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

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Abstract

This paper presents conceptual and operative index for assessment qualitatively the level of the water quality (WQI) in an Andean micro-watershed. A combination of pressure-state-response (PSR) indicators and logic fuzzy were used. The inputs of WQI are indicators in each zone: high, medium and low of the micro-watershed. The output is index value. The WQI was applied in an Andean watershed named “El Chocho”, in Colombia. The results indicated the high water quality degradation in the watershed. This study indicates the possibility of building and applying a WQI to support management decision process in Andean watersheds.

Introduction

Accessible and high quality freshwater is a limited and highly variable resource. OECD projections show that 40% of the world’s population currently lives in water-stressed river basins, and that water demand will rise by 55% by 2050 (OECD, 2015; 2). In 2050, 240 million people are expected to remain without access to clean water, and 1.4 billion without access to basic sanitation (OECD, 2015; 2). Water quality is an effective tool to investigate, describe and predict the ecological state of an aquatic ecosystem. Various environmental variables may simultaneously affect water quality. Appropriate selection of a limited number of key variables facilitates cost-effective management of water resources (Eurie et al., 2017: 1). Environmental indicators and indexes are essential tools for tracking environmental progress, supporting policy evaluation and informing the stakeholders. Decision makers need the appropriate indicators and indices to assess, track, and equitably weigh integrated human health, socio-economic, environmental, and ecological factors to foster 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 to conceptualize and to present a water quality index (WQI) for Andean micro-watershed.

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 and Sandoval, 2001: 4). 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 Vacick, 2008: 2) (see Figure 1).

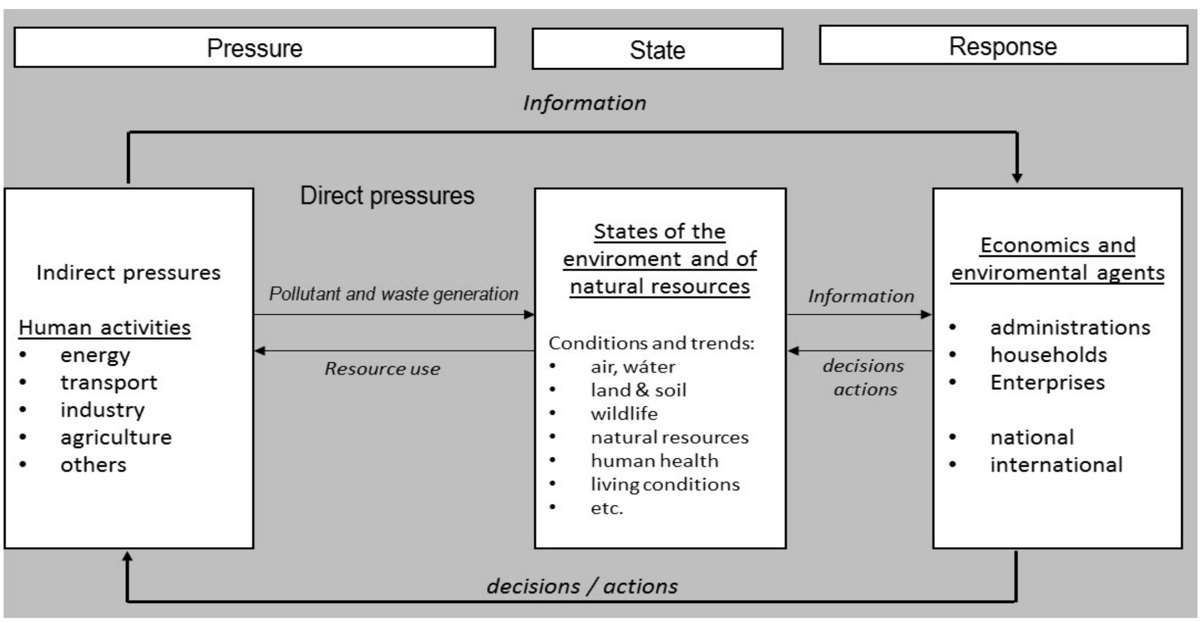

Figure 1. Pressure - State – Response (PSR) model (OECD, 1993)

General criteria include properties that must be fulfilled by any possible indicator. These criteria are (Camacho-Sandoval, 2001; 2):

· To represent an issue that is important to sustainable development.

· To be understandable to a general audience.

· To be quantifiable.

· To be based on available data.

· To be national in scope or relevant to an issue of national concern.
· To be scalable to different levels.

Fuzzy logic is a suitable mathematical tool with which to treat heterogeneous information that is affected by uncertainty and inaccuracy. Such is the case of the data handled in many environmental studies, which are frequently achieved from subjective judgments and assessments. The concept of fuzzy logic was introduced more than 40 years ago by Zadeh (Turek, 2009: 1). In general, fuzzy logic is an artificial intelligence (AI) technique that tries to emulate human decision processes, which are usually based on comparative estimation rather than on fixed thresholds (Turek, 2009: 2). AI consists of several branches, namely, Expert Systems (ES), Neural Networks (NN), Fuzzy Logic (FL), Evolutionary Algorithms (EA), Problem Solving and Planning (PSP), Knowledge Representation (KP), Common Sense Knowledge and Reasoning (CSKR), Logic Programming (LP), Natural Language Processing (NLP), Computer Vision (CV), Genetic Programming (GP), Non-Monotonic Reasoning (NMR), Pattern Recognition (PR), Heuristics, Robotics (HR), Hybrid Intelligent Electromechanical Systems (HIS), etc (Tabanjat, 2015: 3).

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. In Figure 2 is show an overview of the fuzzy inference process. These process allowed build a quality water index (QWI).

The water quality index (WQI) 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^{o}N, 76.34^{o}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, 2006). The elevation ranges from 950 to 2.000 m above sea level (see Figure3). 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.

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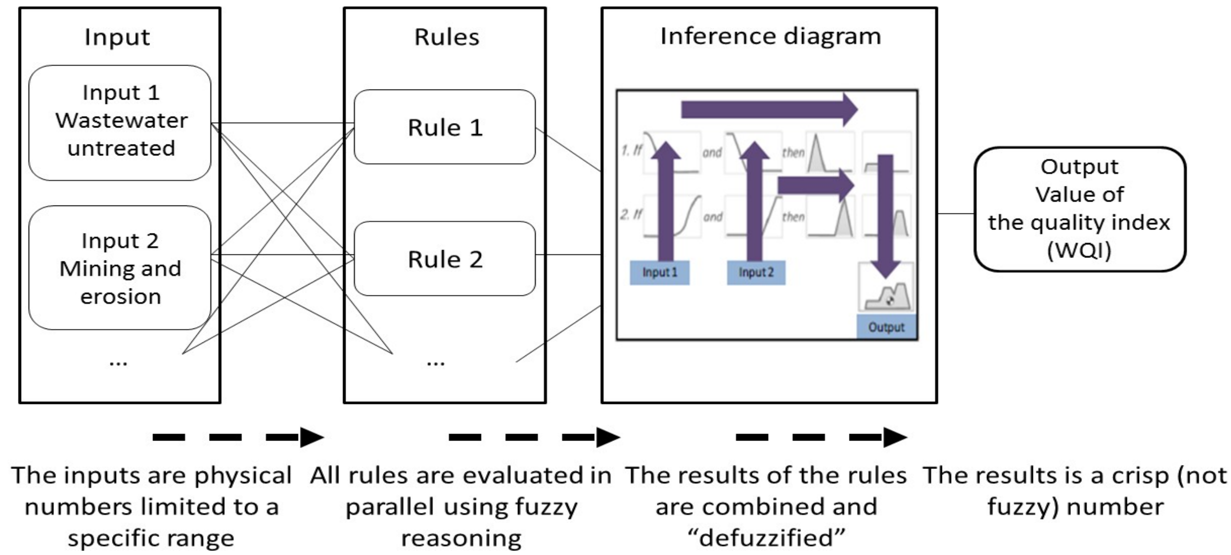

Figure 2. Overview of the fuzzy inference process (Adapted from Jia et al., 2016: 5).

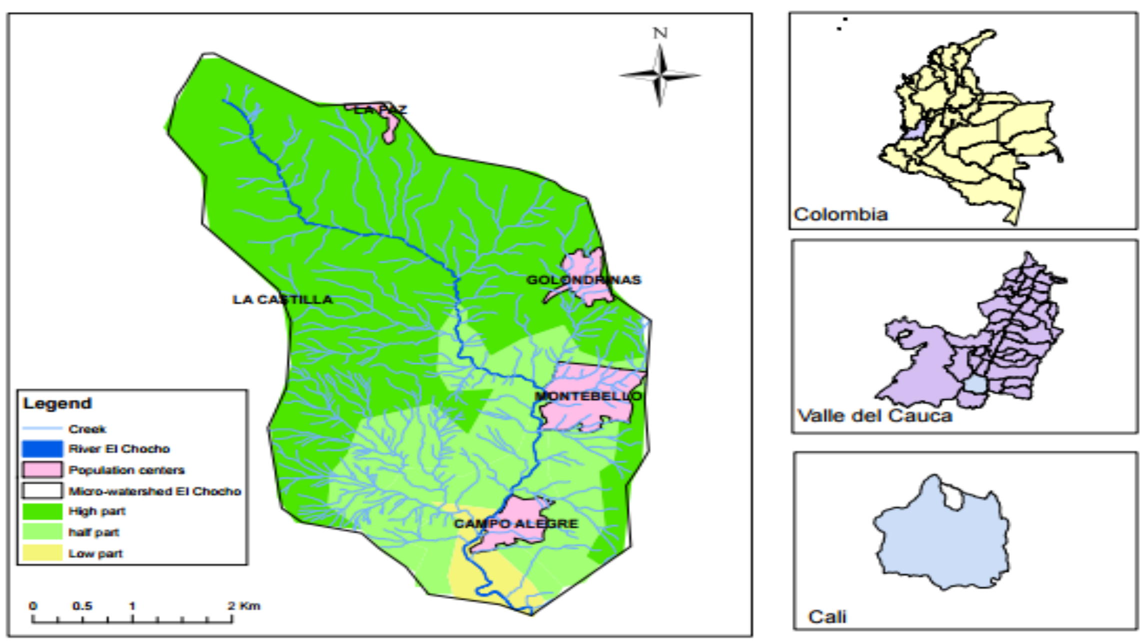

Figure 3. Localization of Chocho micro-watershed in Colombia

This micro-watershed has suffered a huge environmental damage, as a consequence 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 which affects the quantity and quality of water. Institutions that work in this area sometimes contribute with solutions, but sometimes make worse these problems

Result and discussion

Three indicators of pressure were defined: wastewater untreated, mining and erosion level. Two indicators of state were defined: water contamination by chemical oxygen demand and microbiological contamination by fecal coliforms. Three indicators of response were defined: Water waste treated, strategies mining sustainable and politics of reforestation and revegetation. 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).

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

Pressure	State	Response
Water waste untreated (WWU) Mining (M) Erosion Level (EL)	Water contamination by DQO (DQO) Microbiological contamination by fecal coliforms (FECAL)	Water waste treated (WWT) Strategies mining sustainable (SMS) Politics of reforestation and revegatation (PRR)

To each indicator was defined a function of fuzzy logic. 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). Through the combination of these indicators was defined the water quality index (WQI).

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

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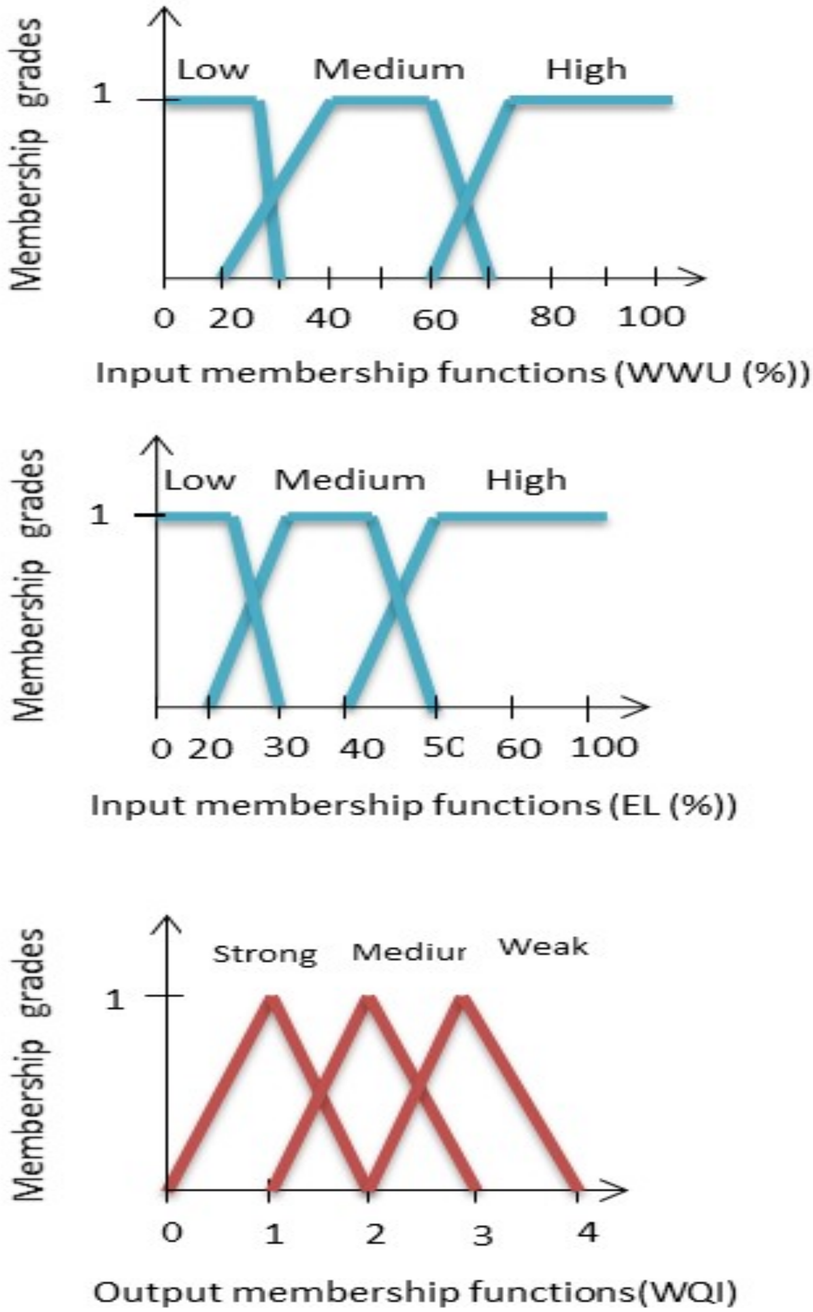

Figure 4. Some fuzzy functions to build index WQI

Table 2. Some inference rules for Pressure indicator from water quality index (WQI)

Rule No.	WWU	Mining	Erotion Level	Pressure	Rule
1	Low	Yes	Low	Strong	IF (WWU IS Low) AND (M IS Yes) AND (EL IS Low) THEN PRESSURE IS Strong
2	Low	Yes	Medium	Strong	IF (WWU IS Low) AND (M IS Yes) AND (EL IS Medium) THEN PRESSURE IS Strong
3	Low	Yes	High	Strong	IF (WWU IS Low) AND (M IS Yes) AND (EL IS High) THEN PRESSURE IS Strong
4	Medium	Yes	Low	Strong	IF (WWU IS Medium) AND (M IS Yes) AND (EL IS Low) THEN PRESSURE IS Strong
5	Medium	Yes	Medium	Strong	IF (WWU IS Medium) AND (M IS Yes) AND (EL IS Medium) THEN PRESSURE IS Strong
6	Medium	Yes	High	Strong	IF (WWU IS Medium) AND (M IS Yes) AND (EL IS High) THEN PRESSURE IS Strong
7	High	Yes	Low	Strong	IF (WWU IS High) AND (M IS Yes) AND (EL IS Low) THEN PRESSURE IS Strong
8	High	Yes	Medium	Strong	IF (WWU IS High) AND (M IS Yes) AND (EL IS Medium) THEN PRESSURE IS Strong
9	High	Yes	High	Strong	IF (WWU IS High) AND (M IS Yes) AND (EL IS High) THEN PRESSURE IS Strong
10	Low	No	Low	Weak	IF (WWU IS Low) AND (M IS No) AND (EL IS Low) THEN PRESSURE IS Weak
11	Low	No	Medium	Weak	IF (WWU IS Low) AND (M IS No) AND (EL IS Medium) THEN PRESSURE IS Weak
12	Low	No	High	Strong	IF (WWU IS Low) AND (M IS No) AND (EL IS High) THEN PRESSURE IS Strong
13	Medium	No	Low	Moderate	IF (WWU IS Medium) AND (M IS No) AND (EL IS Low) THEN PRESSURE IS Moderate
14	Medium	No	Medium	Moderate	IF (WWU IS Medium) AND (M IS No) AND (EL IS Medium) THEN PRESSURE IS Moderate
15	Medium	No	High	Strong	IF (WWU IS Medium) AND (M IS No) AND (EL IS High) THEN PRESSURE IS Strong
16	High	No	Low	Strong	IF (WWU IS HIGH) AND (M IS No) AND (EL IS Low) THEN PRESSURE IS Strong
17	High	No	Medium	Strong	IF (WWU IS HIGH) AND (M IS No) AND (EL IS Medium) THEN PRESSURE IS Strong
18	High	No	High	Strong	IF (WWU IS High) AND (M IS No) AND (EL 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 IQW in micro watershed El Chocho in Valle del Cauca from Colombia.

Table 3. Values of indicators and index WQI in the micro watershed El Chocho

Zone	Pressure	State	Response	Values of WQI
High	WWU=90% M=Yes EL=50%	DQO=400 (mg/l) FC=1.000(UFC/100ml)	WWT=0% SMS=No PRR=No	BAD
Medium	WWU=80% M=Yes EL=60%	DQO=800mg/l FC=20.000(UFC/100ml)	WWT=0% SMS=No PRR=No	BAD
Low	WWU=80% M=Yes EL=60%	DQO=800mg/l FC=20.000(UFC/100ml)	WWT=0% SMS=No PRR=No	BAD

The results of water quality index shows require immediate, urgent and critical actions be taken because the overall performance was the lowest, which is indicative of poor performance in water quality in this micro watershed. These results are consistent with others studies development in this watershed (DAGMA, 2006; Domínguez y Corrales, 2006). In this micro watershed, it is necessary to applied principles that serve as basis for sustainability in quality water.

The WQI 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 quality. 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. Water quality indexes based on fuzzy systems have been recently proposed in scientific literature with relative success. The fuzzy frame clearly improves the conceptual design of the indexes, because they are computed with expert rules and sets to provide final numerical/linguistic scores that include a convenient treatment of linguistic uncertainty and subjectivity (Ocampo-Duque, 2013: 27).

Conclusions

The water quality index (WQI) presented in this article is a new approach that combines pressure-state-response model with fuzzy logic for support decision-making in micro-watershed management. The results obtained helped to show the potential benefits of this index as tool for identifying zones in need of improvement in micro watershed in water quality. The water quality index (WQI) presented in this article is a new approach that combines pressure-state-response with fuzzy logic for support planning management in watershed. Planning management in watershed involves both complex and several parameters with a high degree of uncertainty due to incomplete understanding and models in all this parameters. The water quality index (WGI) allowed to measure the performance of water quality in the Chocho watershed in a more integrated and comprehensive manner. The computation of the IQW index and indicators associate makes it possible to evaluate and identify some weaknesses and strengths of the water quality system. This is important, because of the set-ting in short future of the right priority actions to improve water quality. This study indicates the possibility of building and applying an index of water quality to support management decision process in Andean watersheds. Nevertheless, more applications are necessary to assessment this new index. Knowledge management describes the strategies and processes of acquiring, converting, applying, protecting and transferring knowledge to improve decisions.

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