Thus, as the Cintra River is not yet framed, for the purposes of analysis, the obtained results were compared with the maximum values established for watercourses belonging to class 2. The results of the analysis, WQI and degree of conservation of the Cintra River are presented in Table 3.

Table 3. Results of the analysis for calculation of Water Quality Index.

Parameters Analyzed	Unit of measurement	Point 1 Nascent	Point 2	Point 3	Point 4 River mouth	Maximum allowed value *
DO	mg L^{-1}	8.0	4.0	6.0	6.0	> 5.0
BDO	mg L^{-1}	1.0	3.0	2.0	3. 0	≤ 5.0
T	ºC	23	25	24	25	-
TC	Most Likely Number in 100 mL	240	1600	1780	1900	200
TS	mg L^{-1}	312.67	664.26	482.33	608.34	500
TH	Nephelometric Turbidity Unit (NTU)	6.0	18.0	5.0	10.0	100
TP	mg L^{-1}	0	0.9789	0.9789	0.6526	0.050
TN	mg L^{-1}	0.607	2.428	3.642	3.642	**
pH	-	6.5	8.0	8.0	9.0	6.0 to 9.0
WQI		76	46	52	49	
Degree of Conservation		Good	Bad	Reasonable	Bad	
Color						

*Maximum value established for watercourses class 2, according to Conama Resolution 357/2005 (BRASIL, 2005).
** 3.7 mg L^{-1} N, for pH ≤ 7.5; 2.0 mg L^{-1} N, for 7.5 < pH ≤ 8.0; 1.0 mg L^{-1} N, for 8.0<pH≤ 8.5; 0.5 mg L^{-1} N, for pH > 8.5.
DO: dissolved oxygen; BOD: biochemical oxygen demand; T: temperature; TC: total coliforms; TS: total solids; TH: turbidity; TP: total phosphorus; TN: total nitrogen; pH: hydrogen potential; WQI = Water Quality Index.

Point 1 - Coordinates 16°44'21.65" S and 43°51'9.47" W, corresponding to the spring: The WQI value obtained was 76, indicating a good degree of conservation. At this point, the analyzed parameters showed to be of a quality degree close to the desired one, except for total coliforms and total solids. These results can be related by the fact that the water at this point is used for domestic activities. Consequently, the anthropic activity is intense, which can lead to contamination, as well as sediment transport to the water.

Point 2 - Coordinates 16°43'20.32" S and 43°50'52.46" W, intermediate point of the Cintra River: The WQI value was 46, corresponding to a bad degree of conservation. The parameters of total coliforms, nitrogen, phosphorus and total solids, were high. This is the point that is located closest to residences and urbanization. Therefore, there is a greater anthropic interference, causing several impacts in the watercourse. Previous studies report that land use and occupation influence the water quality of a river basin (Santos et al., 2017). These results are directly related to the wastewater discharge near the point, leading to serious impacts. These effluents, when not properly treated, potentiate the process of degradation of water quality (Li et al., 2015).

Point 3 - Coordinates 16°42'15.65" S and 43°50'42.54" W, intermediate point of the Cintra River: The WQI result found was 52, indicating a reasonable degree of conservation. At this point, the results of total nitrogen, phosphorus and total coliforms were high. This fact has the influence of the wastewater discharge in this river. Studies show that discharging untreated domestic and industrial wastewater is a source of water pollution (Bilgin, 2018). The release of these effluents contributes to nutrient enrichment in the water (Karadžić et al., 2010). High levels of phosphorus in nature can create algal blooms, causing eutrophication. This process decreases sunlight and oxygen levels (hypoxia) thus, affecting fish and other aquatic life (Hamdan, Dawood & Naeem, 2018).

Point 4 - Coordinates 16°41'18.51" S and 43°51'20.25" W, corresponding to the mouth river: The value of WQI obtained was 49, indicating a bad degree of conservation. At this point, the analysis indicated high values of total coliforms, nitrogen, phosphorus and total solids. These parameters indicate the bad water quality of the water course, due to the wastewater discharge and the presence of waste and sediments. The transport of sediments, nutrients and organic matter to the riverbed, can lead to irreversible effects, surpassing the self-purification capacity of the river (Wittman et al., 2013).

Resolution No. 357/2005 (BRASIL, 2005), defines coliforms as a group of gram-negative bacteria in the form of bacilli, oxidase-negative, characterized by the activity of the enzyme β-galactosidase, and can ferment lactose at temperatures of 44.5 ± 0.2 °C in 24 hours with acid, gas and aldehyde production. In addition to being present in human feces and homeothermic animals, they occur in soils, plants or other environmental matrices that have not been contaminated by fecal material (BRASIL, 2005).

Although total coliforms also occur in places where there was no fecal contamination, their use is due to the fact that they are biological indicators. According to Resolution No. 357/2005, biological indicators are bacteria, plants and animals whose presence or behavior are so closely related to certain environmental conditions that can be used to evaluate them (BRASIL, 2005). Thus, a suitable bioindicator will synthetically reveal, through values or parameters, modifications that have occurred or are occurring in a specific system (Reche, Pittol & Fiuza, 2010).

In this study, it was found that in all analyzed points, the presence of total coliforms was higher than the maximum value established (Table 3). This high concentration of coliforms indicates the contamination of the watercourse by domestic effluents, identified in points 2, 3 and 4, representing in risks to the population. When contamination by total coliforms is detected, it means that there was wastewater discharge in the recent period. The presence of total coliforms in water indicates contamination by human or animal feces, with a potential risk of the presence of pathogenic organisms (Cabral, 2010; Pandey et al., 2014; Uprety et al., 2020).

Nitrogen is an important parameter of water quality, considering that this is a nutrient that contributes to the growth of plants and algae, and can contribute to the eutrophication of the watercourse. In the aquatic environment, the most common forms of this element are nitrate, nitrite, ammonia and dissolved nitrogen compounds. These nutrients may have anthropogenic origin through the release of domestic and industrial waste, animal excrement and fertilizers (Santos et al., 2018; Hassan et al., 2017). In points 2, 3 and 4 the nitrogen determined was above the values established by the legislation in force. In these points it was verified the release of domestic effluents, which are related to the increase of this parameter.

Another important nutrient is phosphorus, considering that it can also contribute to the eutrophication process. Their presence in the water can originate through natural processes such as rock dissolution, soil deposition, organic matter decomposition and rainfall. Major source of phosphorus in water is effluent discharge from sewage treatment plants, domestic wastewater, runoff that comes from agricultural fields sprayed with phosphate fertilizers, phosphate additives used in detergents for washing clothes (Hassan et al., 2017). At the spring (point 1), phosphorus was not detected, but in points 2, 3 and 4 is above the permitted values, being able to attribute relation with the wastewater discharge and disposal of solid residues in the watercourse.

Dissolved oxygen and biochemical oxygen demand (BOD) have been attributed to great importance as indicators of water quality assessment, since they influence almost all chemical and biological processes within watercourses. They are important limnological parameters that indicate the degree of water quality and the load of organic pollution in the watercourse. (Hassan et al., 2017). Thus, the higher the organic matter, solids and sediments in a body of water, the smaller the DO and the larger the DOB. The DO can also be related to the flow of the watercourse. The increase in DO concentration can be attributed to the increased turbulence in the river flow (Girardi. et al., 2016). Only at point 2 the DO is below the allowable value. In the other points, the DO as well as the BDO are within the established standards (BRASIL, 2005) (Table 3).

The pH, as well as temperature, are important parameters in monitoring as they contribute to the maintenance and survival of aquatic organisms. Variations of these parameters can be related to the wastewater discharge, as well as in the greater quantity of organic matter and other compounds. At all points analyzed, the pH and temperature are within the established standards (BRASIL, 2005).

The total solids (TS) are related to the wastewater discharge, erosion and solid transport to the watercourse. In points 2 and 4, the TS are above the established values. The high presence of organic matter and sediments from the discharge of domestic effluents and disposal of solid waste removal of riparian vegetation are responsible for this high value.

The turbidity is related to the presence of suspended solids in the water. According to Sperling (2014), turbidity does not generate sanitary problems, however it is aesthetically unpleasant in water. According to the same author, the total solids responsible for turbidity in the water serve as shelter for microorganisms, which may be pathogenic. At all points, the turbidity values are below the maximum allowed value.

The WQI analyzed in the four points of the Cintra River indicated that the watercourse has a good degree of preservation only in the spring. At intermediate points and river mouth, the environmental impacts from anthropic activity, are evident. It is the cause of changes in physical-chemical and microbiological properties of water. According to Lima et al. (2015) the deterioration of water quality can occur more significantly when there is wastewater discharge. In addiction, urbanization and the consequent removal of riparian vegetation tend to degrade the banks of watercourses and alter the physical and chemical characteristics of their waters (Li et al., 2015). Another important aspect that should be considered is the negative impact on their quality and the demand for the maintenance of aquatic life in these ecosystems (Cunha, Calijuri & Lamparelli, 2013).

4. Conclusion

In this study, the water quality index (WQI) was applied to monitor the degree of conservation of the Cintra River. It was possible to verify that this important watercourse has a good degree of preservation only in the area of its spring. In the downstream points, the degree of conservation varies from reasonable to bad, due to the impacts resulting from anthropic activity, such as wastewater discharge, irregular disposition of solid waste and removal of riparian vegetation.

The wastewater discharge and irregular disposition of solid waste constitute the most significant impacts for the degradation of the Cintra River. For these reasons, it is fundamental to propose a plan for the recovery and preservation of the Cintra River basin, in addition to monitoring the quality of its waters. These actions can guarantee the quality of the water for the uses required by the population, in addition to contributing to the maintenance of ecological processes and aquatic communities.

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