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DEVELOPMENT OF INDEX OF RESILIENCE FOR SURFACE WATER IN WATERSHEDS

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Abstract: This work aimed to propose an instrument to represent the sensitivity, fragility, adaptability and the risk of pollution of water resources, by measuring and identifying indexes and indicators that assign characteristics to a certain area (basin). This research consists of three steps: the first was based on the recollection of data needed to execute this proposal. The second, we applied the used indexes and indicators into this research. The third sought to determine, identify and understand the impacts produced, the fragility generated to ecosystems due to pollution levels found. Through this methodological proposal, we sought to know the changes of the resistance potential, the negative impact on aquatic ecosystems and the ease in which they can be self-Debug-water resources. It was indicated that the resilience index of surface water resources (IR), in which he presented are examples applied in two watersheds, highlighting that this index can be applied at any scale.

Keywords: Adaptability, Environmental Modeling, indicator, self-purification.

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INTRODUCTION

The implementation of indices and indicators to measure the states, trends and developments of natural resources, be it water, soil and air are becoming a recurring concern in recent years, especially since the emergence of the concept of sustainability (Carvalho, 2008).

The methodology of this article is to suggest an improvement in the approach and measurement of the sensitivity of surface water resources due to human activities, taking into account inherent characteristics of a given study area that could help reduce environmental degradation.

In this sense, concepts such as biodiversity conservation are not included in the concept of “territorial development”, as ecosystems both terrestrial and aquatic, can influence the changes in a small or large magnitude, which affect its normal ecological development.

In regards to the conceptual aspect, the practical applications of the knowledge and the measurement of sustainability, resiliency index provides greater accuracy as well as statistical information on the availability of important requirements for testing environmental breakdown of the spatial point of view and multi-time. This index is of great importance since it evaluates actual data of pollution and the adaptation of other factors distinct to each area of study in order to identify the weakness it causes and its potential resistance to change, the negative impact on aquatic ecosystems and the ease with which they can self-evaporate.

The functionality of features of the proposed index are based on measurements and parameters applied in an environmental study, thus, to demand a performance that is as close as possible to the reality of the current situation of pollution in water resources, thus simplifying the values of the studies, efforts and communication processes, as well as the perception of the results in order to be understood and used efficiently.

Precisely, this indicator is used to test the levels of pollution in water bodies, thus, identifying the actions of pollutants found in the ground, it is also to help finding and prioritizing actions to establish resilience in the shortest time possible. The importance of this indicator is justified to inform decision makers or users on the interrelationships of natural dynamic systems on the physical elements, biological, social and economic due to human activities, being an excellent scientific information tool to the public, contributing to the understanding of environmental problems.

Finally, the resilience index of surface water resources (IR) aims to contain features that are easy to understand, easy to interpret, accurate, simple, specific and accessible. Above all, it must have a relevant meaning; it must be scientifically valid, reproducible and able to be applied in any country, on any scale.

MATERIALS AND METHODS

Through qualitative and quantitative data, can qualify a region, depending on your own risk, and assign a value to the susceptibility to pollution process which carries negative changes in water resources, where to obtain direct measurements can reach diagnoses could in the future be a difference in water management. Viewing a trend of the current situation with regards to the minimum criteria and trying to predict in advance the final results of the environmental impacts of a studied area.

Due to these factors, the following variables were chosen to compose the proposed index; Water Quality Index (WQI), Urban area (u), Flow/inhabitants (C/h), Anthropogenic Transformation Index (ATI) and the Slope (m). The choice of these variables was made because in them condense the actual values that contribute to pollution and the pressure that the main human actions have on the quality and quantity of water, land use and occupation and the inherent natural features that could change the composition physical, chemical and biological water resources.

Description of variables

Water quality index (WQI)

Water quality, surface or ground depends both on natural factors as well as the human action.

In general, the quality of water is an important guideline for the evaluation of environmental impacts. In the case of drinking water, standards are established to ensure a supply of clean, healthy water for human consumption and thus protect human health. These standards are usually based on scientifically acceptable levels of toxicity to both humans and to aquatic organisms, hence the importance of WQI.

The Water Quality Index (WQI) is determined by the weighted product of nine parameters of water quality indicators corresponding to the parameters: sample temperature, pH, dissolved oxygen, biochemical oxygen demand (5 days, 20°C), fecal coliform, total nitrogen, total phosphorus, total residue and turbidity. The following formula is **Eqs (1)** and **(2)**:

$$QA = \prod_{i=1}^{n} qi^{wi} \qquad (1)$$

where WQI = Quality Index of Waters; qi = quality of the i-th parameter, a number between 0 and 100, obtained from their "mean curve of quality variation", due to its concentration or measure and; wi = weight corresponding to the i-th parameter, a number between 0 and 1, allocated on the basis of their importance to the overall conformation of quality.

Indicating the number of parameters included in the calculation of the WQI.

$$\sum_{i=1}^{n} wi = 1 \qquad (2)$$

Indicating the number of parameters included in the calculation of the WQI.

In the case of not having a value of some of the nine parameters, the calculation of the WQI is made impossible.

The quality of raw water, as indicated by WQI, on a scale of 0 to 100, can be classified to the public supply, according to the scale shown in **Table 1**. The value of this index is used for an average of all samples.

Urban area (u)

According Domenech (2008), although the urbanization play a central role in the development process, urban growth often leads to a deterioration of environmental conditions. This is due to population growth, commercial, industrial and those who have the use of resources, thus creating a point of overload the capacity of natural systems.

Pedregal *et al.* (2007) state that when we speak of the urban environment, it is necessary to introduce the concept of the environment interacting with the urban processes, but in a friendly way. Unfortunately, the increase in population has come to increase the pollution problems, to create a deficit in resources (water, drainage, energy, etc.), reducing its quality. One of the most common problems is the pollution of water resources for domestic sewage water, since most of this water comes from the population living in urban centers, which dump their waste in surface water.

To know the exact values of the amount of urbanized area in the study area, there are multiple satellite imaging applications, which make it much easier to collect data needed to integrate this variable to the proposed index, with a fast and effective method.

The other is through direct observation of the study area, by letters registered or aerial photographs, however this can only be applied to small-scale areas. Then, divide the urbanized area obtained by total area, or if the value is a percentage, divide 100% of the urbanized area found.

Table 1 - Water quality range indicated by the WQI

Quality	value of the WQI
Great	$79 < WQI \leq 100$
Good	$51 < WQI \leq 79$
Fair	$36 < WQI \leq 51$
Poor	$19 < WQI \leq 36$
Extremely poor	$WQI \leq 19$

Source: CETESB (2004)

Flow/inhabitants (v/h)

The flow variable plays a very important role, because to know the flow, according SEMASA (2007) also know their potential for self-purification. If we know the number of inhabitants in the study area, we will determine availability of water and also the pressure on this resource. The ease of regeneration and the water depuration has, makes the waste disposal is normal.

The World Health Organization (2006) considers that the proper amount of water for human consumption (drinking, cooking, personal hygiene and cleaning) is 50 L/inhabitant*day (0.05 m^3). To this amount it should be added the water used for agriculture, industry and the effect of water used for the conservation of aquatic ecosystems in a given area.

Given these parameters, it is considered a minimum of 100 L/inhabitant*day (0.1 m^3) to have a normal development of the inhabitants of that area, now second. The United States have a per capita use of 1868 m^3/year, and 5.1 m^3 per day on its territory. Thus, recognizing that when water is used to perform some activities such as (agricultural, urban or industrial) can no longer be reused again. We decided to split the flow m^3 found in the number of inhabitants contained in the study area in order to obtain a value that represents the availability of water resources and its potential pressure in the area.

Anthropogenic transformation index (ATI)

Richter (2004) states that the ATI allows, on the one hand, getting a diagnosis of the degree of landscape transformation within a given region and on the other, help in recognition of the areas affected by degrading processes such as deforestation, erosion and changes in use and land use. These problems are usually caused by inadequate management of agricultural crops as little surface is suitable and may be used for this use, thus producing dangerous changes by deforestation due to installation of new areas with crops.

The ATI was presented by Lémechev and applied by Mateo (1984), Vicens (1997), Teixeira (2003), Richter (2004) and Perez (2010) in geoecological studies, in order to quantify the anthropogenic pressure on some component of environment, such as protected areas, watersheds or national parks.

For the delimitation of the study area, the classification of images and quantification of thematic classes will be accurate in four phases: (i) Technical geo-processing and environmental monitoring, (ii) Identification of areas modified by man, (ii) Classification and preparation of thematic maps and (iv) Taking of actual data of the study area, seeking a good detail.

The determination of the use of classes and land use can be performed on digital or satellite images orthophotos from which takes place the division of classes of use and occupation of land by manual scanning in vector editing or by visual interpretation process.

The classes and occupation of soil are: Urbanized Areas (AU), Culture Thunderstorms (CT), permanent crops (CP), pastures (P), Forests (F), and Water of Bodies (BW). The weights given are established for each use and occupation of land in the area, region, area or basin to review. Later we obtain the area of each use and occupation, and their equivalence in percentages.

The ATI is calculated and performed from the use and land cover map, **Eq. (3)**:

$$ATI = \sum_{i=1}^{n} (ri \times pi)/100 \qquad (3)$$

where: ri = anthropogenic transformation of landscape level for a certain type of land use i, pi = area (%), the type of land use, and n = maximum number of types of land use. As workers Pérez (2010), each class has a weight assigned from the information that the author has about the same in relation to the degree of human disturbance. To calculate the ITA areas are classified as follows: (i) partially degraded (0 to 2.5), (ii) regularly degraded (2.5 to 5), (iii) degraded (7.5 to 5) (iv) very degraded (7.5 to 10).

Slope (m)

This proposed index consists of variables associated to the influence of human activities and their impacts on water resources; it also studies the spatial distribution and its transformation by human action.

Garcia (2006) states that the terrain slope is one of the parameters that most use in fragile studies in addition to their correct knowledge depend on many infrastructure planned by engineers: roads, reforestation, hydrological restoration There lies its importance in the soil, not only in knowing the concept, but also in calculating it.

Soil is a valuable natural resource that contains water and nutrients that living things use. Erosion is the loss of fertile soil, due to the fact that the water and the wind usually drag the surface layer of the earth to the water resources available in the area. This loss of soil accelerates to withdraw from the vegetation cover through deforestation and expands the steep slopes. The slope is one of the leading factors contributing to environmental degradation. In high slope lands, inadequate agricultural practices and changes in land use and deforestation, replacing large amounts of forests for farmland and pastures are very helpful in the process of erosion. This eroded soil may contain large amounts of pesticide residues and fertilizers, some of which have large residual capacity that pollute water resources, increasing the turbidity of the water.

The slope values required for the implementation of the proposed index in this study were established in degrees with corresponding values in percentages as the conversion table below (**Table 2**). To determine the value of course, a relationship was established between the gap (Y) and the horizontal distance (X). This is expressed, therefore, usually at% or degrees. To obtain the slope degree is calculated by the tangent of the angle at% “m = tan (m °)”, **Eq. (4)**:

$$slope(\%) = \frac{y}{x}(100) \qquad (4)$$

Steps to the application

The index was created to understand the deterioration generated by intensive farming, and the correlations between the occupied areas, natural ecosystems modified, environmental degradation and its influence on both quantitative and qualitative degradation of water resources in protected areas such as forest reserves, watersheds and areas for conservation. There are 3 steps to your application: (i) Technical geo-processing: knowledge of the exact values of the total study area and the% of the urbanized area, (ii) Application of indices (WQI - ATI): for the WQA the

Table 2 - Conversion of Steepness

Pen %	Pen °	Pen%	Pen °	Pen %
5	2.86	50	26.57	50.95
10	5.71	5.24	3	57.74
15	8.53	10.51	6	55
20	11.31	15.84	9	60
25	14.04	21.26	12	65
30	16.70	26.79	15	70
35	19.29	32.49	18	75
40	21.80	38.39	21	80
45	24.23	44.52	24	85

Description resilience rating for surface waters in river basins (IR)

Table 3 - Variables used for the IR

N	Variable	Description
1	WQI	Water Quality Index
2	U	100 /% of the urbanized area
3	F/I	Flow rate in m^3/s/inhabitant in the study site.
4	ATI	Anthropogenic Transformation Index
5	M	Slope of the study area, in degrees

Table 4 - Classification values according to the RI index

Value	Classification
≥ 50	Resilience High
36 ≤ 49	Resilience Media
26 ≤ 35	Resilience Low
0 ≤ 25	Null Resilience

higher the number of samples, the higher the reliability of the data; is recommended to perform the surveys with monthly samples in at least three different points in the study area, upper, middle and low, it is a watershed. To the ground working with the average of the samples. For ITA after obtaining values through GIS, the use of different GIS systems for corroborating data and (iii) Recognition slope is recommended: Specifies that the slope value must be in degrees.

The IR is calculated from the equation: **Eqs (5)** and **(6)**:

$$y_i = w_i x_i \qquad (5)$$

For $i = 1, 2, 3, \ldots n$

$$IR = \sum_{i=1}^{n} w_i x_i \qquad (6)$$

where: w_i = weight corresponding to each indicator, n = number of indicators used, i = subscript. and x_i = Indicators. Each class is assigned a weight according to the environmental resilience that displays the area, study area or basin:

RESULTS AND DISCUSSION

To illustrate the methodology proposed in this work, there were two studies of river basins of different scales in Colombia, a great extension called Magdalena River Basin and the other a micro basin called Las Minas high end of the Pasto River Basin, this study had two objectives: to observe the versatility of content to different scales, and corroborate the usefulness and validity of this as a tool for environmental valuation.

Example 1. Magdalena River Basin

The Magdalena River is the most important body of water in Colombia, with a length of 1.550 kilometers across 11 states since its birth in Huila, covering the states of Tolima, Cundinamarca, Boyaca, Caldas, Antioquia, Santander, Cesar, Magdalena, Bolívar and Atlantic to its mouth in the Caribbean Sea.

The Magdalena River Basin has an area of 250 000 square kilometers, which corresponds to 22.8% of the Colombian national territory. This area is concentrated about 70% of the population, containing about 730 municipalities. Traverses the country from north to south over a distance of 1536 km, with an average of 7100 m^3/s.

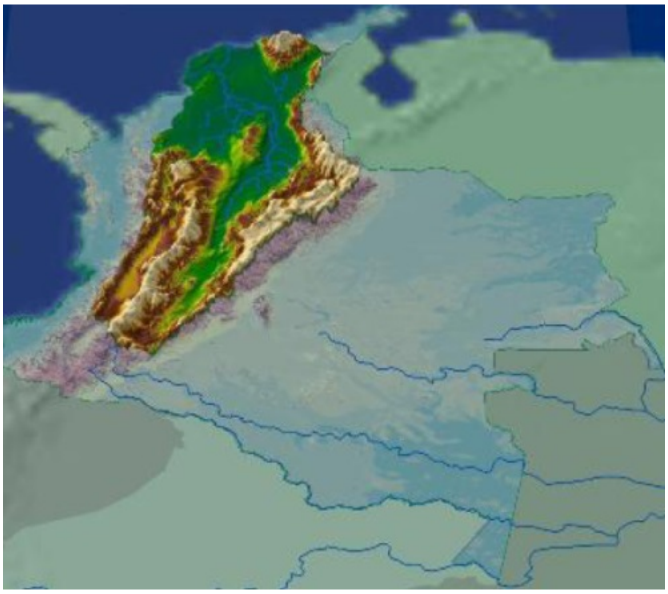

Fig. 1 Location of the Magdalena River Basin in Colombia

Located in northern Colombia on the east bank of the river of the same name, this river covers the low and flat part to find the back of the Caribbean Sea, which extends from the mouth of the river.

Within its general configuration has an independent geographic system formed by the sheer volume of the Sierra Nevada de Santa Marta, which gives this area special characteristics, because within it can be found from the low lands, many of them flooded or flooded during almost year-round, to areas of high levels of the peaks that make up this extraordinary orogenic training. The Magdalena River basin is the largest and most extensive of the state and is made up of a lot of streams and tributaries flowing to the marshes and the river Magdalena.

Within this basin is the so-called “depression” This is a collecting area of water, for there converge the Cauca rivers, San Jorge and Cesar, the latter through Zapatosa Marsh. The Magdalena River supports the largest proportion of water in floods and forces, the river suffers overflow causing the overflow wetlands and tributaries in this area. It is also used as transport and contains a huge range of biodiversity, which reaffirms the importance of this basin in the Colombian country.

Water quality index

The IDEAM made an inventory of monitoring points and stations of the Autonomous Regional Corporations and Departments of Environment of cities with over a million inhabitants, finding a total of 139 stations in the basin of the Magdalena River. This was done in order to establish a baseline water quality of the river Magdalena resources by developing the first monitoring campaign of the national network of water quality.

As water samples were determined the following variables are present in the field: temperature, pH, Electrical Conductivity, Dissolved Oxygen and Temperature; laboratory: Biochemical Oxygen Demand, Turbidity, Total Suspended Solids, Total Solids, Chemical Oxygen Demand, Eschericchia coli, Total Coliforms, Phosphates, Total phosphorus, nitrogen Organic, Nitrate, Nitrite, Ammonia nitrogen, sulfate, Total Hydrocarbons, total phenols , total metals in water and sediments (Cadmium, Copper, Chromium, Mercury, Nickel, Lead, Zinc). Surveys of sediments were analyzed for heavy metals and intensifying the samples in mining exploration areas for Mercury.

We calculated the Quality Index for the Magdalena River observing values that are located in three of the five possible ratings: "Rubbish" ($\leq$ 19) to 3% of the monitored points, "Bad" (19 $\leq$ 36) to 13% "Regular" (36 $\leq$ 51) to 64% and 20% of the points in the classification "good" (51 $\leq$ 79). The mean value was 46.25 "classified as regular".

Urban area (u)

Knowing the real value of the process of urbanization of a given area is the knowledge of its potential threat or likelihood of a particular natural or induced phenomenon that endangers the safety of human beings that occupy it. Increased urbanization increases their vulnerability and susceptibility to some degree of damage to the people, buildings, facilities, environmental goods etc. before the occurrence of external events. The value of the urban area was found to be 26.64%, which is equivalent to 6857.

Flow/inhabitants (v/h)

The flow rate was found to be 7100 m^3/s and number of inhabitants that are located in the basin of the Magdalena River is 32 500 000 inhabitants.

Anthropogenic transformation index (ATI)

Technical tools such as GIS and satellite images are of great help to apply this index satisfactorily, also the option of holding a real sequence for effective environmental monitoring.

From the thematic classes already generated by the Geographic Institute Agustín Codazzi (IGAC), a quantitative and qualitative analysis of the study area in the dynamics of land use in the watershed of the Rio Magdalena **Fig. 5**. **Table 5** shows the area in ha and %.

In preparing the base map of the Magdalena River basin were used mapping and satellite imagery, information available in the Geographic Institute Agustín Codazzi - IGAC. We used the version of ArcGIS 10.1, and the Landsat Satellite Image 7: L710080597_05919980122 of January 28, 2002 window, L71008059 _05920010824 of August 24, 2001 and L71008059_05920021007 of October 7, 2002, windows that allowed to define the limit of basin (water division) and restore streams in the sectors in which the mapping of the IGAC presents sectors without information (Clouds).

Urban Cartography (File format digital AUTOCAD, dwg) was obtained from the spatial plan of the Magdalena River Basin, to delimit the urban perimeters and urban sprawl.

The SRTM image used to perform the mapping refund in essence is a two-dimensional plane representing the height of sea level, this is an isometric map, which for each lift is assigned a color gradient, which in turn is assigned a value between 0 (black) to 255 (white) through the full range of colors (See **Fig. 2**).

This (study area of the window) was georeferenced, taking control points of the topographic IGAC letters. Following that window was carried out a classification "slicing", which is to assign a code to a range of values of the cells "pixel"; thus all pixel values 0 to 5 is

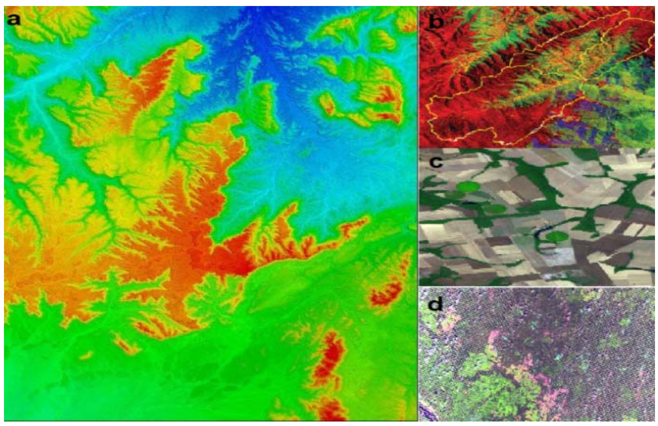

Fig. 2 a. Image (SRTM_u03_n001w076) surface map, **b**. thematic map, **c**. Georeferencing raster **d**. reference map.

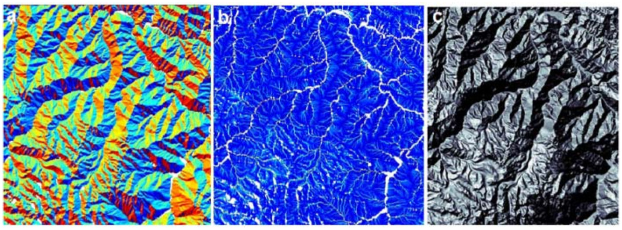

Fig. 3 Classification and image conversion SRTM raster to vector **a.** Pixel classification, **b.** SRTM image conversion to raster format, **c.** Raster to vector processing.

assigned the first code; the pixel values between 5 and 10 code is assigned 2 and so on up to and including the maximum pixel value recorded on the image. Then the image becomes a cell format "raster" to a vector format. (**Fig. 3**).

In the image in vector format, each line represents a theoretical contour, where initially unaware of its value, that is, a series of lines that do not have attributes, despite the scanning of the hydrographic network, the contour and in partitions basin waters.

Following these cases even without attributes (partition, hydrography and contour lines), were superimposed the image Landsat 7: L710080597_05919980122 and topographic maps IGAC, performing a visual recognition to confront obtained by processing image SRTM against the result of processing the satellite image and entered in the topographic maps (see **Fig. 4**).

In this confrontation, there was a high correlation between the product obtained by SRTM image, the Landsat image and mapping the IGAC.

Quantitative analysis of the areas found

Non-agricultural anthropic areas - Urbanized Areas: Corresponding to the urban area and Riparian Zone.

Agricultural disturbed areas: (i) Temporary Culture: Matches subsistence crops or food crops (rice, tomatoes,

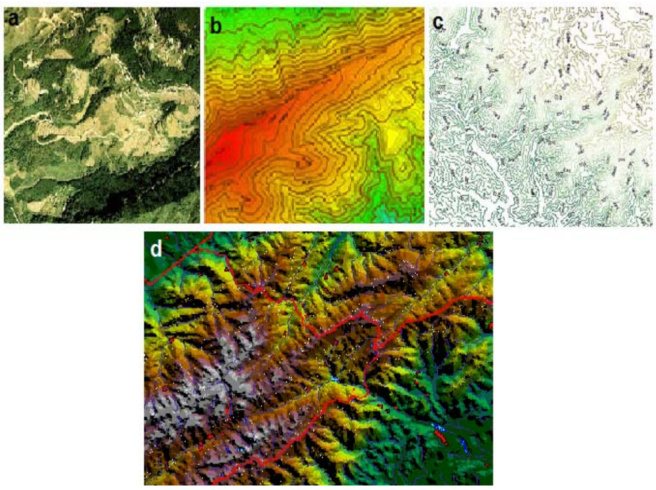

Fig. 4 Overlap and confrontation of the obtained layers, **a.** Landsat, **b.** Base Mapping, **c.** SRTM processing.

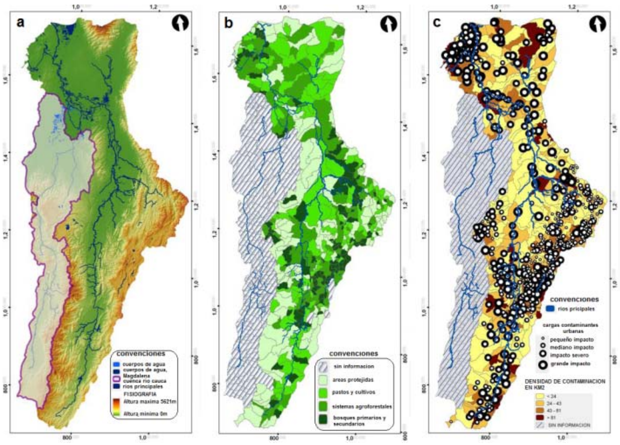

Fig. 5 Catchment Areas Maps of the Magdalena River, to the ITA Enforcement, **a.** map of heights and physiography of the Magdalena basin, **b.** map of protected areas and occupation of land, **c.** population density map.

cassava, cotton, corn, tobacco, banana), (ii) Permanent crops: fruits (passion fruit, banana), cocoa, sugar cane, rubber, coffee. (iii) Pastures: Pastures improved as jaraguá grass (Hyparrhenia rufa), Brachiaria (Brachiaria decumbens), guinea grass (Panicum maximum), bermudagrass (Cynodon dactylon) and a native pasture called Comina (Paspalum sp.). Within the dry love sobressae up pulses (Desmodim spp.), All these forage for livestock production cutting.

Natural vegetation areas: (i) Forests: Forests as species (Pinus Hatwegii, religious Abies, Quercus laurina, Quercus rugosa, Pinus patula, cupresus lusitanica) and mixed forests, with some endogenous vegetation of the region. (ii) Bodies of Water: main channel, streams, creeks, lakes, ponds, marshes and reservoirs.

Was obtained value of 622.01/100 = 6.22, this value according to the calculation of anthropogenic transformation index (ITA), allows you to sort the Magdalena River Basin as a Degraded bowl according to the degree of human modification of the natural ecosystems.

Slope (m)

The figures below show the differences in slope in the total area of the Rio Magdalena basin. Total area of the Rio Magdalena basin in km^2 257 400 km^2

(i) Mountainous area = 140 000 km^2 (54% of the basin), (ii) Flat area = 117 400 km^2 Rolling (46% of the basin), (iii) The mean slope is 20%

where:

$$m = \text{tang}\,[20\%] = 11,31^{\circ} \qquad (7)$$

Table 5 - Land use in the Magdalena River basin, in area and %

Land Use	Weight (1)	Area ha	Area % (2)	ATI result (1 × 2)
Urban areas (UA)	9.5	6857.136	26.64	253.08
Seasonal crops (SC)	7	5886.738	22.87	160.09
Perennial crops (PC)	6	5961.384	23.16	138.96
Pastures (P)	4	4154.436	16.14	64.56
Forests (F)	0.3	2581.722	10.03	3.009
Water bodies (WB)	2	298.584	1.16	2.32
Total		25740	100	622.019

Table 6 - Data used to calculate RI

indicator	Value
WQI	46.25
u	100/3.75 = 26.64%
v/h	7,100 m^3/s/32 500 000 inhabitants = 2.18 $m^3/s/h$
ATI	6.20
S	m = tan [20%] = 11.31º

Table 7 – Application of IR

Indicator	Value x_i	Weighting coefficient w_i	Total Value $(x_i \times w_i)$
WQI	46.25	0.35	16.1875
u	3.75	0.3	1.125
v/h	2.18	0.2	0.436
ATI	6.20	0.1	0.62
S	11.31	0.05	0.5655
	Total	1	18.934

According to the classification of the methodology proposed by the IR Magdalena River basin has a Null Resilience in their surface water resources, which indicates a high pollution, limiting the depuration by the amount of pollutants received by the river.

It is emphasized that the overall water quality was framed as Regular, according to the classification of the WQI. It is observed that 3.75% of the watershed is urbanized due to industrial development and posing serious man-made problems. The basin has a great flow which helps self-purification of water resources, but the pressure from the oil industry, mining, coal and pollution from agricultural waste is exerting great impact on the water of the basin. The ATI showed environmental degradation by agriculture of large tracts of land, where deforestation is permanent, but it was also observed great potential to contain protected areas with riparian vegetation. The slope shows two areas, one with a very pronounced slope, susceptible to landslides, erosion and sediment pollution of water resources, and the other, wavy flat with a high vulnerability to floods and health problems.

Under the proposed index, one comes to the conclusion that the pollution of the river basin of the Magdalena River increases, but also increases the risk of biodiversity loss, as well as causing an imbalance in terrestrial and aquatic ecosystems and increases soil vulnerability and natural resources. This makes the inhabitants of the basin area more vulnerable to flooding, mass removals and health problems among others.

The index confirms that there is need for immediate management in the basin of the Magdalena River with projects aiming at reducing pollution by release of domestic and industrial wastewater. In addition, attention should be paid to soil conservation and the incorporation of trees in temporal and permanent crops as are agroforestry systems which mitigate the problems of erosion and loss of biodiversity. Regarding the flood problem, the construction of separate residences on relevant parts of the basin is recommended.

Example 2. Watershed Las Minas Colombia

The Las Minas micro basin is contained in the upper High River Basin Pasto, which is limited to the north by the stream Las Tiendas, to the northeast with the path San Agustín, to the east is the path of Alto San Pedro and the south with La Cuchilla del Tabano. It has an area of 362 Ha and a perimeter of 10:38 Km; is between 2900 and 3500 meters and is located southeast of the city of Pasto, Nariño Department.

It is significant that the flow measurement period comprises a dry season (August), in which the water source volume is very high. This study also carried out a measurement in times of high rainfall whose results are similar to those found in August and the average volume was obtained 989.6333 L/s. = 0.9 896 333m^3/s.

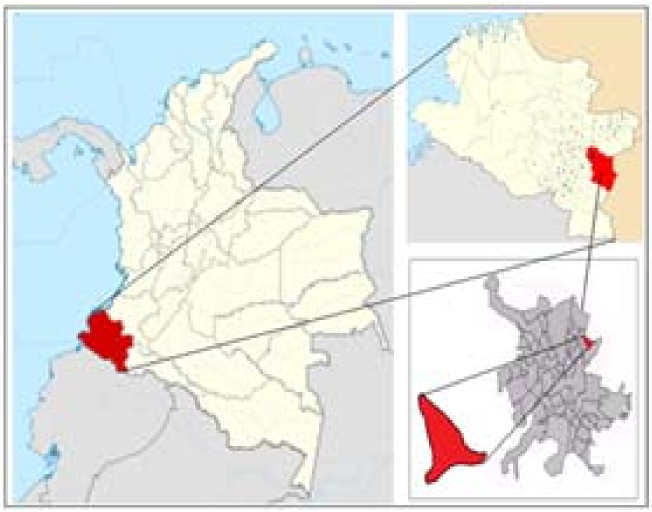

Fig. 6 Location of the Las Minas watershed – Colombia

(i) Quality Index Water obtained value = 57, (ii) Urban area (u) /0.9 = 100% = 111.1, (iii) Flow / inhabitants = 0.9 896 333 m^3/s / 560 inhabitants = 0.0017 m^3/s </ h.

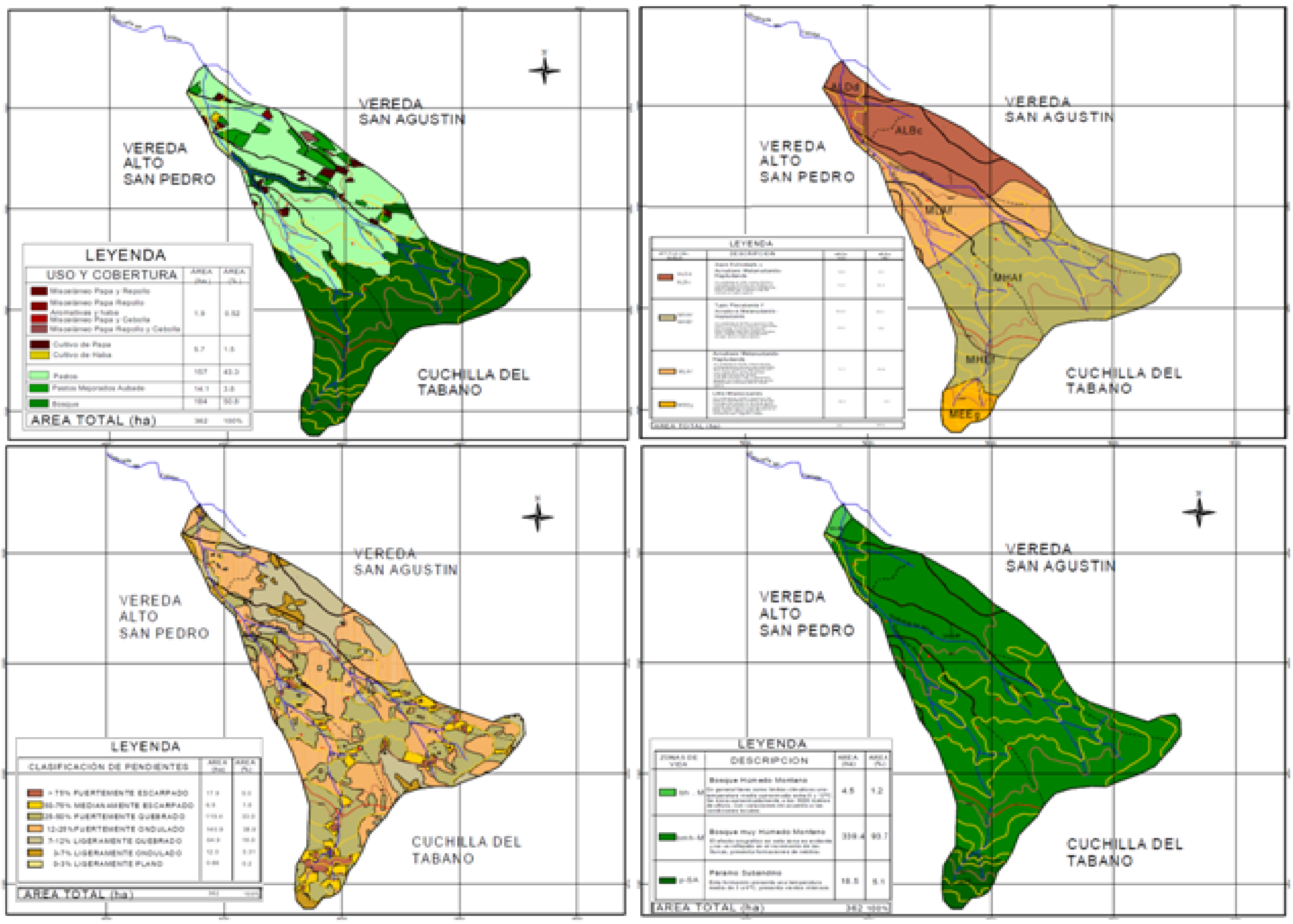

Fig. 7 Map of the Las Minas watershed area, for applying ATI.

Quantitative analysis of the areas found

Non-agricultural anthropic areas - very little Urban Area. Agricultural disturbed areas: (i) Temporary Culture: potato crops and vegetables (cauliflower, radish, broccoli, onions, cabbage), (ii) Permanent Culture: cold weather fruits *Solanum betaceum* (Japanese tomato), and *Passiflora tarminiana* (Curuba). (iii) Pastures: 166 882 ha been identified pasture consisting of natural grass (157 ha) which show a certain degree of erosion to the deformation of soil compaction exerted by the cattle, which lead to opening cracks in the soil. There was also the implementation of improved pasture with an area of 14.1 ha.

Natural vegetation areas: (i) Forest: The areas with forest cover correspond to two types of forest in general. Natural forests are areas consisting of primary riparian forest and secondary forests, distributed in the upper watershed, between 3000 and 3400 m, (ii) Bodies of Water: main cause, creeks and streams.

A percentage of 222.11/100 = 2.22 which is defined by the calculation of anthropogenic transformation index (ATI). This allows you to sort the watershed Las Minas with an area that is little degraded, because it contains a large percentage of forest, and where the process of urbanization has been slow. This has caused the degree of anthropogenic transformation does not exercise representative changes in natural ecosystems contained in the watershed.

Table 8 - Land use in the Las Minas Micro-basin, in area and %

Land Use	Weight (1)	Area ha	Area % (2)	ATI result (1 × 2)
Urban áreas (UA)	9.5	3.258	0.9	8.55
Seasonal crops (SC)	7	6.9988	1.74	12.18
Perennial crops (PC)	6	0.181	0.05	0.3
Pastures (P)	4	166.882	46.1	184.4
Forests (F)	0,3	181.724	50.2	15.06
Water bodies (WB)	2	2.93	0.81	1.62
Total		362	100	222.11

Slope (m)

Average slope: Pm = D × W × 100/A, Pm = average Slope, D = distance between level curves, L = total length of the curves, A = area of the watershed.

(i) Pm = 25 cm × 22500m/3.62 km^2 × 100%, (ii) Pm = 0.025 km × 22.5 km/3.62 km^2 × 100%, (iii) Pm =

Table 9 - Data used to calculate RI

indicator	Value
WQI	57
U	100 /0.9 % = 111.1
v/h	0.9 896 333m³/s / 560 inhabitants = 0.0017 m³/s*h
ATI	2.22
P	m = tan [15%] = 8.53º

Table 10 - Application of Index RI

Indicator	Value x_i	Weighting coefficient w_i	Total Value $(x_i \times w_i)$
WQI	57	0.35	19.95
u	111.1	0.3	33.33
v/h	0.0017	0.2	0.000 34
ATI	2.22	0.1	0.222
P	8.53	0.05	0.4265
	Total	1	53.92884

$0.5625\ km^2 / 3.62\ km^2 \times 100\%$, (iv) $Pm = 0.15 \times 100\% = 15\%$.

where: m = tan [15%] = 8.53º

According to the classification of the methodology proposed by the IR, the watershed Las Minas has a High Resilience in their surface water resources.

In it the overall water quality was rated as Good, little polluted, according to the value 57 in the classification of WQI. Moreover, its urbanization percentage is minimal, and has considerable percentage of forest (50.2%), representing just over half of its total area. This causes the watershed to be stable, which exerts a minimal pressure on land and water resources. This fact does not mean that there are no degradation problems, as there are steep slopes, but these areas are occupied by areas with riparian forests and there is availability of water at any time of the year for the population's needs, both for consumption, as for other purposes. Despite being located very close to the city of Pasto with more than 500 000 inhabitants, this watershed is one of the most preserved, thus protecting its biodiversity and being a great support to the city of San Juan de Pasto, since it contributes for the consumption of the inhabitants of this city.

CONCLUSIONS

This methodological approach is based on measurement of variables and approximation of actual data of water pollution, to identify the sensitivity, fragility, adaptability and the risk to these water resources, because of human activities in certain areas or areas of study.

The importance of this indicator proposed is based on informing decision makers or users of the interactions and interrelationships dynamic natural systems of physical elements, biological, social and economic factors that relate to each other, due to human activities, one excellent scientific information tool to the public, contributing to the understanding of environmental problems that occur.

Variables that really test the pressure were used and water resources were chosen: among them, the waters Quality Index (WQI), which provides indications of pollution of water resources, and that reflects the process of urban growth that leads to deteriorating environmental conditions, and the growth of commercial and industrial activities, so as to generate overloads the capacity of natural systems.

By analyzing the flow to meet its potential for self-purification, the amount of people to know the availability of water and also the pressure on this feature, the landscape of the degree of transformation through (ATI), assists in recognition of affected areas by degrading processes such as deforestation, erosion and changes in the use and occupation of land. The degree of land slope, which is one of the parameters used, the proper knowledge depends on many planned infrastructures such as roads, reforestation, hydrological restoration and which depend on processes such as soil erosion arriving polluting resources water and increase turbidity.

The methodology calculates the mentioned variables and combines to create this proposal and identifies the risks of pollution and its potential for self-purification of water resources in the territorial development of analysis, their production activities and their impacts, which ultimately generate a search of good environmental practices and sustainability of water resources.

We highlight the methodology that can be implemented on any scale, as was applied in two research basins, a greater scale as the Magdalena River Basin in northern Colombia, and the other a watershed, showing a good adaptability to the application of the index at different scales.

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