Water Resources Management: Green Watershed Index (GWI)

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Abstract. A large number of indices and indicators of water performance at the basin level exist throughout the world, however, the need to generate tools that allow the monitoring of basins from their administration and water and environmental management, takes greater force in a global context where sustainability takes great importance. The GWI (green watershed index) methodology is presented, as an extension of urban control methodologies, but this time for rural watersheds. The method is implemented in some rural areas of Colombia, and in some cases the difficulty of implementing the methodology is evidenced, and in other cases the opportunity to improve the management and administration of water resources at the level of rural basins.

1. Introduction

The scarcity of water in general terms is not a problem of water supply, it is a problem derived from availability. In this sense, the quantification of flows or climatological variables for the respective hydrological models, must be accompanied, for every basin, by a comprehensive plan that guarantees the union of this offer with the availability of water.

Likewise, there is a serious problem of vulnerability to flood events, notorious in plains areas. To achieve this, it is necessary to bring together government policies, state will and an action plan that allows a path that unites the community with the state and science. The state and the community must be made aware that in Colombia there should not be talk of scarcity, there should be talk of adequate water governance, which guarantees the availability of the resource in all sectors of society, and also guarantees the sustainable use of it.

Consequently, the recent phenomenon of climate change has led to reflection on the rational and efficient use of water resources in the world, however, Latin America is an important study point due to the rarity of events around the issue of water. Despite the fact that there are important references regarding the number of water supply studies, and the existence now of numerous flow prediction tools using high-resolution hydrological models, the existing disconnect between technology and science with the government policy, make water management a problem that has been ausing interest in different sectors of science and development [2]. In order to formulate tools that allow control and monitoring of the use of water resources in rural or urban basins, some control indices in the world have been taken as a reference. They allow the evaluation of sustainability and use of water resources in the world. In the same sense, we can see which of the referenced indicators, and in the context of
rural watersheds, could have greater relevance at the time of an analysis of water resource management [2].

2. Formulation of Monitoring Indicators

There is a lot of monitoring indexes in terms of water resources management in the world are dedicated to urban and rural basins, taking that base and in the same way it was necessary to analyze the most urgent and objective needs regarding the use of water resources in rural watersheds, in order to formulate an index that would allow its efficient management and administration. To select the most relevant indicators, an assessment is made for each of these, observing the importance, development and impact generated, among which are the maintenance of infrastructure, water demand, water quality, and the water shortage, factors with greater incidence for the index to be generated. Thus, after a detailed evaluation of each of the indicators and of the factors that intervene in their evaluation and execution, it is decided to select 18 indicators which turn out to be sufficient for the characterization of a rural basin based on a drinking water supply system. Some indicators are the result of the analysis of other indices at world levels, as shown in table 1.

| Indicator                          | origin reference | Spacing                                                                 |
|-----------------------------------|------------------|-------------------------------------------------------------------------|
| Infrastructure Maintenance        | BCI UWCS European green | All the technical rigor considerations established in the resolution for the granting of the water concession are complied with in the face of the hydraulic conditions of the structure, as well as the proper calibrations of the measurement systems in order to avoid losses in the system. |
| Effectiveness in general water management | WMEI            | Evaluates supply, water quality and sewer system coverage.             |
| Water vulnerability               | WMVI             | Evaluates physical, economic, social and political representation conditions. |
| Water risk                        | WMIRI            | Vulnerability and Threat.                                               |
| Water stress                      | EPI              | When the demand for the water resource affects the supply. It is considered that there is water stress when there are annual domestic uses per person between 1000 and 1700 m3. |
| Water footprint                   | EPI              | Total volume of fresh water used to produce goods and services in the area of influence. This should be established in relation to the requirements of domestic use required in the region, that is, the consumption of fresh water must prevail over any other activity. |
| Water self-sufficiency            | EPI              | Self-sufficiency is 100% if all the necessary water is available and taken from the territory itself. |
| Efficient water use and saving programs | rule 373 of 1997, Col. | It has all the measures for the proper use of water resources through the implementation of the PUEA, which must be duly approved by the environmental authority. |
| Category                        | Abbreviation | Description                                                                 |
|--------------------------------|--------------|-----------------------------------------------------------------------------|
| Biodiversity                    | BCI          | The stable ecological conditions of the area of influence of the source are presented despite anthropic intervention. |
| Environmental efficiency        | world wide   | Environmental compensation in the areas of direct influence of the water body from which the resource is derived. For this, the forest compensation established by the Environmental Authority can be measurable against the flow that is derived. |
| Waste Treatment Efficiency      | BCI World wide | Percentage of wastewater treated.                                           |
| Attractive                      | BCI          | Water supports the quality of the rural landscape as measured by community sentiment within the rural area. |
| Human capital                   | world wide   | Personnel required for the optimal operation of the supply system.          |
| Measured audience participation | BCI UWCS     | It can be established through annual accountability meetings, through community action boards, at least once a year. |
| Economic efficiency             | UWCS         | Monthly billing according to the estimated consumption of each subscriber. |
| Adaptability to climate change  | UWCS         | The bypass and supply system design has adequate hydraulic capacity for critical conditions. Protection system in flooded areas. |
| Information quality and knowledge management system | UWCS     | Files and records of the compliance plans established by the environmental authority, such as an information system in which the number of users and the demand required by them are determined; as well as records of system conditions. |
| Corruption Control              | world wide   | Strategies are carried out to improve and supervise the performance of those in charge of the administration and operation of the supply system by subscribers. |

According to the reference of each one of the evaluation indices analyzed, the best way to show an adequate or deficient management is the one that can be easily and practically visualized. For this reason, the Blue Cities Index methodology has been followed, where each factor or indicator is scored from 0 to 10, depending on the degree of compliance in the possession or not of the required process, with full justification. In this way, a municipality, province or department, where its rural watersheds fully comply with the objectives of each of the indicators, in full and before its inhabitants by way of perception, the average of their respective qualifications will have an average score close to 10. The justification for qualifying each indicator must show, according to its objective, the degree of compliance. In this case, the above has been established taking into account the following criteria (Table 2):
Table 2. General criterion of the indicators.

| Criterion | Weighing       |
|-----------|----------------|
| 0-5       | Not sustainable|
| 6-8       | Moderately sustainable|
| 9-10      | Sustainable    |

Source: Own

Specifically (table 3):

Table 3. Specific evaluation of the management criteria.

| Criterion | Evaluation                                      |
|-----------|------------------------------------------------|
| 0         | does not fulfil                                |
| 2         | Start of activity planning                     |
| 4         | The operational part of planning ends          |
| 6         | It has the approach and begins the development of the activity for execution |
| 8         | Run the activity partially                     |
| 10        | fully complies                                 |

Source: Own

The history and development of societies suggest that a basin belonging to a developed region will surely have its management indicators within a highly sustainable framework, and a basin belonging to a developing region will surely have lower levels of sustainability, but the ideal is that said basin has started the planning phase of activities to reach the desired sustainability goal [7].

3. Individual Analysis of Indicators

To give continuity to the characterization of the indicators, 6 degrees of compliance are defined for each of the indicators, as shown in table 3, according to the purpose of each of them, in which a score is assigned in a range from 1 to 10, whose rating depends on the quality and use of resources in order to offer a service, each of these steps focused on strategic planning and start-up of works to satisfy basic needs related to the water supply in optimal conditions.

3.1. Approach to the Index of Water Management in Rural Basins, GWI (Green Watersheds Index).

In order to present an overview of the quality assessment of rural watershed water management, a new index called GWI (Green watersheds Index) is proposed, which, as its acronym proposes, will evaluate the continuous process of a watershed with the purpose to reach a good service result that involves biodiversity, sustainability, water resources, and social well-being, in a way that does not allow to obtain strictly real results since these depend on the valuation of each process in a certain indicator.

3.2. Definition of the GWI index

The GWI index (Green watersheds Index) can be defined as the definition, determination and evaluation of a series of indicators (18), which for the case study turn out to be of greater importance all those that present data with greater impact for the management of quality of rural watersheds.
The proposed GWI index, it establishes a simple average of the indicators to be analyzed in the respective study area in the following order:

(MI) Infrastructure Maintenance, (EGH) General Water Management Effectiveness, (VH) Water Vulnerability, (RI), Risk, (EH) Water Stress, (HA) Water Footprint, (AUA) Water Self-sufficiency, (UAH) Efficient water use and saving programs, (BD) Biodiversity, (EMA) Environmental Efficiency, (ETR) Waste Treatment Efficiency, (A) Attractive, (CH) Human Capital, (PP) Measured Public Participation, (ECC) Economic efficiency, (ACC) Adaptability to climate change, (CI) Quality of the information and knowledge management system, (CC) Control of Corruption.

\[ GWI = P \times \left(MI + EGH + VH + RI + EH + HA + AUA + UAH + BD + EMA + ETR + A + CH + PP + ECC + ACC + CI + CC\right) \]

(1)

here each indicator is evaluated as mentioned in the individual indicator analysis, with an evaluated value between 1 and 10, GWI is the rural watershed management index, and P is the differentiated weighting coefficient for each of the indicators according to area of study.

For greater clarity of the previous formula, the following expression is proposed [8]:

\[ GWI = \frac{\sum_{i=1}^{n} F_i \times P_i}{\sum P_i} \]

(2)

Where GWI is the rural watershed management index, n the number of management indicators, Fi the numerical result of management indicator i, and Pi the weighting factor of each indicator according to the study area.

3.3. Weighting Factor by P Indicator.

The weighting factor to be used for each indicator is explained by its importance or weight within the management of a hydrographic basin, depending on its spatial and morphometric location (0-1). In this way, the indicator of adaptability to climate change will surely have a higher weight if it is a basin located in a coastal zone, compared to another basin where it is located in an inland area and without greater morphometric accidents.

4. Experimental Procedure

The procedure to obtain the GWI index was implemented in some rural basins with consolidated local governments, with the objective of seeing the degree of development in terms of management and administration of water and environmental resources in each one of them.

Before starting the choice of the respective basins, some premises were taken in order to give context to the subsequent presentation of results and their analysis:

1). The selected basins are located in Colombia, South America, in a department characterized by large rural areas and agricultural use [9,10], where the use of water resources would enhance this important economic sector for the country.

2). The human development index in Colombia for 2018 stood at 0.76 [11], however, this is an average where the lowest rating occurs precisely in rural areas or jurisdictions, where the country still does not adequately take advantage of the water and environmental potential that owns for the use of activities such as agriculture or natural tourism.

3). The lack of knowledge in many areas or regions in Colombia regarding water management and administration generates situations or activities for the benefit of the communities, but in an isolated or disorganized manner, which makes monitoring or control difficult over time, a situation that It could give results with some uncertainty in some indicators to be evaluated, or lack of information in this regard.

The municipalities chosen within the context of rural watershed management, belonging to the Department of Boyacá, in Colombia, were Arcabuco, Chíquiza, Gachantivá and Villa de Leyva, whose main characteristics are highlighted in table 4.
Table 4. General characteristics Study municipalities.

| Municipality     | Area (Km²) | Rural population (# hab) | Total Population (# hab) | Main economic activity       |
|------------------|------------|--------------------------|--------------------------|-----------------------------|
| Gachantivá       | 66         | 2290                     | 2654                     | farming                     |
| Chíquiza         | 119,5      | 5390                     | 5484                     | farming                     |
| Arcabuco         | 155        | 3279                     | 5240                     | Farming and cattle raising  |
| Villa de Leiva   | 128        | 7058                     | 16984                    | Tourism, agriculture, exploitation of stone, clay and marble |

Source: Own

5. Results of Experimental Design and Conclusions (Applying the GWI index)
Given that for each indicator it is necessary to propose a defined methodology that involves the different parameters set out in the Technical regulation of the drinking water sector 2017, as well as the different conditions of the rural basin available for the supply of water resources, it is necessary to have entities that allow the provision of information through tools such as the census, which allows typifying the population served. Likewise, field visits and data collection (in situ) allow for visual inspections and measurements of the current state of the hydraulic structures of the concessions (random samples), compared with the indicators established by the aforementioned standard. For this, the real conditions of the population must be verified (including floating population) in which it is possible to obtain assertive data due to the degree of complexity of the characterization of a specific study area in which the conditions vary according to the management given for the planning, development and execution of works for the supply of drinking water in a rural community.

It is important to clarify that the implementation of the methodologies set out for each of the 18 indicators, explained above, are proposed taking into account that the points, basins or regions studied have clearly identified governance structures. For different situations or contexts, this protocol might not have the same control or monitoring effect. The results in each of the municipalities, which in most cases include a predominance of rural basins over urban basins, show an evident lack of control in general terms of community participation and application of management policies and use of water resources and environmental. Too much subjectivity is evidenced in some cases, for example in the corruption control indicator, one of the items where it is evidenced from the perception of the community one of the greatest concerns in general in Colombia, and yet it is the item best rated in most case studies. In the case of Gachantivá, the local authorities recognized a lack of total control in each of the topics covered in the indicators, clarifying that there is not necessarily a correlation between activities carried out and planning and control of said activities, which is qualified through of the tool.

One of the most interesting aspects of the study carried out is that in principle it was assumed that a municipality e.g. Villa de Leyva, whose income from taxes and tourism is high in relation to most rural municipalities in Colombia, presents an index result that does not reach 5.0. At a comparative level, the municipality of Chíquiza generates the best general performance of the GWI index, however, it surpasses Villa de Leyva, the latter being a rich municipality in terms of income or annual budget capacity by its privileged tourist condition. Taking into account the type of category for each municipality, in Colombia municipalities are classified into categories one to six and a special category according to their number of inhabitants and their Free Destination...
Current Income, as indicated by Law 617 of 2000 (Colombia). A condition of extreme lack of historical management presents the municipality of Gachantivá, where no indicator exceeds the unit, which coincides with the category of the municipality (sixth), assuming that the resources contributed by the nation are not destined to management tasks of this type. It is interesting to note that Villa de Leyva, Arcabuco and Chíquiza, municipalities that have historically been characterized by having problems of access to water, have had their best scores per indicator in those aspects that have to do with water stress and water self-sufficiency, showing a special interest in what they show as day-to-day deficiencies, or immediate needs.

The effort of the municipality of Chíquiza in the beginning of sustainable policies is highlighted, specifically in what has to do with wastewater treatment, complying with the environmental regulations in force in Colombia given by the Ministry of the Environment. In general terms, in the municipalities analyzed and in general in the reality of rural municipalities in Colombia, we could anticipate that there is evidence of an absence of a planning culture in environmental terms.

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