Evaluation of the Condition of Affluent of Aburra-Medellin River through Indices

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***Abstract*-This article evaluates and analyzes water quality of 21 streams tributaries of Medellin-Aburrá river, with the information obtained since 2004 in the project entitled "Network for Monitoring Water Resource at Aburrá Medellin River Basin, RedRío" executed between environmental authority "Area Metropolitana del Valle de Aburrá" and Universidad de Antioquia. This evaluation was performed through several water quality indices and allowed identifying the water bodies requiring immediate recovery actions. Among the indices considered, the ICACOSU (qualitative index) formulated by IDEAM in 2009, was evaluated; this index is a tool used by the Ministry of Environment and Sustainable Development to evaluate water resources in the entire country; it was then found that it is the least drastic tool. However, all indices showed a number of critical streams, but always including the following tributaries: La García and La Hueso. This latter stream is of special importance since different actions of the Wastewater Discharge Sanitation and Handling Plan have already been implemented. Finally, it should be noted that the application of each index will depend on the objective pursued in the study, and that the quantitative index obtained from the information measured in the basin streams is a good tool to make specific decisions on these water streams, since the biological component is involved and water bodies of the region with minor intervention are taken as a reference.**

Keywords- Water Quality; Streams; Aburrá-Medellin River; Indices

I. INTRODUCTION

Different regions of the world are being challenged by the lack of water for their own consumption due to its scarcity and poor quality. Necessary measures should be taken to decrease pollution and protect streams in order to assure their availability for present and future generations. In the search for evaluating necessary actions to recover water and the impact of measures taken, several monitoring programs have been implemented to achieve a systematic measurement of several parameters intended to evaluate water conditions; to make interpretation easier, relevant quality indices are formulated as a tool to have the community informed [1].

Since the emergence of indices in the 1960's with Horton, a methodology has been harmonized to determine the indices with three fundamental steps: selection of parameters, setting of a sub-index for each parameter, and sub-index aggregation formula [2-4].

With the purpose of interpreting the data obtained from samples, the use of water quality indices as practical tools to reduce the number of parameters to a simple expression for facilitating interpretation of results is an increasingly common practice today [5]. The index can be represented by a number, a range, an oral description, a symbol or even a color; for this reason, it is an important communication instrument to transmit information [6].

Indices can be used to improve and increase the information on water quality and its communication, without replacing the existing information disclosure means. According to the potential use, indices can be classified into six groups [7]:

- Resource management: in this case, these indices can provide information to people who make decisions about water priorities.
- Area classification: these indices are used to compare water conditions in different geographic areas.
- Application of norms: under specific situations of interest, these indices are used to determine whether or not existing environmental norms and policies have been exceeded.
- Tendency analysis: the analysis of indices within a period of time can indicate if environmental quality is diminishing or improving.
- Public information: these indices can be used in environmental awareness and education actions.
- Scientific research: these indices are intended to simplify a significant amount of data in such a way that data can be easily analyzed and have a clear vision of the environmental phenomena.

Water Quality Indices (ICAS, for its initials in Spanish) can be conceived, formulated, and described in different ways (quantitative and qualitative methods). Quantitative indices are based on numerical methods; qualitative indices are based on conceptual methods. Formulation with quantitative methods is performed through statistical and mathematical techniques, which generate an equation reflecting quality of an environment through a numerical result. Qualitative indices, instead,

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require concepts and valuations of different variables, which is translated in a selection of variables, a quality valuation of each variable in a conceptual manner with theoretical and theoretical-practical bases; then, variables are grouped and weighted within a group of parameters to obtain a percentage or fraction that represents quality of the resource, through a simple linear combination [8].

Indices are used worldwide to diagnose quality of water bodies under different techniques and types of quantification; some of them are limited to a specific space, but there are other ones that have always proven their theoretical solidity and validity of results; this allows their application in different sites and to different types of streams, as the case of the ICA WQI, formulated by the U.S. entity National Sanitation Foundation (NSF) [9]. This index has been successfully applied in different regions and streams around the world. At a local level, there are different Water Quality Indices formulated and adjusted to operate under specific environmental conditions in Colombia, such as the ICACOSU qualitative index formulated by IDEAM in 2009.

Using information obtained through Agreement 313 of 2005, Agreement 397 of 2009, and Agreement 421 of 2012, subscribed between Universidad de Antioquia and "Area Metropolitana del Valle de Aburrá" (environmental monitoring network at Aburrá Medellín river basin – RedRío-), an analysis of water conditions was performed in 21 streams tributaries of the river. This document describes the procedure executed to obtain a quantitative index; other indices were assessed and streams were classified according to their conditions and the need for executing recovery actions.

This document provides the following research question: Which are Aburrá valley streams that exhibit the most critical water quality conditions? In order to give response to this question, physical-chemical conditions of 21 streams tributaries of Aburrá-Medellin River should be evaluated through several indices; one of these indices was formulated through the information obtained from water bodies, including the biological component. Additionally, results of indices were compared and applicability of each index was suggested.

II. MATERIALS AND METHODS

A. Study Field

Aburrá valley is located in the central southern side of Antioquia (Colombia) in the middle of the Andes Central Cordillera. Its importance lies in the fact that Medellin City is located along this valley. Medellin is the country's third most populated and second most important city. Other nine municipalities are located along the valley; 3.7 million people live in the valley. This valley has a predominantly urban river that goes across ten municipalities and has become a center of activity for the historical development of the region [10].

Aburrá-Medellin river hydrographic basin consists of central and eastern branches of the Andes Central Cordillera [11] that elevate to heights ranging between 2,500 and 3,000 m.a.s.l. and separated by the river valley that runs in south-north direction. This valley extends from an elevation of 1,795 m.a.s.l. (Caldas) to an elevation of 1,048 m.a.s.l. (confluence with Río Grande) [10].

Climate of the basin is within the tropical climate or mountain equatorial climate, and is mainly characterized by two phenomena:

a) Slight variation of mean temperatures during the entire year. Colombia geographic location is within the tropical latitude region; this location implies that the country's temperature is defined by the meters above the sea level.

In Medellin, mean yearly temperature is 22ºC, with maximum and minimum temperatures of 29ºC and 16ºC, respectively. Normal temperature ranges between 18ºC and 26ºC.

b) Presence of two seasons of maximum rainfall, with two intermediate seasons with less rain [12].

Figure 1 shows a map with the location of the study site; this map was created based on two plans included in the POMCA (Aburrá River Basin Organization and Handling Plan).

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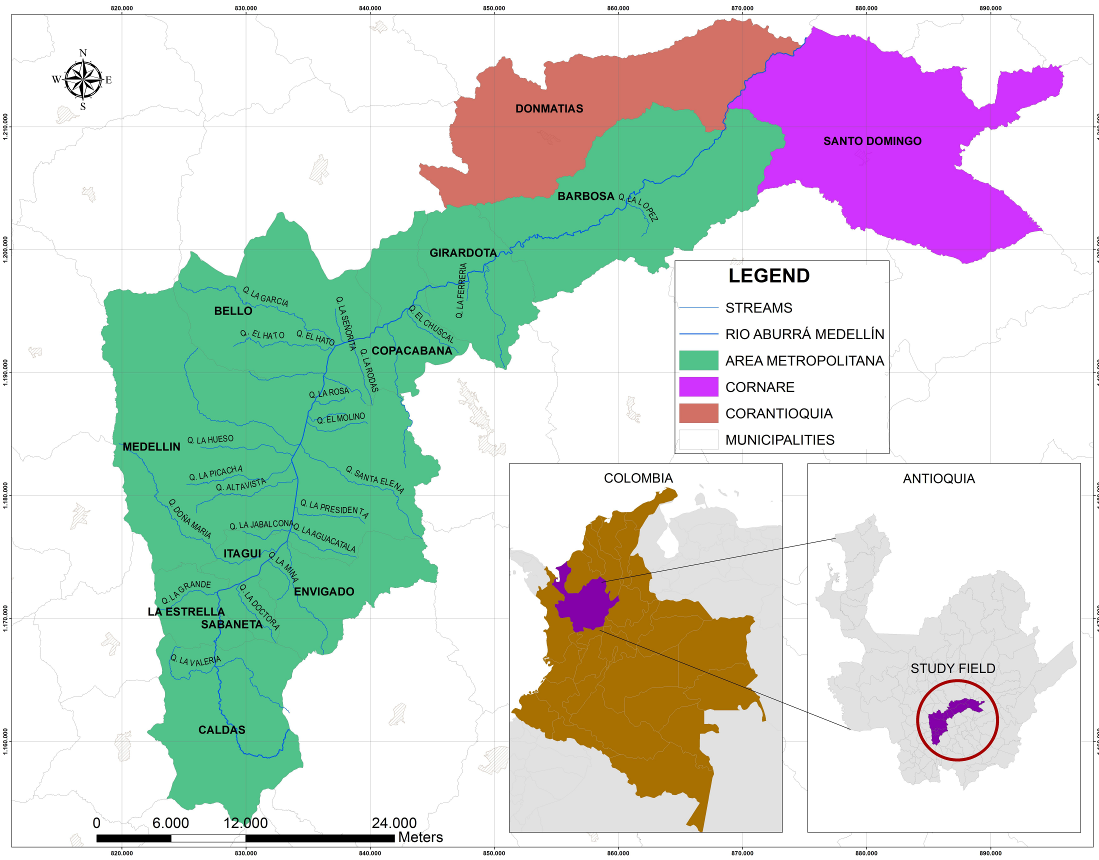

Fig. 1 Geographic location of the study area (Modification [13])

B. Field Procedure

Quality results used correspond to 10-hour sampling sessions, starting at 6:00 a.m. During these sessions, a sample in each stream was taken each hour; the sample was stored in two 2-litre containers.

C. Climate Conditions

Climate conditions during the sampling sessions varied, with rain of different intensity. Table 1 shows climate values during the sampling months, obtained from Weather Station 801100 (SKMD) located at Olaya Herrera Airport.

TABLE 1 CLIMATE CONDITIONS DURING SAMPLING DAYS

Phase	Sampling	Month	Mean Temperature (°C)	Rainfall (Mm/Month)
3	1	May 8, 2006	25.0	
3	2	May 30, 2006	25.0	
3	3	June 11, 2006	23.0	
3	4	June 27, 2006	23.0	
3	5	July 17, 2006	24.7	0.00
3	10	August 28, 2006	21.9	
3	11	March 17, 2010	21.0	3.01
3	12	March 23	26.1	0.00
3	13	April 14, 2010	24.1	29.97
3	14	April 21, 2010	24.8	0.00
3	15	April 28, 2010	22.4	6.10
3	18	September 8, 2010	21.2	2.03
3	20	September 22, 2010	21.6	7.11
3	25	August 3, 2011	21.4	7.87
3	26	August 31	25.6	0.00
4	2	October 24, 2012	23.8	0.51
4	3	October 31, 2012	22.6	26.92
4	4	November 14, 2012	23.3	28.96
4	8	March 6, 2013	25.5	0.00
4	10	May 22, 2013	22.1	8.89
4	15	July 31, 2013	25.4	4.06
4	17	September 18, 2013	23.2	0.25

NOTE: Blank spaces indicate the absence of daily measurement data.

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D. Experimental Procedure

Water sample collection, necessary for measuring physical-chemical variables in the water column was made according to the "Guide for Monitoring of Wastewater Discharge, Surface Water, and Groundwater" proposed by IDEAM (Institute of Hydrology, Meteorology, and Environmental Studies) [14].

Water samples collected were transported at 4ºC. Table 2 shows chemical variables and methods used.

TABLE 2 CHEMICAL VARIABLES ANALYZED IN THIS STUDY

Variable	Méthod (*)	Reference
Conductivity	Conductivity method	2510-B
pH	Electrometric method	4500-H+-B
Dissolved Oxygen	Electrometric method	
Total COD	Colorimetric method – Closed Reflux	5220-D
Total BOD5	Potentiometric method - Oxymeter – 5-Day Test	5210-B
Total Phosphorous	Colorimetric method – Ascorbic Acid	4500-P-E
Phosphates	Spectrophotometric method	4500-P-E
Organic Phosphorous	Spectrophotometric method	4500-P-E
Total Nitrogen	Titrimetric method - Macro Kjeldahl	4500-Norg-B
Nitrates	Electrometric method (nitrate selective ion)	4500 (NO3)-D
Nitrites	Colorimetric method – Ascorbic Acid	4500-NO2-B
Organic Nitrogen	Micro Kjeldahl – Titrimetric method	4500-Norg and NH3-C
Total Suspended Solids	Gravimetric method - Drying (103-105)ºC	2540-D
Total Solids	Gravimetric method	SM-2540-D
Total Fixed Solids	Gravimetric method	SM-2540-C

BMWP Col index was included within the analysis as the biological component; the index was estimated based on the collection of macro-invertebrates with the support of a screen net used for fordable sections and a triangular net for edge sweep. When micro-habitats present in each monitoring station were identified, stones were removed and turned to extract organisms. Sampling time per microhabitat was 5 minutes.

Content of nets is placed in a plastic container with water taken from the sampling site; net is turned over and rinsed with water from the container until it was found free of microorganisms. Before setting the sample and covering the container, stones, branches, and other materials are removed to facilitate their identification in the laboratory. These microorganisms are preserved in plastic containers with alcohol 70% and duly labeled and taken to the laboratory for relevant identification.

E. Processing and Analysis of Information for Formulation of Quantitative Indices

Data collected during the development of Phases III and IV of RedRío Project between 2010 and 2014 [15] were organized and tabulated for processing the information. Then, a number was assigned to each water body as shows in Table 3.

TABLE 3 CODES ASSIGNED TO STREAMS

Stream	Station
La Valeria	1
La Miel	2
La Doctora	3
La Ayurá	4
La Grande	5
La Aguacatala	6
La Presidenta	7
Altavista	8
La Hueso	9
Santa Elena	10
La Iguaná	11
La Rosa	12
La Madera	13
El Hato	14
Piedras Blancas	15
La Santiago	16
La Señorita	17
La Picacha	20
La Seca	21
Doña María	34
La García	35

In order to perform a statistical analysis that allows supporting and consolidating the validity of indices, the following steps were taken: Definition of water quality parameters; validation of data to check atypical values; statistical evaluation of data normalness and homoscedasticity; and factorial analysis on the Statgraphics Centurion XV software [16].

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1) Definition of Variables:

In order to define variables, a correlation analysis of different parameters that were measured in the streams by using Spearman correlations was performed.

Biological component BMWP-Col was taken into consideration for the selection of variables; this biological component corresponds to a biological indicator of water quality (this indicator shows the ecologic quality and integrates the impact of different stress factors), which measurement is important to monitor the communities of macro-invertebrates. During the application of the BMWP-Col Index the water macro-invertebrate families were classified in 10 groups following a gradient from lower to higher tolerance to pollution [17]. The use of this index requires the allocation of a score to different families of water macro-invertebrates and each family is located in a value scale ranging between 1 and 10, where the highest value is given to the families that are more sensitive to pollution; the lowest values are assigned to the families showing more tolerance. Total summation of values indicates the community biological quality and corresponds to a specific class, as shown in Table 4 [18].

TABLE 4 QUALITY CLASSES. MEANING OF BMWP-COL VALUES

Quality	Value	Meaning	Color
Good	>150 101-120	Very clean water Unpolluted or not very altered water	Blue
Acceptable	61-100	Some pollution effects are evident	Green
Suspicious	36-60	Polluted water	Yellow
Critical	16-35	Very polluted water	Orange
Very critical	<15	Seriously polluted water	Red

2) Data Validation to Check Atypical Data Selection:

Results of significant variables in compound samples were taken from selected samplings and tabulated in a matrix which classification factors were organized into hierarchies by sampling and station; then, revision of atypical data was performed.

3) Statistical Evaluation of Data Normalness and Homoscedasticity:

Validation of data is completed with a univariate analysis, where data distribution and form are observed; that is, asymmetry and homoscedasticity (homogeneity of variances) are evaluated through the normal probability graph, the Goodness of Fit test, and the Bartlett's test (analysis of variance) on Statgraphics Centurion.

4) Factorial Analysis:

A factorial analysis was performed to reduce size of data and find non directly observable factors that explain the variables observed losing minimum information (quantitative index), in such a way that they can be easily interpreted, with minimum directly observable factors. Factorial analysis is a data reduction technique used to examine interdependence of variables; it allows knowing the underlying data structure.

5) Analysis of Variance Components and Contrast Tests:

Once the quantitative index was obtained through the factorial analysis, the factor of highest influence (sampling, station) on data variability was found; differences among sample medians were established by using the Kruskal Wallis test.

The entire data processing for the index structuring was performed with the statistical package Statgraphics Centurion XV.

F. Information Processing for Estimating the Quality Index for Surface Water (ICACOSU; [19])

Formulation of ICACOSU Quality Index is based on a qualitative concept and on the following procedures:

- Selection of parameters.
- Establishment of values for each parameter: Sub-indices.
- Establishment of the index for addition of sub-indices.

ICACOSU Index reduces several field and laboratory data to a numerical value (zero and one); this value is classified according to water quality in an ascending order within one of the following categories in terms of quality: Very bad, bad, fair, acceptable, and good (Table 5).

The index value is derived by using an extensively tested model, which compares field data with specific water quality objectives for the site (safe boundaries and norms to protect specific use of a water body).

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TABLE 5 VALUATION OR MEANING OF ICACOSUS INDICES

Classification of Water Resource Quality	Numerical Range of Values	Color
Good	0.91 – 1.00	Blue
Acceptable	0.71 – 0.90	Green
Fair	0.51 – 0.70	Yellow
Bad	0.26 – 0.50	Orange
Very Bad	0.00 – 0.25	Red

G. Information Process for Estimating Surface Water Quality Index (ICOSUS)

This is established from concentration of suspended solids that generally make reference to inorganic compounds. The pollution index per suspended solids (ICOCUS) is presented as follows:

$$ICOSUS = -0{,}02 + 0.003\ SS \quad (1)$$

Where the Index takes a value of 1 if SS > 340.0 mg/L; index is 0 if SS < 10.0 mg/L [20].

Valuation or meaning in terms of the degree of pollution of analyzed water bodies, according to values estimated with expressions above, is shown in Table 6.

TABLE 6 VALUATION OR MEANING OF ICO'S

Ico	Degree of Pollution	Color Scale
0 - 0,2	None	Blue
> 0,2 - 0,4	Low	Green
> 0,4 - 0,6	Medium	Yellow
> 0,6 - 0,8	High	Orange
> 0,8 - 1,0	Very High	Red

H. ICOTRO

The Trophic Pollution Index is based on total concentration of phosphorous and its classification is made based on values of Table 7; it should be noted that assignation of colors is made as an exercise to compare indices evaluated in this paper [8].

TABLE 7 ICOTRO VALUATION

Phosphorous	Degree of Pollution	Color Scale
< 0,01 mg/L	Oligotrophic	Blue
0,01 – 0.02 mg/L	Mesotrophic	Green
0,02 – 1 mg/L	Eutrophic	Orange
>1 mg/L	Hypertrophic	Red

III. RESULTS

21 streams evaluated are part of Aburrá-Medellin river basin; their distribution by municipalities is shown in Fig. 2. Figure 2 shows that the highest percentage of streams under study is located in Medellin and Bello municipalities.

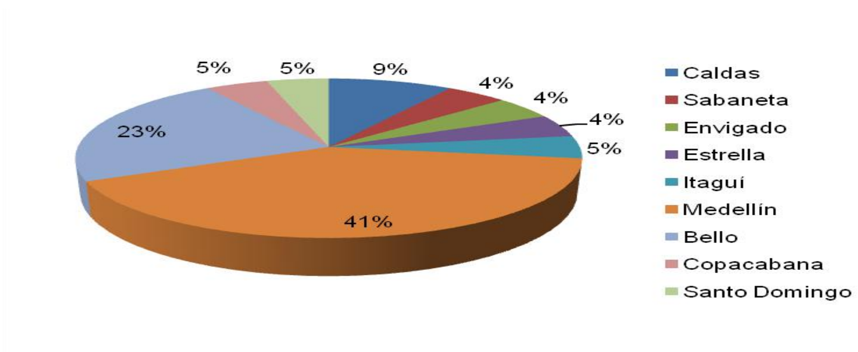

Fig. 2 Distribution of Streams Evaluated by Municipalities

A. Exploratory Analysis of Stations

Similarities of mean and median values are not observed in parameter estimators; difference of solids is the highest parameter; this indicates a significant variability of this parameter. According to kurtosis values, very few variables show a

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normal distribution. Additionally, with the minimum and maximum values of each variable, water quality variability of the region's streams (Table 8) is clearly seen.

TABLE 8 CONSOLIDATED ESTIMATORS FOR THE GROUP OF STREAMS

	Average	Median	Standard deviation	Coefficient of variation	Minimum	Maximum	Standard Skewness	Standard Kurtosis
pH	8.002	7.900	0.561	7.01%	6.700	10.20	8.867	12.368
OD	5.771	6.245	1.559	27.01%	1.000	8.09	-4.698	0.346
Conductivity	279.609	249.450	159.558	57.06%	52.600	636.70	2.014	-2.210
DBO	74.466	46.100	86.155	115.70%	1.000	412.40	9.622	10.616
DQO	171.617	118.100	154.975	90.30%	1.000	751.90	6.214	3.607
Ptotal	2.647	1.851	2.689	101.59%	0.001	16.67	9.136	12.784
PO4	1.273	0.752	1.347	105.83%	0.001	5.91	5.990	1.925
Porg	0.841	0.408	1.403	166.75%	0.001	10.28	19.229	47.387
NO3	0.680	0.302	1.019	149.88%	0.000	5.94	14.709	26.814
NO2	0.097	0.043	0.163	167.80%	0.001	1.13	16.976	36.084
Norg	6.434	4.320	5.949	92.47%	0.000	26.20	5.591	1.735
NTK	13.569	10.650	12.179	89.76%	0.000	47.70	4.667	0.170
SST	476.512	162.215	688.205	144.43%	4.000	3181.00	10.251	10.253
ST	732.222	429.000	816.486	111.51%	53.000	3998.00	10.017	9.875
SDT	214.870	146.000	217.309	101.14%	11.000	1300.25	11.813	17.492
SVT	190.287	173.000	148.405	77.99%	0.000	1302.50	16.108	52.761
SFT	582.775	250.300	741.572	127.25%	22.000	3568.00	10.265	10.089
BMWP Col	10.043	6.000	13.035	129.79%	0.000	80.00	12.044	19.846

B. Definition of Variables

When a correlation analysis was performed, it was found that variables such as pH, NO_2, NO_3, ST, SST, SFT, and SVT showed less correlation with remaining variables; that is, for this group most correlation evaluations showed *p* values above 0.05, which indicates that there are no statistically significant correlations of each variable with remaining ones.

C. Factorial Analysis

When factorial analysis was performed with the data matrix from 21 streams studied, it was found that data should be transformed and the logarithm was the transformation that validated the two assumptions.

TABLE 9. FACTORIAL ANALYSIS FOR LOW WATER VOLUMES

FACTOR NUMBER	VARIANCE PERCENTAGE	ACCRUED PERCENTAGE
1	87.73	87.73
2	7.46	95.19
3	3.75	98.94
4	0.79	99.73
5	0.27	100.00

According to the factorial analysis performed, only one linear combination of parameters accounts for 87.73% of data variability (Table 9); then, other two combinations are ruled out and an index is obtained (factor – quantitative index) that should only be used to evaluate these streams. As a result, the following equation was obtained:

Quantitative ICA = -0.469002*(LOG(OD)) + 0.766595* (LOG(Conductivity)) + 0.947927* (LOG(DBO)) + 0.923625* (LOG(DQO)) + 0.895183* (LOG(Ptotal)) + 0.867778* (LOG(PO4)) + 0.706673* (LOG(Porg)) + 0.846893* (LOG(Norg)) + 0.944554* (LOG(NTK)) + 0.505594* (LOG(SST)) - 0.335683* (LOG(BMWP Col))+21,1.

Where, values of variables in the equation are normalized subtracting their means and dividing by their standard deviations.

When index for each stream was estimated, their variation range was analyzed and ranges with the same increase were proportionally distributed and the highest range was kept open in order to include atypical values that emerge from time to time.

Table 10 shows the classification according to the numerical value and relevant color code for the quantitative index that showed better qualification in terms of quality at lower values and as such values increase water quality deterioration occurs.

TABLE 10 CLASSIFICATION OF WATER QUALITY ACCORDING TO THE NUMERICAL VALUE OBTAINED FROM THE WATER QUALITY INDICATOR AND ITS COLOR CODE

Classification of Water Quality	Numerical Range of Values	Color
Good	<=4,40	Blue
Acceptable	4,41 – 8,80	Green
Fair	8,81 – 13,20	Yellow
Bad	13,21 – 18,70	Orange
Very Bad	>18,71	Red

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Based on the factor (index) obtained, the index for each stream was evaluated during different samplings; graphic results are shown in Fig. 3.

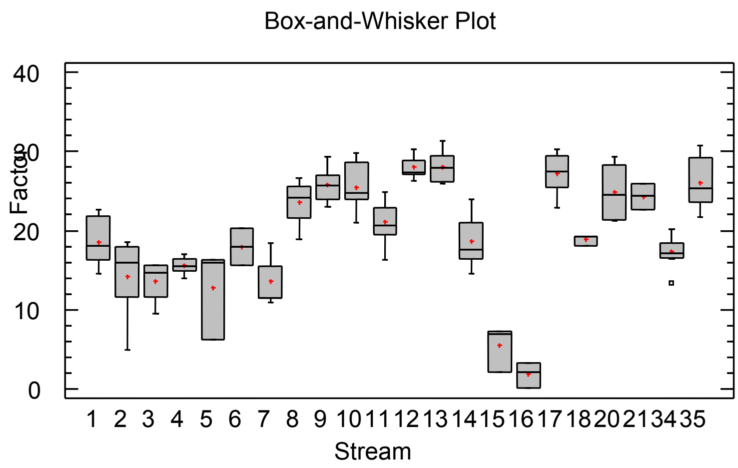

Fig. 3 Box and Whisker Plot for the Quantitative Index (Factor) in 22 Monitored treams

Taking assigned quality as a reference and interpreting results of Fig. 3 the following classification was obtained:

TABLE 11 CLASSIFICATION BY RANGES ACCORDING TO VALUES OF INDICATORS

Quality	Streams
Good	La Santiago, Piedras Blancas.
Fair	Doña María, El Hato, La Doctora, La Miel, La Ayura, La Grande, La Aguacatala, La Presidenta.
Bad	La Valeria, Altavista, Santa Elena, La Iguaná, La Picacha, La Seca.
Very Bad	La Hueso, La Rosa, La Madera, La Señorita, La García, Rodas.

From Table 11 should be noted that streams showing better quality are located in the north: Copacabana (Piedras Blancas) and Santo Domingo (La Santiago), while those showing poor quality correspond to streams located in Medellin and Bello; some of them, such as La Señorita and La García, show a deficient implementation of the Wastewater Discharge Sanitation and Handling Plan.

D. Analysis of Variance Components and Contrast Tests

In order to identify which factors (sampling or stream) showed the highest influence on data variability, the analysis of variance components was made for the index; it was found that "stream" was the factor with the highest influence on the variance (50.47%) followed by "sampling" (Table 12).

TABLE 12 ANALYSIS OF VARIANCE COMPONENTS

Factor	Percentage
Sampling	25.68
Stream	50.47

Since "stream" factor showed the highest influence on data variability during the analysis of variance components, the Kruskal-Wallis test was applied and some differences among streams were found; with the Multiple Range Test ten groups were obtained and then redefined into five groups since some of them were repeated in different groups and showed similarities concerning use of soil and water (Table 13).

TABLE 13 MULTIPLE RANGE TEST (LSD)

Group	Streams
1	La Santiago, Piedras Blancas.
2	La Grande, La Presidenta, La Doctora, La Miel, La Ayura.
3	Doña María, La Aguacatala, La Valeria, El Hato, Rodas, La Iguana.
4	La Picacha, Santa Elena, La Seca, La Hueso, Altavista.
5	La García, La Señorita, La Madera, La Rosa.

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E. BMWP Col

According to the biological quality index BMWP Col (Table 4), the 21 streams under study are distributed in three biological quality groups, as shown in Table 14.

TABLE 14 CLASSIFICATION ACCORDING TO BMWP COL VALUES

Quality	Streams
Suspicious	La Santiago, Piedras Blancas.
Critical	La Miel, La Ayura, La Grande.
Very Critical	La Aguacatala, La Presidenta, Doña María, El Hato, La Doctora, La Valeria, Altavista, Santa Elena, La Iguaná, La Picacha, La Seca,La Hueso, La Rosa, La Madera, La Señorita, La García.

F. ICACOSU

Once the data matrix was organized, the ICACOSU Index was calculated for each water body, and results shown in Table 15 were obtained.

TABLE 15 CLASSIFICATION ACCORDING TO THE ICACOSU INDEX

Quality	Streams
Acceptable	La Santiago, Piedras Blancas.
Fair	La Valeria, La Miel, La Doctora, La Ayurá, La Grande, Doña María, La Aguacatala, La Presidenta, Rodas.
Bad	Altavista, Santa Elena, La Hueso, La Iguaná, La Rosa, La García, La Madera, El Hato, La Señorita, La Picacha, La Seca.

G. ICOSUS

When the ICOSUS Index was calculated, it was found that four streams (La Hueso, La García, El Hato, and La Picacha) showed a high degree of pollution associated to content of solids (Table 16).

TABLE 16. CLASSIFICATION ACCORDING TO THE ICOSUS INDEX

Degree of Pollution	Streams
None	La Miel, La Doctora, La Aguacatala, La Presidenta, La Santiago, Piedras Blancas, Rodas.
Low	La Valeria, La Grande, Santa Elena, La Iguaná.
Medium	La Ayurá, Doña María, La Rosa, La Madera, La Señorita, La Seca.
High	Altavista.
Very High	La Hueso, La García, El Hato, La Picacha.

H. ICOTRO

When trophic state was classified according to content of phosphorous, only two groups of streams that were classified as hypertrophic and eutrophic were found. However, it should be noted that La Santiago stream obtained a value of 0.03; that is, this stream shows water with the minimum content of phosphorous (Table 17).

TABLE 17. CLASSIFICATION ACCORDING TO THE ICOTRO INDEX

Degree of Pollution	Streams
Eutrophic	La Doctora, La Ayurá, La Grande, La Aguacatala, La Presidenta, Piedras Blancas, La Santiago, Doña María, Rodas.
Hypertrophic	La Miel, La Valeria, Altavista La Hueso, Santa Elena, La Iguaná La Rosa, La Madera, El Hato, La Señorita, La Picacha, La Seca, La García.

As an attempt to view the spatial distribution of studied streams associated to the quality indices, a plan was prepared (Figs. 4 and 5) where a circular plot is used to show results of quantitative index, ICACOSU and BMWP Col.

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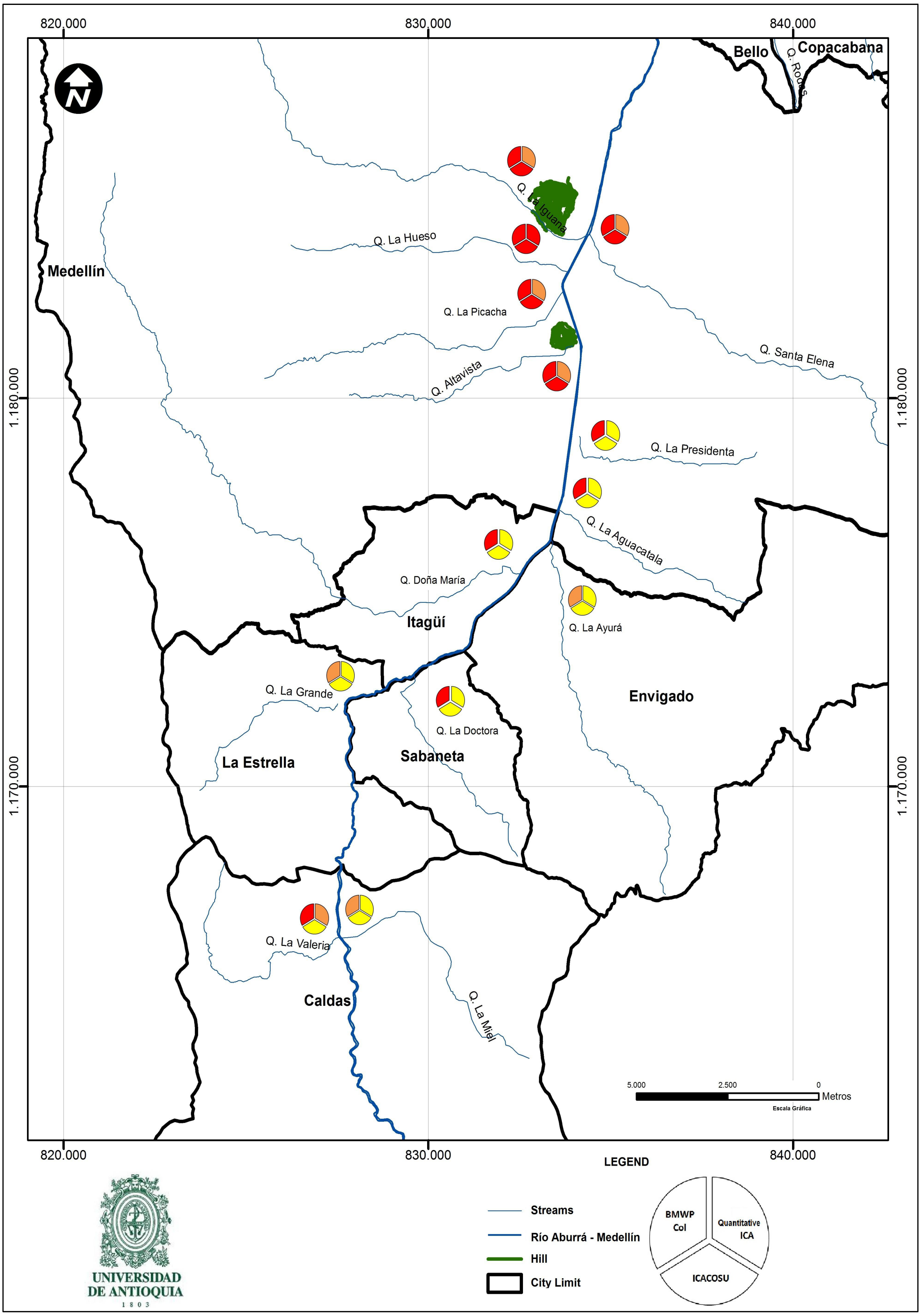

Fig. 4 Spatial Results of Quality Indices in Studied Streams, Central South Area

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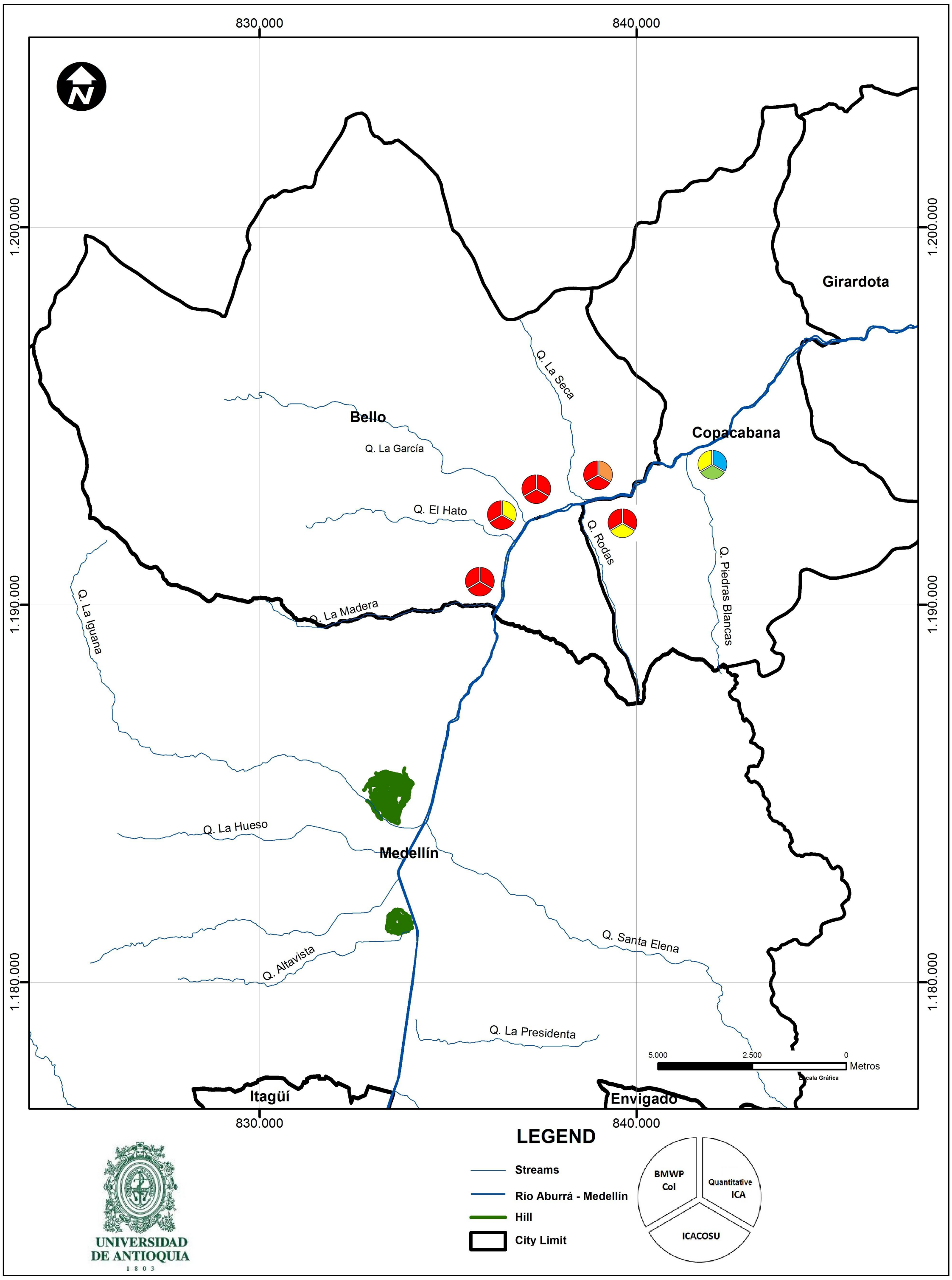

Fig. 5 Spatial Results of Quality Indices in Studied Streams, North Area

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I. Problems with the Surface Water Resource

According to results obtained with evaluated indices and the knowledge of studied streams, the problems found to be generally associated to the entire water resource of the region were summarized:

1) Water Pollution Due to Direct Discharge:

Despite the progress in the implementation of the Wastewater Discharge Sanitation and Handling Plan, direct discharges in water bodies are still detected (Picture 1).

"La García" Stream

"El Hato" Stream

Picture 1 Direct Discharge in Streams

2) Improper Solid Waste Disposal:

The improper disposal of solid and special wastes is a problem that significantly affects water (Picture 2).

"La García" Stream

"La Hueso" Stream

"Altavista" Stream

"La Señorita" Stream

Picture 2 Improper Disposal of Solid and Special Wastes in Aburrá-Medellin River

3) Exploitation of Construction Material:

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Exploitation of construction material is an activity developed in some streams, and this is not always a legal or environmentally audited activity (Picture 3).

"Ana Diaz" Stream, affluent of "La Hueso" Stream

"La Hueso" Stream

Discharge in "El Hato" Stream

"La García" Stream

Picture 3 Extraction of Construction Material in Stream

4) Uncontrolled Occupancy:

The accelerated and unplanned urban growth at the water rounds (frontier of protection that should cushion the immediate frenzy and often unconcerned about the man to occupy and exploit nature) results in river soil instability and this produces landslides and overflows (Picture 4).

"La García" Stream

"La Rosa" Stream (September 1st, 2011)

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“El Hato” Stream	“La García” Stream

Picture 4 Pictures on Occupancy of Water Rounds

Note: Pictures obtained since 2004 in the project entitled “Network for Monitoring Water Resource at Aburrá Medellin River Basin, RedRío” executed between environmental authority “Area Metropolitana del Valle de Aburrá” and Universidad de Antioquia.

IV. DISCUSSION

After the statistical analysis a quantitative (statistical) index that includes information of 21 streams which environmental state vary was obtained; streams such as La Hueso, La Rosa, La Madera, La Señorita, and La García were outstanding for their serious deterioration and because they require prompt actions to recover the ecosystem balance. Additionally, it was found that variation of data matrix is more associated to the 21 streams and the use of the resource than to time (that is, to the dates monitoring samplings were performed) (climate conditions).

Based on the information shown in Fig.3, streams such as La Grande, La Picacha, Miel, Valeria, and García exhibit the widest variation range, which is associated to water quality variations obtained during the study; therefore, they are responding to climate conditions; La Grande stream, however, shows less repetitions, which can be impacting the variability results.

In general terms, according to the results obtained with indices from 21 evaluated streams, La Santiago and Piedras Blancas show the best quality; all other streams exhibit pollution and the following streams show the poorest water quality: La Hueso, La Rosa, La Madera, La Señorita, and La García; similar results were found by Beamonte E. *et al.* [21] when several indices at Júcar river basin (in Spain) were compared. In this study, classification of stations -with very good and very bad qualities- coincided, which validates the use of indices.

In relation to content of solids, the most impacted streams were La Hueso, La García, El Hato, and La Picacha as consequence of the exploitation of materials at the high sites; therefore, quality variation, in terms of content of solids in these streams, depends on the demand of materials (Picture 3). This situation demonstrates how important it is to take measures to apply good practices in this type of activities. Despite these activities are deemed as legal, they should be performed in a sustainable manner in order to keep balance at each ecosystem and assure the responsible use of this resource.

Concerning the biological component, it was found that neither stream showed good quality; this indicates that no families with a high-quality score were found; however, streams such as La Santiago and Piedras Blancas are remarkable due to their quality and acceptable qualification; this can be associated to the best physical-chemical quality of them; in all other streams the velocity effect and the organic discharges from wastewater only allow the survival of few families that became adjusted to the physical and chemical properties. Similar results in relation to the existence of a strong relationship between physical-chemical quality and biological quality was also observed in Febros River in Portugal by Bio A. et al. [22] and in Xindian basin by Narangarvuu D. *et. al* in 2014 [23]; in these cases, it is clear how human activities impact water quality and habitats, eliminating non-tolerant species. This reduces diversity of the rivers.

Additionally, it was determined that 21 streams show high content of phosphorous for the entry of home wastewater in most of them; however, La Santiago stream shows a different situation since the values found are due to agricultural and livestock breeding practices within its area of influence. For this reason, groups corresponded to eutrophic and hypertrophic waters. It should be noted that results found at Doña María stream match those found by Jiménez M. and Vélez V. [24].

This shows the direct relationship between use of soils and water quality, this latter being a response to the progress of sanitation plans and water conservation programs. This relationship was also observed by Recatalá L. and Sacristán D. [25], in their study in Mediterranean Europe; these results were published in 2014 and they recommend a number of indices obtained from the multivariate statistics that can be useful to predict and control environmental impact on natural resources as response to planning instruments; they also clearly show the relationship between use of soil and water quality in streams, taking into account the weights of variables in the first main component obtained.

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In general, taking the groups of streams obtained with indices as reference, the BMWP Col index is the most demanding one; this is due to the fact that good water quality conditions are required for the survival of some families of macro-invertebrates, followed by the ICOTRO index associated to pollution with phosphorous; then we have the quantitative index and the ICOSUS index. Contrarily, the least demanding index is the ICACOSU; according to this index, neither stream shows conditions rated as “very bad” or “critical.”

Based on the results found, the definition of the most adequate index depends on the objective pursued; for example, if one wants to value a specific event in a water body located in Aburrá valley, a quantitative index is recommended; if the intention is to evaluate the state of a stream in comparison with the state of all streams in the entire country, BMWP Col, ICACOSU, ICOSUS, and ICOTRO indices are the choice; these indices exhibit different objectives. If one wants to determine the impact by content of solids, the ICOSUS index is the adequate index to be used; but if the presence of nutrients is under evaluation, the ICOTRO index is the choice. Life in water is evaluated with the BMWP Col index. The ICACOSU is an integral index to evaluate the general conditions of a stream from the physical and chemical point of view, given that it includes several parameters for this determination. Based on the results and taking applicability of each index into consideration, it is possible to affirm that these indices frequently used in Colombia to evaluate water quality are in compliance with basic requirements, as proposed by Terrado M. et al. [26], such as: synthesis capacity, easy application, sensitivity to changes in water, and capacity to achieve a reasonable balance between reality simplification and environmental complexity.

Taking into account the evaluation obtained with this group of indices, the strong impact on the region’s streams due to solid and special waste discharges should be noted; in addition to the occupancy of the water rounds, which generates certain alarms during winter. This ratifies the immediate need for executing certain actions associated to the education on waste handling included in the Solid Waste Management Plans executed by different municipalities, since it has been observed that these plans are not responding to expectations or have not been implemented. It establishes that formulation and implementation of awareness and education campaigns for water protection in the region through the “Plan de Ordenamiento del Recurso Hídrico en la cuenca del río Aburrá – Medellín” are mandatory. In relation to this plan, it is worth mentioning that Universidad de Antioquia is currently formulating it through the “RedRío” Project.

These actions, together with the execution of the Wastewater Discharge Sanitation and Handling Plan, will allow witness the recovery of ecosystems and surface water in the region. Authors such as Ocampo W. et al. [27], after evaluating water quality through indices, have proposed an intensive protection program to be executed by regional and national governments as an attempt to recover the Cauca river ecosystem.

When municipalities are associated to the results found in indices, it has been found that Bello and Medellin are the municipalities exhibiting the most deteriorated streams mainly due to the pollution with waste waters; this is the result of a deficient progress of infrastructure works contemplated in Empresas Públicas Sanitation and Waste Handling Plan, compared to the positive progress seen in municipalities located in the south area of Aburrá valley.

An emphasis has been made on the fact that the levels of pollution on the main riverbed of Aburrá-Medellin River are a response of physical and anthropic processes developed in each one of their affluent streams. The implementation of measures to improve quality of streams to recover the river is a need, since this river is deemed as a reference of the city and the development center of the region.

Finally, it should be noted that during the last days the use of these water bodies and the use of their banks or bridges as sites to live for homeless people have been more evident; this increases the problem even more since most people from this population lack good water protection sensitivity.

V. CONCLUSION

The use of water quality indices is a good alternative for informing the community the state of a current, however, it is necessary to define the objective of the applied index, since each one expresses a different state of water quality and it is important to clarify this fact so the community may interpret it and it is not misunderstood.

The index obtained using multivariate analysis from the information of currents is deemed integral because it meets chemical and biological parameters; besides, water quality state is obtained from measured streams; however, to refine this linear combination with data from other measurements in different places of the streams has been suggested as a future need.

As a result of indices application, it was found that streams with less advancement in sanitation works in the region, have a more deteriorated water quality. The need for implementing “solid waste integral management plans – PGIRS” was also evidenced in each municipality in order to prevent that wastes go to water, and the need for taking measures for establishing an exploitation of beach material with good practices in such a way that the impact of this activity is minimized.

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VI. ACRONYMS

The following is a list of meanings to water related acronyms:

pH	pH
OD	Dissolved oxygen
Conductivity	Electric conductivity
DBO	Oxygen Biological Demand
DQO	Oxygen Chemical Demand
Ptotal	Total Phosphorus
PO4	Orthophosphates
Porg	Organic Phosphorus
NO3	Nitrogen with nitrates
NO2	Nitrogen as nitrites
Norg	Organic Nitrogen
NTK	Kendal Total Nitrogen
SST	Total Suspended Solids
ST	Total Solids
SDT	Total Dissolved Solids
SVT	Total Volatile Solids
SFT	Total Fixed Solids
BMWP Col	Biotic index: Biological Monitoring Working Party score

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