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ScienceDirect

Procedia Computer Science 177 (2020) 300–307

Procedia Computer Science

www.elsevier.com/locate/procedia

The 11th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN 2020)
November 2-5, 2020, Madeira, Portugal

Evaluation of water quality state through regulations and physicochemical indicators for the administration of water resources in the Integrated Management District of Salto del Tequendama

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Abstract

Water resources are of great importance in the administration of protected areas. This is linked to the quality of surface water bodies that pro-vide different eco-systemic services, since they shelter different species of fauna and flora. In relation to Resolution 1596 of 2006 adopted by the General Direction of the CAR, which states the Management Plan for the Integrated Management District (DMI by its abbreviation in Spanish) in the area of Salto del Tequendama - Cerro Manjui, attached to the Water Cycle Management program and in relation with the "Water Quality Control" project, states the evaluation of the conditions of the different water sources in relation to water collection given by the communities as one of its objectives, and at the same time exposes the determinants of the conditions that take place in the surface water bodies. In this article, a correlation of the uses that are stated in the management plan will be performed in order to com-pare the results, which are obtained by means of the environmental monitoring that is evaluating the control and management of the "Water Quality Control". Based on the evaluation of water quality, it was possible to determine whether the uses that are defined in the Management Plan are appropriate, by linking them to the Water Quality Control program. Calculations were also made conducive to obtain indicators that would allow us to estimate the quality of the water and possible sources of pollution.

Keywords: Water quality; water utilization; normativity; indicators; management plan; water resource management.

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10.1016/j.procs.2020.10.041

1. Introduction

Surface water sources are of vital importance for the development of life and ecosystems, since they provide resources and allow interaction among communities, as indicated by the Alexander Von Humboldt Biological Resources Research Institute in the National Pol-icy for the Integrated Management of Biodiversity and its Ecosystem Services (PNGIBSE by its abbreviation in Spanish) [1]. In the same way, water is a development engine and its efficient and sustainable use depends on the information and knowledge that we have about water systems [2] [3], as well as their regimes and responses to climate variability and change. These aspects are crucial for determining the domains of sustainability of the resource for its utilization [4], given that they are the development axis of human settlements and the support to many important socioeconomic activities. It is estimated that approximately 71% of the Earth's surface is covered by water, out of which 97% is salt water, leading us to assert that one of the greatest difficulties that humanity is facing is the scarcity of fresh water [5] [6]; additionally, there are some activities of anthropogenic origin such as water harvesting, site occupancy, and discharges that generate excessive pressure on water resources due to their contributions of pollutant loads, leading to the modification of the natural channel, alterations to the channels, and excessive water collection [7] [8]. Nevertheless, it would be possible to pose to a greater or lesser extent, the possibility to carry out analyses that allow for the identification of a level of affectation of some of these ecosystem services by specific anthropogenic activities depending on the ecosystem service being evaluated [9] [10]. Like-wise, the concentration of other variables is analyzed, which not only represent a risk for the water resource as such and for the life sustained there, but also these affectations may even have repercussions on human health.

Due to the great importance of the water re-sources, it is important to conduct characterizations in critical or susceptible areas, in order to identify whether the resource is undergoing any alteration of anthropic origin, or whether the activities that require the water resource as an ecosystem service are generating any impact and if this can be avoided or mitigated [11]. This is why current regulations specify some maximum concentration values that are admit-ted in surface water sources, which can guarantee the quality of the resource depending on its use, as specified in the Regulatory Decree No 1076 of 2015, issued by the Ministry of the Environment and Sustainable Development (MADS by its abbreviation in Spanish) [12].

Water bodies are very important within the areas that are environmentally critical, such as Protected Areas, which are regulated by Decree 2372 of 2010 [13], which establishes the National System of Protected Areas, setting out the principles and categories of management. These include Integrated Management Districts, which are defined by the Ministry of the Environment, Housing, and Territorial Development [13], such as: geographical space, in which landscapes and ecosystems maintain their composition and function, although their structure has been modified and whose associated natural and cultural values are made available to the human population for their sustainable use, preservation, restoration, knowledge, and enjoyment [14].

On the basis of the foregoing, in 1999, agreement No. 43 of the Regional Autonomous Corporation (CAR by its abbreviation in Spanish) [15], established the Integrated Management District located within the area of Salto del Tequendama - Cerro Manjui, with an ex-tension of 10,442 hectares (Figure 1) and with jurisdiction over nine municipalities in Cundinamarca. In relation to this, a management process is incorporated, through which the Integral Management Plan is established in order to promote its conservation and preservation. It is important to clarify that, based on the collection of data, the government departments establish their water quality indexes based on the contamination of the water and its levels of toxicity [16]. In order to evaluate the quality of the water bodies that are located in the municipality of Chicaque within the Salto del Tequendama Cerro Manjui Integrated Management District, we carried out a comparison of the uses that are set forth in the Environmental Management Plan (EMP) [17] [18], taking into ac-count the weighting obtained from indices such as WQI[19] and WPIs, we also related the uses described in Decree 1076 of 2015 [12], in order to demonstrate that there is agreement between what is stated by the EMP and the current situation, since it details that the Salto de Tequendama is a place of great historical, cultural, and biological value. It rep-resents a fundamental reference point for the development of the Nation, and the ecosystem that is surrounding the waterfall is a major producer of water, a carbon sink, and a guarantee of an efficient water balance system [18]. Given its high importance, many movements are seeking to recover the area as an environmental, historical, and cultural heritage site for Colombia, and after that, use it in ways that ensure proper management of the resource and protection of human health and the ecosystem.

2. Methodology

The following points are established for the evaluation of current uses in comparison with the uses described in the Management Plan for Salto del Tequendama: [12] [15] [17] [19].

2.1. Comparison of results obtained in relation to the Regulatory Decree 1076 of 2015

As a starting point, it is necessary to carry out a physicochemical comparison of the parameters that have been analyzed, which makes it possible to identify whether the conditions that the monitored water body is currently presenting comply with the limits that are established in Decree 1076 of 2015.

Decree 1076 of 2015 evaluated the articles that are contained in section 9 "Transitional Provisions", which sets out the quality criteria for the destination of the resource for different purposes (Table 1).

Table 1. Provisions decree 1076 of 2015

TRANSITIONAL PROVISIONS	
Article 2.2.3.3.9.3	The admissible quality criteria for the destination of the resource for human and domestic consumption are those listed below, and indicate that only conventional treatment is required for its purification.
Article 2.2.3.3.9.4	The admissible quality criteria for the destination of the resource for human and domestic consumption are those listed below, and indicate that only disinfection is required for its purification.
Article 2.2.3.3.9.5	The admissible quality criteria for the destination of the resource for agricultural use.
Article 2.2.3.3.9.6	Quality criteria for livestock use. The admissible quality criteria for the destination of the resource for livestock use
Article 2.2.3.3.9.7	Quality criteria for primary recreational purposes. The admissible quality criteria for the destination of the resource for recreational purposes by means of primary contact.
Article 2.2.3.3.9.8	The admissible quality criteria for the destination of the resource for aesthetic use.
Article 2.2.3.3.9.9	The admissible quality criteria for the destination of the resource for aesthetic use.
Article 2.2.3.3.9.10	The admissible quality criteria for the destination of the resource for the preservation of flora and fauna, in fresh, cold, or warm waters and in marine or estuarine waters.

Source: Ministry of the Environment, Housing, and Territorial Development (MADS by its abbreviation in Spanish), 2015 [12].

2.2. Calculating the Water Quality Index (WQI) and Water Pollution Index (WPI)

The semi-annual analysis of the related information, and in particular the meticulous control of the behavior of the WQIs over the years, is a strategy that will enable the identification of decaying trends in the quality of water bodies, and thus, the generation of strategies from the functions of the environmental authority that will permit a direct influence on the factors of deterioration of the water resource, adopting the corrective and/or preventive measures, as the case may be [20].

The Water Quality Index is the numerical value that qualifies the quality of the water of a sur-face stream in one of five categories, based on the measurements obtained for a set of five or six variables, recorded at a monitoring station (j) over time (t) [21].

In order to calculate the Water Quality Index (WQI), the following formula is used [21]:

$$ICA_{njt} = \left(\sum_{i=1}^{n} W_i * I_{ikjt} \right) \quad (1)$$

Where:

ICAnjt: Is the water quality index of a cer-tain surface flow at the water quality moni-toring station j in time t, evaluated based on n variables.

Wi: Is the weighting factor or relative weight assigned to the quality variable i.

Iikjt: Is the calculated value of the variable i (obtained by applying the corresponding functional curve or equation), at the monitoring station j, recorded during the measurement that is carried out in the quarter k, of the time period t.
N: Is the number of quality variables that are involved in the calculation of the indicator; n is equal to 5, or 6 depending on the selected WQI measurement.

We recommended for the data table of the indicator to include the average value, for inter-agency reporting of that period, which is calculated using the following formula:

$$ICA\ promedio_{njt} = \frac{\sum_{k=1}^{m}\left(\sum_{i=1}^{n} W_i * I_{ikjt}\right)}{m} \quad (2)$$

Where:

- *M: Is the number of samples in which the quality variables that are involved in the calculation of the indicator were measured. $1 \leq m \leq 4$, if it is annual period.*

The following tables summarize the variables that are involved in the calculation of the indicator (Table 2).

Table 2. Variables and weighting of those variables

Variable	Measurement Unit	Weighting
Dissolved Oxygen, DO.	% Saturation	0,17
Total Suspended Solids, TSS.	mg/l	0,17
Chemical oxygen demand, COD.	mg/l	0,17
NT/PT	-	0,17
Electrical conductivity, EC.	µS/cm	0,17
pH	pH Units	0,15

Source: S. G. Barón López, Environmental Health [6]

Table 3 shows the rating for each range of data evaluated for the WQI.

Table 3. WQI Rating

Description	WQI		Color	Use
Very bad	0,0000	0,2500	Red	Restrictions on human contact and limits on aquatic life.
Bad	0,2600	0,5000	Orange	Restrictions on human contact and limits on aquatic life.
Fair	0,5100	0,7000	Yellow	Restrictions on human contact and limits on aquatic life.
Acceptable	0,7100	0,9000	Green	Human contact, aquatic life.
Good	0,9100	1,0000	Blue	Human contact, aquatic life.

Source: S. G. Barón López, Environmental Health [6]

Regarding the calculation of the contamination indices, the correlations that were found be-tween multiple physicochemical variables gave rise to six complementary and independent con-tamination indices of verified application, known as: Index of contamination by mineralization, index of contamination by organic matter, index of trophic contamination, index of contamination by suspended sol-ids, index of contamination by pH [22].

2.3. Comparison of uses

Finally, we made a comparison of the uses de-scribed in the Environmental Management Plan (EMP) [18] of Salto del Tequendama - Cerro Manjui (Table 4), in relation to the current state of water quality, proposing alternatives for the use and exploitation of the water resource, with the purpose of corroborating this information, according to the "Water Cycle Management" program. [18].

Table 4. Uses established within the EMP for Salto del Tequendama

PROGRAM	PROJECT	RECOMMENDED UNIT OF USE	TYPE OF MEASURE
Walter Cycle Management	Water Supply Management / Water Quality Control	Collective Water Supply Systems	Protection and Recovery
LOCATION		DMI Drains	
OBJECTIVE		Promoting projects for the adequate management of waste water, so as to guarantee the quality of the water from which human populations are supplied.	
CHARACTERISTICS		• The monitored water bodies show turbid water due to the presence of organic and inorganic material. • Suspended, which affects its physical aspect. • Water that is collected for human consumption and domestic use must be treated by unitary processes of flocculation, sedimentation, filtration, and disinfection, in order to obtain safe water. • From the water bodies that were monitored, the Apulo River is the one that shows the greatest deterioration. • From the water bodies that were monitored, the one in best condition is Quebrada Honda. • The water from all the monitored sources, in terms of physical variables and inorganic constituents, is classified as acceptable; however, the concentrations of organic and bacteriological constituents (fecal and total coliform bacteria) given by the discharge of wastewater, raise these values in certain points, so according to the table of laboratory results, it can be concluded that it is not suitable for human consumption.	

Source: CAR [23]

3. Results and analysis

3.1. Comparative analysis of the results with Regulatory Decree 1076/15.

Table 5 shows the results obtained from the creek that is directly connected to the Bogotá River, which were also compared to the Regulatory Decree 1076 of 2015. After that, an analysis of each of the criteria evaluated is made.

Table 5. Normative analysis of the uses that are established in regulatory decree 1076 of 2015.

Criteria	Analysis
Conventional treatment and quality criteria for human and domestic consumption.	In relation to this use, the pH, Fecal Coliform Bacteria, and Total Coliform Bacteria parameters were evaluated, recording regulatory compliance for the pH, as it shows a neutral to slightly basic trend, being in accordance with the water quality requirements for human and domestic consumption. Similarly, a concentration of Fecal Coliform bacteria below the regulatory limit was recorded, which indicates that secondary treatment is not necessary for this component.
Disinfection and quality criteria for human and domestic consumption.	As for this use, the limit for pH is more restrictive; however, compliance with this parameter is recorded as well as for turbidity, this being an indicator in water quality since it allows processes such as photosynthesis and the development of aquatic life. For total coliform bacteria, the limit of 1000 NMP is exceeded by a wide margin, indicating that the load provided is too high for this use.
Quality criteria for agricultural use.	This use presents a wide range for pH as the value of this parameter is within the upper and lower limits; so for this use, the pH is not a limitation compared to the total coliform bacteria, which widely exceed the established limit. It is important to take into account that this type of water is used for irrigation of different crops and may have an effect on human health.
Quality criteria for primary contact recreational purposes.	The criteria established for primary contact water use are related to what is required in terms of pH; however, there is no agreement as per the limits given for fecal coliform bacteria and total coliform bacteria as they are exceeded by a wide margin, a fact that is connected to anthropogenic intervention, that is, domestic discharges interfering with this use.
Quality criteria for secondary contact recreational purposes.	Regarding the criteria established for secondary contact water use, it is evident that parameters such as pH and the percentage of oxygen saturation are within the guidelines that are established for this use; however, the microbiological load, which for this study exceeds the established limits, is taken into account.
Quality criteria for the preservation of flora and fauna.	For the use of Flora and Fauna preservation, it is of great importance to take into account the protection of the environment by maintaining the balance between the different species, so that in connection with this use, parameters such as pH and dissolved oxygen are within the stipulated water quality criteria.

Source: Prepared by the author, 2019

3.2. List of water quality indices (WQI) and water pollution indices (WPI) with respect to the physicochemical parameters

Tables 6 and 7 show the results that were obtained for the calculation of the WQI and WPI of the monitored surface water source in the area of influence of Cerro Manjui - Salto del Tequendama.

Table 6. Water quality indices for direct tributary creek

Place	Direct tributary creek of the Bogotá River
INDEX	Result
$I_{Conductividad}$	0,51
I_{DQO}	0,91
$I_{\% OD}$	0,78
ISST	0,95
$I_{NT/FT}$	0,60
IpH	1,00
RATING	Acceptable

Source: Prepared by the author, 2019

Table 7. Water pollution indices for direct tributary creek

Place	Direct tributary creek of the Bogotá River
$I_{Conductivity}$	0,49
$I_{Alkalinity}$	0,05
$I_{Hardness}$	0,72
ICOMI	0,42
Level of Contamination (ICOMI)	Medium
I_{DBO}	0,28
$I_{Total\ Coliform\ Bacteria}$	1,0000
$I_{\% OD}$	0,22
ICOMO	0,50
Level of Contamination (ICOMO)	Medium
ICOSUS	0,05
Level of Contamination (ICOSUS)	None
Total phosphorus mg/L	0,30
Category	Eutrófico
ICOTRO	0,50
Level of Contamination (ICOTRO)	Medium
ICOpH	0,01
Level of Contamination (ICOpH)	None

3.3. Comparison of the uses described in the EMP regarding the current state of water quality

The Environmental Management Plan issued by the Regional Autonomous Corporation called Corporación Autónoma Regional de Cundinamarca (CAR) in 2006 [23] [24], specifies the uses and establishes the characteristics according to the drainage system in the Salto del Tequendama - Cerro Manjui Integrated Management District. After the review is carried out and the characteristics of the current state are determined, we proceed to make a comparison where the main limitations at the time of destination of resource are addressed (Table 8).

4. Conclusions

Regarding the comparison with the standards, it can be seen that for the state of water quality, the only use permitted according to Regulatory Decree 1076 of 2015 [12], is that set forth in Article 2.2.3.3.9. 10, which establishes "Quality Criteria for the Preservation of Fauna and Flora", given that the parameter Total Coliform Bacteria limits the use of the water use, since it is a variable that considerably affects the destination of the water, it is necessary to take into account that, although total coliform bacteria limit the use of the resource, the total result obtained with the presence of Thermotolerant Coliform Bacteria (Fecal) is not attributed only to this fact, as its origin is linked both to the anthropic and the natural contribution, given the conditions of the water body and the environment. However, the high

levels of fecal coli-form bacteria indicate the deplorable state of some rivers in Colombia, due to the existence of wastewater discharges, and that much of the water in Colombian rivers is unfit for human consumption [25].

Table 8. Comparison of the water uses described in the EMP vs current water uses

Current State	EMP State	Observations
Water quality: Acceptable Contamination takes place due to the presence of solids that are dissolved in the water, and that come from different loads contributed by the surroundings and with anthropic origin. Water is slightly hard, meaning that when conducted through pipes, it generates incrustations. Similarly, the presence of total coliform bacteria is related to the reduction of the concentration of dissolved oxygen. For the rea-sons above, this water is not suitable for human consumption or domestic use due to the presence of micro-organisms.	Physical-chemical variables were established in order to catalogue the water as acceptable, and to relate in terms of physical variables and inorganic constituents why it is catalogued as acceptable; however, according to the table of laboratory results, the concentrations of organic and bacteriological constituents (fecal and total coliform bacteria) coming from the dis-charge of wastewater, raises these values at certain points, making us conclude that this water is not suitable for human consumption.	Physical-chemical variables were established in order to catalogue the water as acceptable, and to relate in terms of physical variables and inorganic constituents why it is catalogued as acceptable; however, according to the table of laboratory results, the concentrations of organic and bacteriological constituents (fecal and total coliform bacteria) coming from the dis-charge of wastewater, raises these values at certain points, making us conclude that this water is not suitable for human consumption.

Source: Prepared by the author, 2019

In general, it can be seen that in relation to what was proposed in the Environmental Management Plan for the Salto del Tequendama - Cerro Manjui Integrated Management District, the conditions that have been registered are linked to current physicochemical characteristics. For this reason, at pre-sent, this water cannot be used for human or domestic consumption, and is only being used for the conservation and preservation of flora and fauna, which makes it possible to demon-strate the anthropic intervention that this drain-age has had [23]. In this way, we seek to con-tribute to the proliferation of governance mod-els that stimulate the water management processes from the same territories, in order to quickly respond to conflicts regarding the planning, management, use, and handling of the resource [26].

From the present study, it is necessary to take into account a primary and secondary treatment that allows the reduction of microorganisms that consume available oxygen and the softening of these waters, and after that a third treatment that allows the removal of these agents that can be pathogenic and harmful in their destination.

Finally, it would be appropriate to point out that caring for the water resources in a timely and regular manner would provide the opportunity to avoid obvious and worrisome situations suffered in the past, and would ensure better luck in water matters by managing the resource in a responsible way, allowing to solve, in real time, any event that may be detrimental to the quality of drinking water or that poses a risk to the health of subscribers, without having to miss the natural benefits of the water cycle [27].

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