WATER MANAGEMENT IN COLOMBIA FROM THE SOCIO-ECOLOGICAL SYSTEMS FRAMEWORK

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ABSTRACT

Nowadays the main challenge for water management is to seek water resilience. The socio-ecological systems approach was developed by Ostrom with the aim of synthesizing knowledge to foster a better understanding of the relationship between people, institutions and the environment. The SES framework allows us to identify the SES main characteristics and provide information on the modes of interaction and self-organization processes between the actors involved in the collective management of the common use resource. Actually, Colombia presents a great vulnerability of water scarcity, so the purpose of this paper was to review actual water management in Colombia and propose the social-ecological systems framework that allows safeguarding and sustaining the water cycle, guaranteeing a sufficient water supply and providing a stable climate system for secure human well-being in Colombia.
Keywords: Colombia, socio-ecological systems, water management, water resilience.

1 INTRODUCTION

Water availability per capita worldwide is steadily decreasing due to the growing world population in relation to available water [1]. The main causes of the deficit in water supply are climate change and climate variability, which determine variations in the amount and temporal distribution of precipitation affecting the hydrological cycle, contributing to water scarcity [2]–[4]. Recent studies have also argued that water demand contributes to water scarcity, with agriculture being the main consumer [5]–[8]. Proof of this is the drastic transformation of land cover, which has led to a conflict between the temporal and spatial distribution of water resources, as well as an intensification of the contradiction between supply and demand, which seriously restricts the sustainable development of a basin [9].

Domínguez et al. [10] studied the Colombian water supply and potential water demand by the different productive sectors, concluding that the maximum demand and supply magnitudes do not coincide in space, causing conflict and high levels of pressure on the water resource. According to the National Water Study 2018 [11], the region with the highest vulnerability to water deficit in Colombia is the Caribbean hydrographic area, the second hydrographic area with the highest demand in the country. Likewise, the study forecasts shortages in the departments of La Guajira, Magdalena, Cesar and Bolivar, where at least 50% of their municipalities will be affected. According to the report of the United Nations Development Programme [12].

Sustainable water management is a growing concern worldwide, Baudoin and Arenas [13] conducted a bibliometric study of current water resource management worldwide and found that it is being approached from different theoretical approaches and that there is a risk that water management research is going in different directions simultaneously, without academics taking advantage of each other's work. Evidencing that management theories do not align toward an improved understanding of sustainable water management. The main objective in this paper was to review water management in Colombia and propose a social-ecological systems framework that allows the water resilience.

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2 SOCIAL-ECOLOGICAL SYSTEMS (SES) FRAMEWORK

The socio-ecological systems (SES) approach was developed by Ostrom [14], [15] and refined by McGinnis and Ostrom [16] with the aim of synthesizing knowledge to foster a better understanding of the relationship between people, institutions and the environment [17]. The SES framework was developed as a tool to study the relationships between the multiple levels that compose a common, its application can support the identification of the main characteristics of the SES and provide information on the modes of interaction and the processes of self-organization between the actors involved in the collective management of the common pool resources [18]. Fig. 1 and Table 1 show the first-tier components and second-tier variables of the SES framework

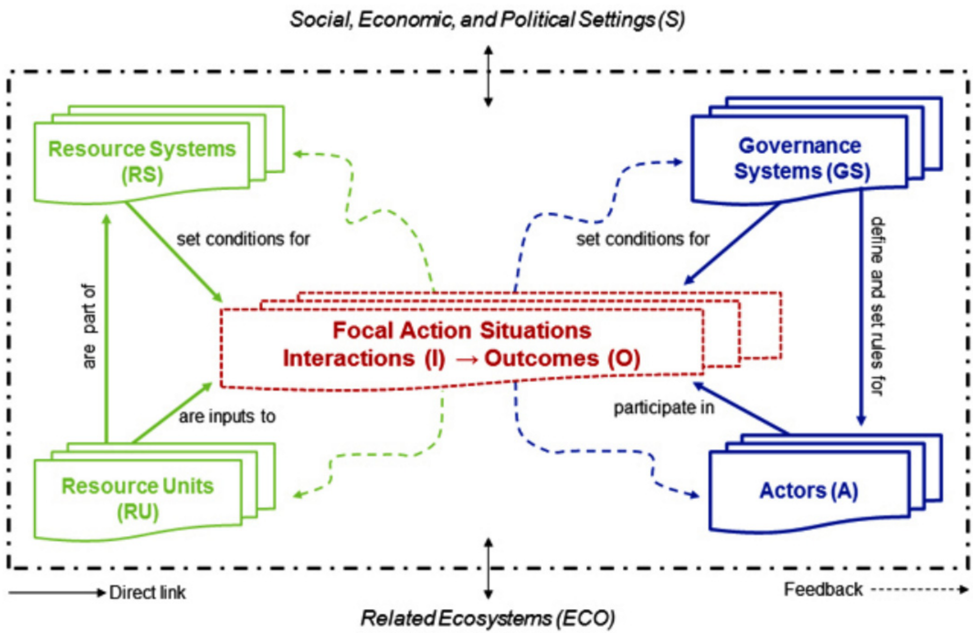

Figure 1: Revised social-ecological system (SES) framework with multiple first-tier components [16].

Application of the SES framework to particular cases requires a three-step process. In the first step, the analyst must select a focal level of analysis by answering such questions as: What types of interactions and outcomes related to a particular resource system (or group of systems) and related resource units (or other relevant goods and services) are most relevant to my analytical or diagnostic concerns? What types of actors are involved? Which governance systems influence the behavior of these actors? [18].

3 COLOMBIA WATER MANAGEMENT

The objective of the water resource management Colombian policy is to guarantee the sustainability of water resources, through efficient and effective management and use, articulated with land use, planning and the conservation of ecosystems that regulate the water supply, considering water as a factor of economic development and social welfare, and

Table 1: Second-tier variables of a social-ecological system [16].

First-tier variable	Second-tier variables
Social, economic, and political settings (S)	S1 – Economic development
	S2 – Demographic trends
	S3 – Political stability
	S4 – Other governance systems
	S5 – Markets
	S6 – Media organizations
	S7 – Technology
Resource systems (RS)	RS1 – Sector (e.g., water, forests, pasture, fish)
	RS2 – Clarity of system boundaries
	RS3 – Size of resource system
	RS4 – Human-constructed facilities
	RS5 – Productivity of system
	RS6 – Equilibrium properties
	RS7 – Predictability of system dynamics
	RS8 – Storage characteristics
	RS9 – Location
Governance systems (GS)	GS1 – Government organizations
	GS2 – Nongovernment organizations
	GS3 – Network structure
	GS4 – Property-rights systems
	GS5 – Operational-choice rules
	GS6 – Collective-choice rules
	GS7 – Constitutional-choice rules
	GS8 – Monitoring and sanctioning rules
Resource units (RU)	RU1 – Resource unit mobility
	RU2 – Growth or replacement rate
	RU3 – Interaction among resource units
	RU4 – Economic value
	RU5 – Number of units
	RU6 – Distinctive characteristics
	RU7 – Spatial and temporal distribution
Actors (A)	A1 – Number of relevant actors
	A2 – Socioeconomic attributes
	A3 – History or past experiences
	A4 – Location
	A5 – Leadership/entrepreneurship
	A6 – Norms (trust-reciprocity)/social capital
	A7 – Knowledge of SES/mental models
	A8 – Importance of resource (dependence)
	A9 – Technologies available

Table 1: Continued.

First-tier variable	Second-tier variables
Action situations: Interactions (I) → Outcomes (O)	I1 – Harvesting
	I2 – Information sharing
	I3 – Deliberation processes
	I4 – Conflicts
	I5 – Investment activities
	I6 – Lobbying activities
	I7 – Self-organizing activities
	I8 – Networking activities
	I9 – Monitoring activities
	I10 – Evaluative activities
Related ecosystems (ECO)	O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability)
	O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)
	O3 – Externalities to other SESs Related ecosystems (ECO)
	ECO1 – Climate patterns
	ECO2 – Pollution patterns
	ECO3 – Flows into and out of focal SES

implementing processes of equitable and inclusive participation [19]. The above was divided into several objectives focused on supply, demand, quality, risk, institutional strengthening and governance. However, in 2019 the Office of the Comptroller General of the Republic [20] concluded that three years after finalizing the implementation of the policy, there are weaknesses and problems, the main ones being difficulties in the study of supply and demand. The water resource information system to evaluate supply is not clear, the environmental authorities are unaware of the real demand for water resources in their territories, and finally, the actions aimed at protecting water resources are not coordinated with planning and land use instruments. The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) is in charge of carrying out the integral evaluation of water resources in Colombia through the National Water Study, which is presented every 4 years. The conceptual framework of the National Water Study is the hydrological cycle, which is based on the water balance to estimate the natural amount of renewable freshwater available and its spatial and temporal distribution according to the behavior of precipitation, evapotranspiration and runoff variables in the hydrographic subzones that make up the Colombian territory [11]. From the socio-ecological systems approach, it is evident that the study is focused on the system and the resource units, not taking into account the variables of the social, economic and political environment, the governance systems, action situations and related ecosystems.

The following is a bibliographic review of water resource management in Colombia, for which a search was conducted in both Spanish and English. The search covered the years 2000–2022 in the google academic, ScienceDirect and Scopus databases. Journal articles and doctoral theses were reviewed. To perform the analysis, each article was reviewed from two approaches. The first consisted of evaluating the factual characteristics, theoretical framework and methodology, in order to identify the line of research. The second consisted of a qualitative evaluation of the content using the social-ecological systems approach, in

Table 2: Descriptive overview of the research stream and analysis through the social-ecological systems framework.

Articles	Article type	Research stream	Analysis through the social-ecological systems framework
Climate change and water resources in Colombia [21].	Research	Spatial water availability modeling	Resource systems (RS), Resource units (RU), Related ecosystems (ECO)
Reflection on the vision of integrated management of vulnerability due to water shortages in rural zone of Colombia [22]	Review	Analysis of the concepts of adaptive management, resilience and governance for integrated water resource management	Governance systems (GS), Related ecosystems (ECO)
Integration of hydrological and economical aspects for water management in tropical regions. Case study: Middle Magdalena Valley, Colombia [23]	Research	Spatial and temporal water availability modeling and Integrated water resource management	Social, economic, and political settings (S), Concern, resource systems (RS), Resource units (RU), Action situations: Interactions (I), Related ecosystems (ECO)
Integrated water resource management in Colombia: Paralysis by analysis? [24]	Review	Integrated water resource management	Governance systems (GS)
Water management analysis in the Magdalena basin in Colombia [25]	Research	Spatial and temporal water availability and water demand modeling	Social, economic, and political settings (S), Concern, resource systems (RS), Resource units (RU), Action situations: Interactions (I), Related ecosystems (ECO)
Collective action for watershed management: Field experiments in Colombia and Kenya [26]	Research	Collective action on basins	Resource systems (RS), Governance systems (GS), Actors (A), Action situations: Interactions (I) → Outcomes (O)
Development and testing of a river basin management simulation game for integrated management of the Magdalena-Cauca river basin [27]	Research	Serious game for basin integrated management	Resource systems (RS), Governance systems (GS), Resource units (RU), Actors (A), Action situations: Interactions (I) → Outcomes (O)
Relaciones demanda-oferta de agua y el índice de escasez de agua como herramientas de evaluación del recurso hídrico Colombiano [10]	Research	Spatial and temporal water availability and water demand modeling	Resource systems (RS), Resource units (RU), Related ecosystems (ECO)

Table 2: Continued.

Articles	Article type	Research stream	Analysis through the social-ecological systems framework
Validation of the three-step strategic approach for improving urban water management and water resource quality improvement [28]	Research	Water resource quality improvement	Action situations: Interactions (I) → Outcomes (O)
Considerations of environmental ethics in the comprehensive management of water resources in the Quindío River basin [29]	Review	Environmental ethics in the integrated management of water resources	Resource systems (RS), Resource units (RU), Related ecosystems (ECO)
Components to formulate an integrated water resources management. Case study in Quindío Basin [30]	Research	Elements for formulating integrated water resource management	Resource systems (RS), Resource units (RU), Action situations: Interactions (I) → Outcomes (O), Related ecosystems (ECO)
Climate variability, climate change and water resources in Colombia [31]	Review	Climate variability and climate change	Resource systems (RS), Resource units (RU), Related ecosystems (ECO)
Integrated water resource management as a strategy for adaptation to climate change [32]	Review	Integrated water resource management	Resource systems (RS), Resource units (RU), Related ecosystems (ECO)
Challenges in environmental governance: An approach to the implications of integrated water resource management in Colombia [33]	Review	Water governance	Governance systems (GS)
A case study of group decision method for environmental foresight and water resources planning using a fuzzy approach [34]	Research	Fuzzy opinion to solve the decision-making problem on water management	Resource systems (RS), Resource units (RU), Action situations: Interactions (I), Related ecosystems (ECO)
Research advances on the integral management of water resource in Colombia [35]	Research	Integrated water resource management	Resource systems (RS), Resource units (RU)
Water resource management and economic value [36]	Review	Management and economic value of water resources	Resource units (RU)

Table 2: Continued.

Articles	Article type	Research stream	Analysis through the social-ecological systems framework
Planning and management of water resources: A review of the importance of climate variability [37]	Review	Climate variability	Resource systems (RS)
Simulation of infrastructure options for urban water management in two urban catchments in Bogotá, Colombia [38]	Research	Stormwater harvesting, reuse of industrial waters, water-saving technology in residential sectors, and reuse of water from washing machines	Resource systems (RS), Resource units (RU)
Engaged universals and community economies: The (human) right to water in Colombia [39]	Research	Right to water	Governance systems (GS)
Development and implementation of a water-safety plan for drinking-water supply system of Cali, Colombia [40]	Research	Water safety plan	Resource systems (RS), Resource units (RU), Governance systems (GS)
El índice de escasez de agua ¿Un indicador de crisis ó una alerta para orientar la gestión del recurso hídrico? [41]	Research	Indicators of water supply and demand	Resource systems (RS), Resource units (RU)
Comparative analysis of integrated water resources management models and instruments in South America: Case studies in Brazil and Colombia [42]	Review	Integrated water resource management	Governance systems (GS)
Framework for water management in the food–energy–water (FEW) nexus in mixed land-use watersheds in Colombia [43]	Research	Food–energy–water nexus framework	Resource systems (RS), Resource units (RU)
Governance of water resources in Colombia: between progress and challenges [44]	Review	Water resources governance	Governance systems (GS)

order to develop an integral perspective of water resource management in the research. Table 2 shows the descriptive overview of the research stream and analysis through the social-ecological systems framework.

We collected 25 articles in total. The articles collected are predominantly research articles with 60% (15). The remaining 40% (10) were literature reviews. The main focus of the research streams were the spatial and temporal water availability and water demand modeling and the Integrated water resource management.

The conclusion of all the articles that studied the Integrated water resource management is that in Colombia it has had a limited application and no spaces have been developed to promote the development of collective water management projects.

From the analysis through the social-ecological systems framework it is evident that in Colombia most of the studies are focused on the Resource systems (RS), Resource units (RU) and Governance systems (GS). Therefore, although these studies on water management cover a part of the problem, there are other unknown variables that have the power to explain better how the socio-ecological system works, so it is necessary to rethink a conceptual framework from all the first-tier components, that will allow to achieve water resilience.

4 COLOMBIA WATER MANAGENMENT SOCIO-ECOLOGICAL SYSTEM FRAMEWORK

The idea that anthropogenic water systems can be resilient to the pressures of scarcity only through economic decision-making (e.g. cost–benefit analysis), engineering and technology is beginning to be undermined [45]. This framework has not previously been applied within the realm of water resources management and may prove a useful tool in planning for better management and, ultimately, future resilience [45]. Governance of water functions for social-ecological resilience must be continuous, adaptive, iterative and incremental in nature to enable learning in a dynamically changing environment, to be nested and harmonized across sectors and scales to manage interactions and interconnections [46].

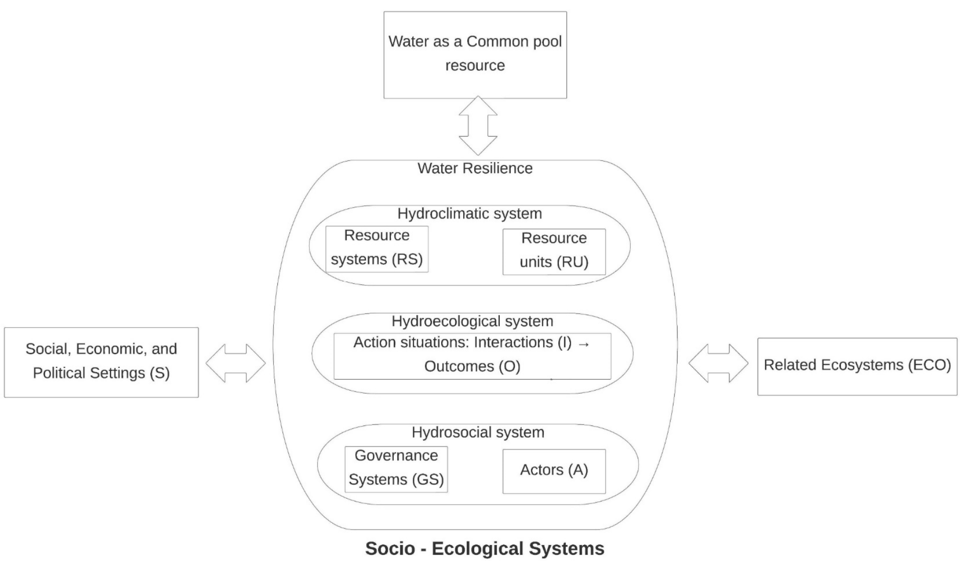

Figure 2: Colombian social-ecological system (SES) framework. *(Source: Adapted from [16].)*

The central topic addressed in the Colombia water management SES framework is the water as a common pool resource. The water as a common pool resource can be viewed as a SES because it entails a human group that is dependent on a resource, an ecosystem that provides it and a socio-cultural system that allows humans interact with the ecosystem.

In Fig. 2 the water as a common pool resource is linked to a socio-ecological systems box where are the main subsystems of a SES and illustrates how the different subsystems occur. These interactions generate outcomes that feedback the SES' subsystems. The SES box includes the concept of water resilience because this is a notion that includes the dynamic perspective to the SESs analysis.

5 CONCLUSIONS

As a result of the review of the state of the art of current water management in Colombia, it is observed that the integrated water resource management approach has not been implemented in the best way. This is due to the fact that all the studies are only focused on some variables that affect the system and the problem of water resilience is not being seen from the socio-ecological system framework.

A new conceptual framework for water management in Colombia was proposed, involving a larger number of variables to better understand the interaction between hydroclimatic, hydrosocial and hydroecological systems. This new l framework is important because water management had never been approached in Latin America from the socio-ecological systems framework.

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