Towards a water governance index (WGI) for Andean micro-watersheds using pressure-state-response indicators and fuzzy logic system. Study case in Colombia

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Abstract

This research presents conceptual and operative index to evaluate qualitatively the level of the water governance (WGI) in an Andean micro-watershed. The index WGI was constructed using for a combination of Pressure-State-Response model and fuzzy logic. The index WGI provides an approach to assessment water governance in the planning management in Andean micro watershed. WGI has as input values PSR indicators, in each zone: high, medium and low. By using fuzzy logic functions these inputs are combined to build a new water governance index (WGI). An application was realized in a study case in Colombia.

Introduction

Governance is a broad notion that captures both the non-organizational structures and informal processes that shape interactions of stakeholders in decision-making (Li et al., 2017: 1). Measuring governance performance is often complex because in most cases we do not know what and how to measure (Cookey et al., 2016: 1). Environmental indicators and indexes are essential tools for support decision-making, supporting policy evaluation and informing the stakeholders. Decision makers need the appropriate indicators and indices to assess, track, and integrated human health, socio-economic, environmental, and ecological factors to assessment sustainability in watershed and micro- watershed. The Andean region holds 9.5% of the world's fresh water reserves and plays the pivotal role of providing water for the majority of South American watersheds. However, unsustainable practices such as overgrazing in the water recharging zones, deforestation, mining, deficiencies in practices agriculture, changes on the use land and climate changes, directly affect their surrounding environment and water resource. The purpose of this paper is presented a water governance index (WGI) for Andean micro-watershed with application in a micro- watershed in Colombia. Research also revealed that water related sustainability indices tend to be more popular and widely used, while water governance related indicators seem to be more restricted to development and UN related organizations, and international development NGOs (Cookey et al., 2016: 2). Few indicators for micro watershed basins have been studied.

Methodology

The methodology used for build index, was a combination of pressure-state-response (PSR) indicators, logic fuzzy and management knowledge. The PSR model is based on the concept of causality: human activities exert pressures on the environment (pressure) and change its quality and quantity of natural resources (state). Society responds to these changes through environmental, general politics, economics and sectorial responses (response). The PSR model was originally developed by the Organization for Economic Co-operation and Development (OECD, 1993), provides a mechanism to monitor, and evaluated the status of the environmental (Zhang et al., 2012: 4). PSR indicators form the dominant models widely used for environmental issues assessment (Camacho-Sandoval, and Duque, 2001: 2).

The PSR model aims to develop indicators of sustainable development, organized in three categories: pressure (P), state (S) and response (R). The PSR framework is based on a concept of causality, covers causes and effects influencing a measurable state and seems highly capable of showing information to end users in a causal way by differentiating between causes, effects and human responses to control the extent of anthropogenic impacts on nature (Wolfslehner and Vacik, 2008: 2) (see Figure 1).

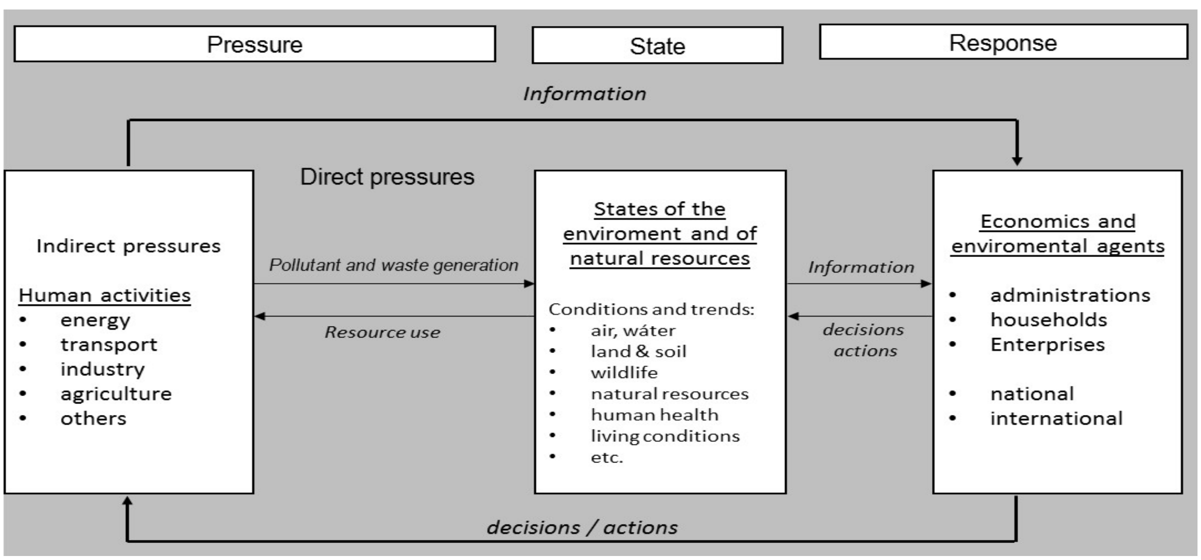

Figure 1. Pressure - State – Response (PSR) model (OECD, 1993)

Fuzzy sets can have a variety of shapes. However, for simplicity in the computation process and adequate representation of the expert knowledge, trapezoidal and triangular functions were defined in this study. Knowledge management describes the strategies and processes of acquiring, converting, applying, protecting and transferring knowledge to improve decisions. Fuzzy logic is a mathematical discipline based on fuzzy set theory instead of classical mathematics, it was introduced by Zadeh (1965). The goal of fuzzy logic algorithm is to establish quantitative relations between inputs and outputs by qualitative relations (Jia et al., 2016: 4). The procedure to build a fuzzy model is as follows (Jia et al., 2016: 4):

Step 1: Selection of criteria. For the restaurant tipping example, the tip is related to food and service.

Step 2: Defining qualitative states for input and output. In this example, service is defined as: “poor”, “good”, and “excellent”; Food is defined as “not very tasty” and “delicious”; the tip is defined as “low”, “average” and “generous”.

Step 3: Defining the membership function for input and output. The membership function is defined for each qualitative state. The degree of membership is used to indicate how much a value is associated with one qualitative state.

Step 4: Defining rules. The tipping fact can be described by the following qualitative rules: If service is poor or food is “not very tasty”, the tip is low; if service is good, the tip is average; if service is excellent or food is delicious, the tip is generous.

Step 5: Fuzzy logic inference and interpretation of output value. As aforementioned, the objective of fuzzy logic tool is to identify quantitative relations between input and output.

Then the maximum (corresponds the logic operation “OR”, while minimum for “AND”) of the corresponding degree of membership is used to “cut” the corresponding output membership function “low” to get a new shape. Then the center of the final shape is calculated, and corresponding horizontal tip value of the center can be obtained. This tip value is interpreted as output value. Thus, the quantitative relation between input and output can be obtained through qualitative relations.

Fuzzy sets can have a variety of shapes. However, for simplicity in the computation process and adequate representation of the expert knowledge, trapezoidal, singleton and triangular functions were defined in this study. Definitions of qualitative variables are mainly extracted from existing research, studies and experiences in the fields of this research (see Figure 2). The rules for these variables of fuzzy system were programmed using the software MATLAB (Fuzzy Logic Toolbox).

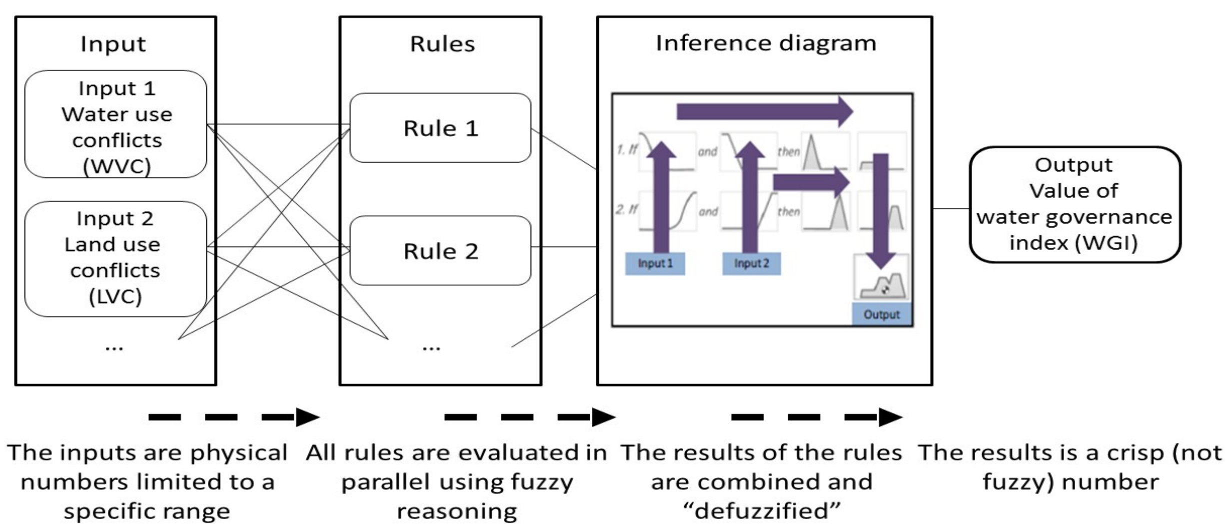

Figure 2. Overview of the fuzzy inference process (Adapted from Jia et al., 2016: 5).

The PSR model proposal was evaluated in the micro-watershed named El Chocho. This micro-catchment is located on the eastern side of the western branch (3.30°N, 76.34°W) in the Department of Valle del Cauca, in Colombia. It is localized in the mountains above Cali in Valle del Cauca Department, in Colombia. The Chocho has 10 km long and 20 km^2, catchment is home about 15.000 people in a rural area that is however strongly influenced by the proximity of the city (Dominguez and Corrales, 2006). The elevation ranges from 950 to 2.000 m above sea level (see Figure 3). It is situated in a humid tropical zone with 2,495 mm.yr-1 of its annual mean precipitation over the last 20 years; meanwhile, the annual mean temperature over the last 10 years was 23.10 °C.

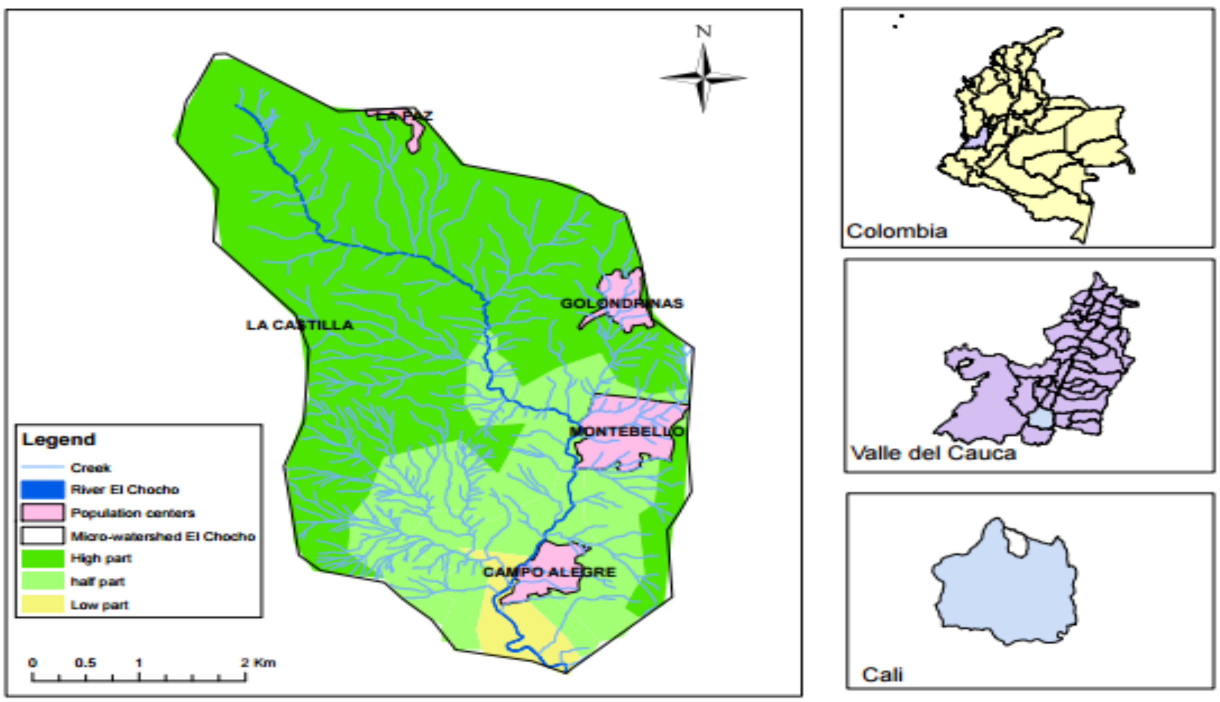

Figure 3. Localization of Chocho micro-watershed in Colombia

This micro-watershed has suffered a huge environmental damage, because of the change in the use of the land, the increase of the population, the discharge of untreated domestic wastewater, the poor management of the solid wastes, and the discharge of the acid coal water. These circumstances generate different kind of conflicts, especially the access to the water, degrading uses of water and activities that affects the quantity and quality of water. Institutions that work in this area sometimes contribute with solutions, but sometimes make worse these problems (Dominguez and Corrales, 2006).

Results and discussion

Indicators PRS were defined as quantitative and qualitative components. To evaluate these indicators can be used a combination of field data, models and expert knowledge. Although, indicators selection is a critical process to represent a natural system, the PSR framework give a structure integrated more than simple indicators. As results of this research were obtained three indicators of pressure: water use conflicts, land use conflicts and population growth. Two indicators of state were defined: community participation and institutional coordination. Two indicators of response were defined: communication strategies and social participation, and council watershed with its own administrative system. These indicators are shown in the Table 1. In this case, indicators selection was based in both literature review and expert judgements on importance of these in assessment of governance in a Andean micro-watershed. A selection of some certain key indicators is recomendable, both to reduce the expenses for data collection and to increase comprehensibility and applicability ot the indicator system (Wolfslehner and Vacik, 2008: 2). Knowledge management describes the strategies and processes of acquiring, converting, applying, protecting and transferring knowledge to improve decisions

Table 1. Indicators Pressure-State-Response to evaluate the water governance in micro watershed Andean

Pressure	State	Response
Water use conflicts (WUC)	Community participation (CP)	Communication strategies and social participation (CSSP)
Land use conflicts (LUC)	Institutional coordination (IC)	Council watershed with its own administrative system (CWAS)
Population growth (PG)		

Triangular, singleton, trapezoidal funtions were assigned to each PSR indicator. These funtions were defined through of both literature review and expert judgement. An example of logic funtions is shown in the figure 4. The main advantage of Fuzzy analysis is the ability to deal with imprecise, unciertain, or ambiguos data or relationship, with clearly fits the study of ecologial and enviroment issues (Mettternicht, 2001). To each indicator was defined a function of fuzzy logic. Through the combination of these indicators was defined the water governance index (WGI).

PSR indicators were assessed by means of fuzzy inference systems through decision rules. To operate index IGW were defined 207 decision rules. In Table 2, are presented some inference rules for Pressure indicator from water governance index (WGI).

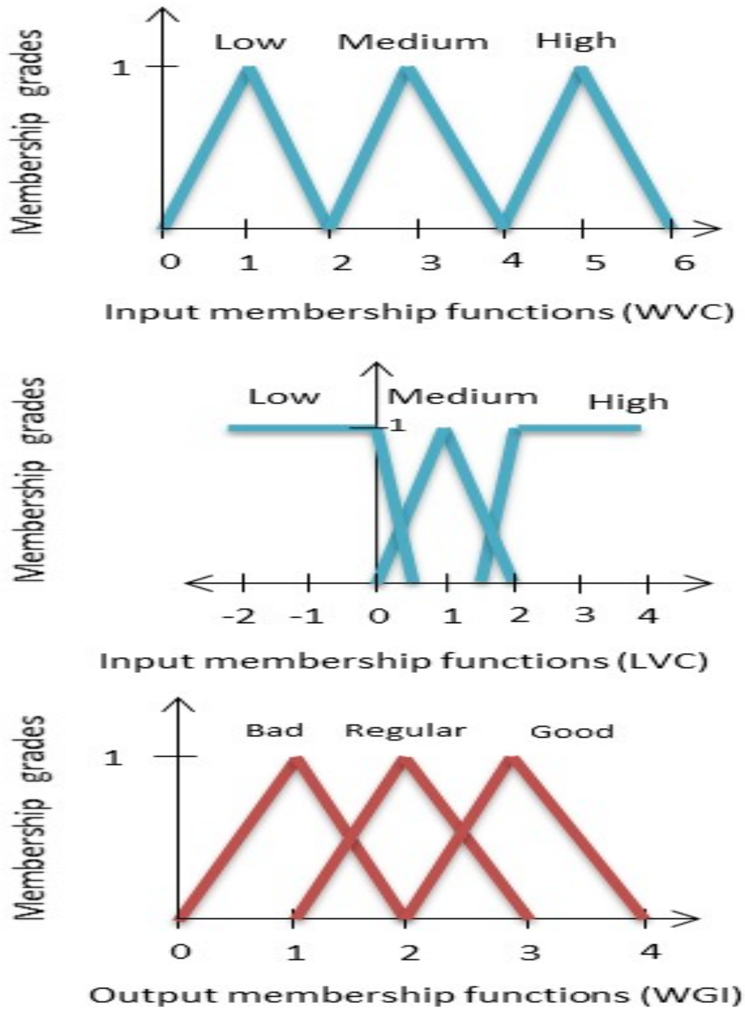

Figure 4. Some fuzzy functions to build index IGW

Table 2. Some inference rules for Pressure indicator from water WGI index

Rule No.	WUC	LUC	PG	Pressure	Rule
1	L	L	L	W	IF (WUC IS LOW) AND (LUC IS LOW) AND (TCP IS LOW) THEN PRESSURE IS WEAK
2	L	M	L	M	IF (WUC IS LOW) AND (LUC IS MEDIUM) AND (TCP IS LOW) THEN PRESSURE IS MEDIUM
3	L	H	L	S	IF (WUC IS LOW) AND (LUC IS HIGH) AND (TCP IS LOW) THEN PRESSURE IS STRONG
4	L	L	M	W	IF (WUC IS LOW) AND (LUC IS LOW) AND (TCP IS MEDIUM) THEN PRESSURE IS WEAK
5	L	M	M	M	IF (WUC IS LOW) AND (LUC IS MEDIUM) AND (TCP IS MEDIUM) THEN PRESSURE IS MEDIUM
::	::	::	::	::	:::
::	::	::	::	::	:::
26	H	M	H	S	IF (WUC IS HIGH) AND (LUC IS MEDIUM) AND (TCP IS HIGH) THEN PRESSURE IS STRONG
27	H	H	H	S	IF (WUC IS HIGH) AND (LUC IS HIGH) AND (TCP IS HIGH) THEN PRESSURE IS STRONG

Indicators were applied to the micro-watershed El Chocho. These were evaluated considering both information and data secondary. Each dataset was collected from reliable local authorities. The collected data were analyzed using Matlab tools. In Table 3 is presented the values of each indicator PSR and index WGI in micro watershed El Chocho in Valle del Cauca from Colombia.

Table 3. Values of indicators and index WGI in the micro watershed El Chocho in Valle del Cauca from Colombia.

Zone	Pressure	State	Response	Values of WGI
High	WUC=High LUC=Low PG=0,03	CP=20% IC=Low	CSSP=Low CWAS=No	BAD
Medium	WUC=High LUC= High PG=1,9	CP=30% IC=Low	CSSP=Low CWAS=No	BAD
Low	WUC=High LUC= High PG=0,1	CP=30% IC=Low	CSSP=Low CWAS=No	BAD

The results of water governance index showed mean require actions in short time, because of the overall performance was the lowest, which is indicative of poor performance in water governance in this micro watershed. These results are consistent with others studies development in this watershed (DAGMA, 2006; Domínguez and Corrales, 2006). In this micro watershed, it is necessary to applied principles that serve as basis for good governance, among others, transparency, fairness, accountability and corporate responsibility, creating mechanisms of control and monitoring, not only by water managers but also by shareholders, making it possible to identify and solve conflicts at different decision-making levels (Guimaraes et al., 2016: 2).

The WGI index is a framework that can be used in others Andean micro-watershed and in the Chocho micro watershed in next years to evaluate the level of advance in water governance. Although other index are been build, few were development with the methodology integrated of Pressure-State-Response and Fuzzy Logic. Similarly, the indexes generally are building to a specific application, no general way. For example, Lake Basin Water Governance Performance Composite Index (LBWGPCI) framework was developed to test and evaluate the performance of water governance for lake basins using the Songkhla Lake Basin (SLB) (Cookey, 2016: 5), this index used the PSR framework, but only can be used to specific Lake.

Conclusions

This study presented and evaluate a new index to qualitatively evaluate the performance of water governance in an Andean micro-watershed. The water governance index (WGI) allowed to measure the performance of water governance in the Chocho watershed in a more integrated and comprehensive manner. The results obtained helped to show the potential benefits of this index as tool for identifying zones in need of improvement in water governance in micro watershed. The computation of the WGI index and indicators associate made it possible to evaluate and identify some weaknesses and strengths of the water governance system. This is important, because of the possibility of definite in short future of the right priority actions to improve water and other related natural resources governance. This study indicates the possibility of building and applying an index of water governance to support management decision process in Andean watersheds. Further research and applications will be necessary to evaluate the capacity of this index as a standardized platform in the assessment of Andean micro-watershed water governance performance. Wide application and use will necessary to improve efficacy and confiability of this index. Stakeholders should provide the inputs of each indicator, through knowledge, information or data, in primary or secondary way.

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