

Systematic Review

Adaptive Water Management from a Socio-Ecological Perspective: A Systematic Review of Co-Learning Strategies and Traditional Knowledge

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Abstract

This article presents a systematic review based on indexed scientific sources, focusing on adaptive water management from a socio-ecological perspective, with an emphasis on co-learning and traditional knowledge. The study used Bibliometrix software to explore the evolution and thematic patterns within the literature. Articles were assessed using the PRISMA framework to identify those most suitable for inclusion. Forty-three articles were selected based on their content validity, relevance to the research question, strength of evidence, and year of publication (2010–2025), including a synthesis and classification of the identified components. This review highlighted relevant research gaps and proposed future areas of study. Furthermore, a conceptual model for adaptive water management is presented, illustrating the interconnection between the various components analyzed. This model establishes a path based on the Participatory Action Research (PAR) approach, which is postulated as a methodological tool that promotes governance, recognizes local knowledge in territories, and fosters resilience in the face of challenges such as climate change.

Keywords: territories; governance; social learning; local knowledge; PAR: participatory action research; resilience



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1. Introduction

In the current context of environmental crisis and increasing pressure on water sources, understanding the interactions between human societies and ecosystems has become crucial. Socio-ecological systems (SES) are integrated systems that dynamically link social components, such as institutions and communities, with ecological components, including biodiversity and ecosystem services [1]. These systems are characterized by their complexity, adaptability, and self-regulatory capacity in the face of external disturbances. From a resilience perspective [2,3], it should be emphasized that SES are not static but evolve through feedback cycles. Additionally, the fundamental vision of common-pool resource governance within these systems must be taken into consideration [4]. Understanding SES allows for the design of sustainable strategies in response to global challenges, such as climate change, biodiversity loss, and hierarchical social approaches (fields and power relations [5]).

The conceptual framework of SES emerges as an alternative for adaptive water management. This perspective recognizes the need to manage water under conditions of uncertainty, promoting institutional flexibility and continuous learning from an integrative vision that links ecological resilience with the active participation of communities [6]. From another perspective, the role of social learning, governance, and institutional transformation is emphasized as central elements of adaptation [7,8]. Furthermore, the importance of experimentation and monitoring in multi-level adaptive water management processes is highlighted; these approaches, though diverse, concur that adaptively managing water requires flexible structures, effective participation, and a systemic understanding of the environment [9].

It is essential to emphasize that this research prioritizes co-learning among local communities, institutional actors, and academia, while also acknowledging the importance of recognizing traditional knowledge as a fundamental contribution to Adaptive water management in territories. Such knowledge enables the incorporation of diverse territorial perspectives, thereby strengthening resilience and generating context-specific solutions [1]. By integrating scientific and ancestral knowledge within this interdisciplinarity, social and ecological innovation is enhanced. This synergy improves collective decision-making and promotes more inclusive governance.

This systemic review article, which addresses adaptive management based on co-learning and traditional knowledge, is structured around the following questions: What are the main thematic components that have been identified? Which studies exist, and how are these themes addressed jointly? What research gaps are identified? How can an SES-based approach promote adaptive water management through co-learning between local communities and institutional actors? To answer these questions, a theoretical synthesis is proposed, articulating the principal academic approaches to SES, adaptive water management, co-learning processes, Participatory Action Research (PAR), and traditional knowledge, conducting a literature review, highlighting the advances and contributions of various studies in these fields.

The structure of this article is divided into three sections: the first presents the materials and methods used to organize and select the relevant literature; the second outlines the results and discussion, addressing the research questions and integrating diverse disciplinary perspectives in order to propose a conceptual model that illustrates how the main components identified are interconnected; and the final section provides the conclusions drawn from this review.

2. Materials and Methods

This work follows the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) systematic review protocol, which consists of a set of standards using a checklist of the following elements [10] (Supplementary Materials):

(a) Definition of the problem, in relation to the following questions:

- How are adaptive management, co-learning, and traditional knowledge integrated in the studies found?
- What are the main thematic components and main contributions?
- What research gaps have been identified?
- How can a Socio-Ecological Systems (ESS) approach promote adaptive water management through co-learning between local communities and institutional actors?

(b) Eligibility criteria: Studies published in English between 2010 and 2025, to ensure the validity of the data and the relevance of the analytical approaches reviewed. The scope of the study included only studies that explicitly address the interrelationship between socio-ecological systems, adaptive water management, co-learning, and traditional knowl-

edge; empirical research, theoretical reviews, or case studies that provide substantial or conceptual evidence on the topics; and publications in English. In addition, exclusion criteria were applied, such as duplicates, publications without access to the full text, and articles that mention key terms superficially without delving into their relationship or joint application.

The references of the selected articles were used as a research source to expand the theoretical and conceptual framework, as well as to specifically identify the fundamental concepts examined in the study. Furthermore, to enrich the conceptual framework and provide a solid theoretical foundation, this article incorporates publications belonging to the discipline's recognized classic theory. These were particularly relevant in the introduction and discussion sections, as they allow for a broader and more contextualized view. Their inclusion allowed not only an understanding of the evolution of the topic over time, but also a dialogue between recent findings and theoretical foundations. In addition to the systematic search conducted in Scopus and Web of Science, additional sources and databases were consulted, such as Google Scholar and the FAO (FAO) AGRIS (International Agricultural Science and Technology System). This complementary search aimed to identify studies that, although not indexed in these databases, are relevant to the study objectives, especially those related to traditional and indigenous knowledge in water management systems.

As a result of this expanded exploration, six additional articles were identified that significantly contribute to the understanding of the interaction between adaptive water management, co-learning, traditional knowledge, and socio-ecological systems. These works were incorporated to enrich the theoretical discussion and offer a more diverse and representative perspective, especially from applied and local contexts.

(c) Databases: Scopus and Web of Science (WoS).

(d) The keywords that best represented the research objective were identified, and the following search equation was applied: ("social-ecological system" OR "socio-ecological system" OR "SES") AND ("adaptive water management" OR "adaptive management of water resources") AND (social AND learning) AND (traditional AND knowledge).

Studies that contribute to the understanding of the interaction between co-learning, traditional knowledge, and adaptive water management will be considered. For the analysis, it was essential that the selected articles address the topic of adaptive water management and encompass various dimensions of sustainability, including social, cultural, educational, political, economic, and technological aspects. Articles specifically focused on fields such as medicine and computer science were excluded from the analysis.

For the bibliometric review, Bibliometrix 4.0 software [11] was used, which facilitates the execution, retrieval, representation and processing of statistical data derived from bibliographic searches. Bibliometrics (the application of quantitative and statistical analysis to scientific publications, such as scientific journal articles) provides objective and reliable information [11], focusing on the examination of patterns and flows of documentary information that characterize and contribute to the advancement of scientific activity [12]. Furthermore, the use of relational bibliometrics through data visualization techniques is useful to delimit topics, publications and authors, thus improving the capacity for analysis and understanding of a specific field of study [13,14]. The following fields were taken into account in the search process: title, keywords and abstract. Applying the defined selection criteria to the sample and considering the period from 2010 to 2025, a total of 71 articles were identified. These articles were related to the topics of Socioecological Systems (SES), adaptive water management, co-learning, and traditional knowledge. A two-stage review was then conducted: first by reading titles and abstracts to discard irrelevant works, and then by a full reading of the selected texts. that met all the established criteria and were

considered relevant for the in-depth analysis. After this rigorous evaluation and filtering process, two reviewers independently evaluated the papers. After reaching a consensus, a final selection of 43 articles was obtained that met all established criteria and were considered relevant for the in-depth analysis. Regarding the geographical origin of the studies analyzed, there is a notable concentration of publications originating in the United States, Australia, and the United Kingdom, reflecting a widespread trend in international scientific literature, dominated by Anglo-Saxon contexts. This search process was carried out using the Scopus and Web of Science databases.

The flowchart of the search process, based on the PRISMA protocol, is presented in Figure 1. The selected documents were then exported to Bibliometrix in BibTeX format, including all available data.

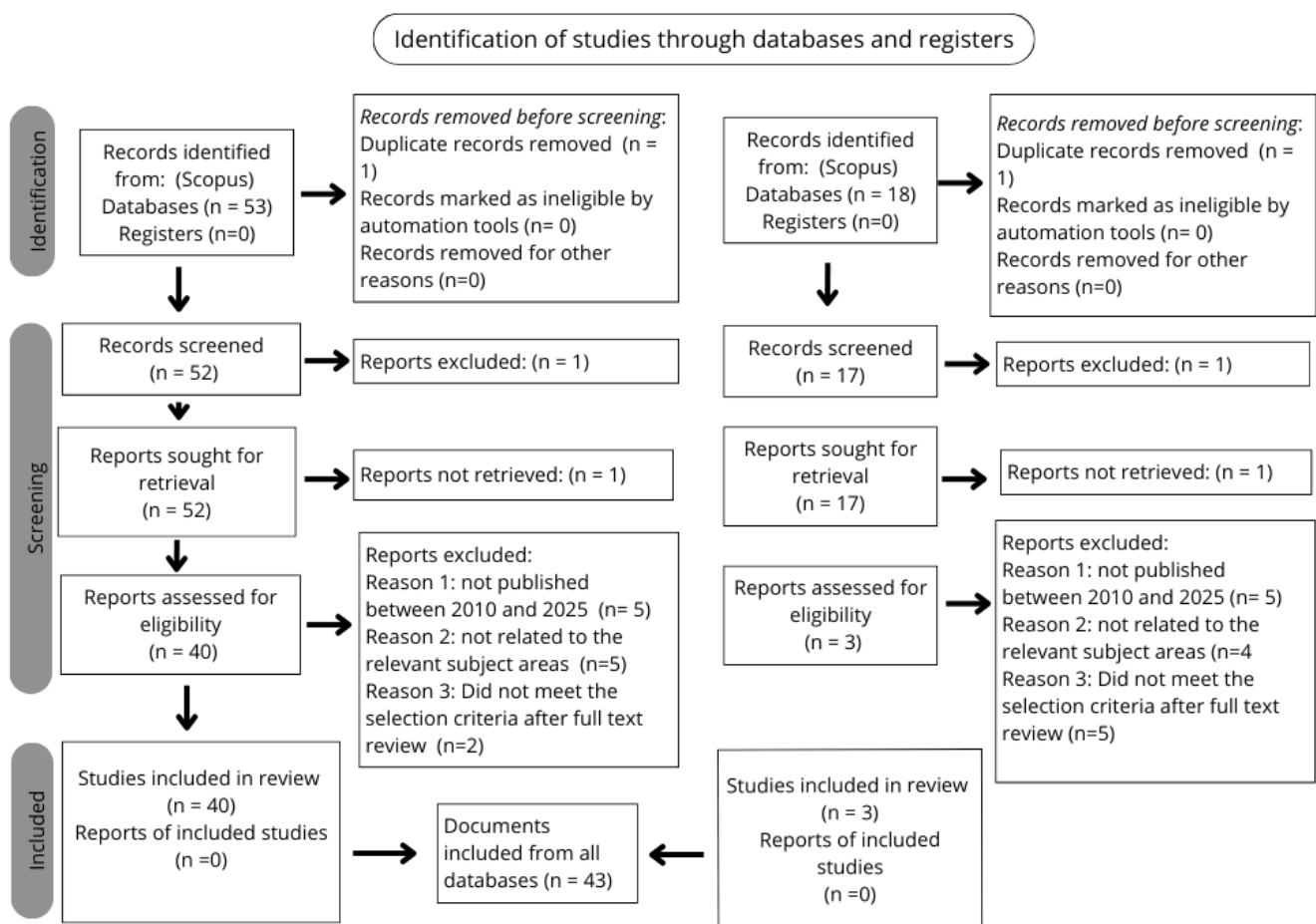


Figure 1. Flow diagram of the search process conducted in accordance with the PRISMA protocol [15].

3. Results

3.1. Thematic Map. Bibliometrix

Using data processed using Bibliometrix software, thematic maps were developed to examine the conceptual structures of the field of study. This technique, based on keyword co-occurrence analysis, organizes concepts in a two-dimensional space composed of two axes: centrality (horizontal), which measures the importance of a topic within the overall field, and density (vertical), which reflects the level of internal development of that topic. This methodological approach is based on the contributions of scientific mapping, an analytical tool [16] that allows for visualizing the evolution and structure of areas of scientific knowledge [17,18].

Figure 2, titled Thematic Map, is divided into four quadrants:

- Driving Themes (upper right quadrant). This quadrant includes themes with high density and high centrality, considered the most established and articulated in the field. This analysis highlights learning, traditional knowledge, and protected areas, which not only demonstrate solid conceptual development but also strong connections to other key areas.
- Emerging or Declining Themes (lower left quadrant). Themes with low density and low centrality are located here, which may indicate underexplored areas or areas in the emerging phase. In this case, the topic of green spaces is identified as emerging. Although widely studied from the perspective of ecology, its approach in other fields—such as education, social work, and urban planning—is recent, indicating its progressive incorporation into the discourse of sustainable development [19,20].
- Basic or Cross-Cutting Themes (Central Quadrant). Themes with intermediate centrality and density are located in the centre of the map. These themes are considered cross-cutting, as they bridge different areas of knowledge. In this study, the concepts of forest management, forest ecosystems, and governance approaches stand out in this position. Their central location indicates that these themes are fundamental within the field, as they connect with multiple lines of research, but are still undergoing deeper theoretical development. Their cross-cutting nature suggests that they are key concepts for the integration of ecological, social, and political perspectives, especially in the contexts of conservation and territorial management.

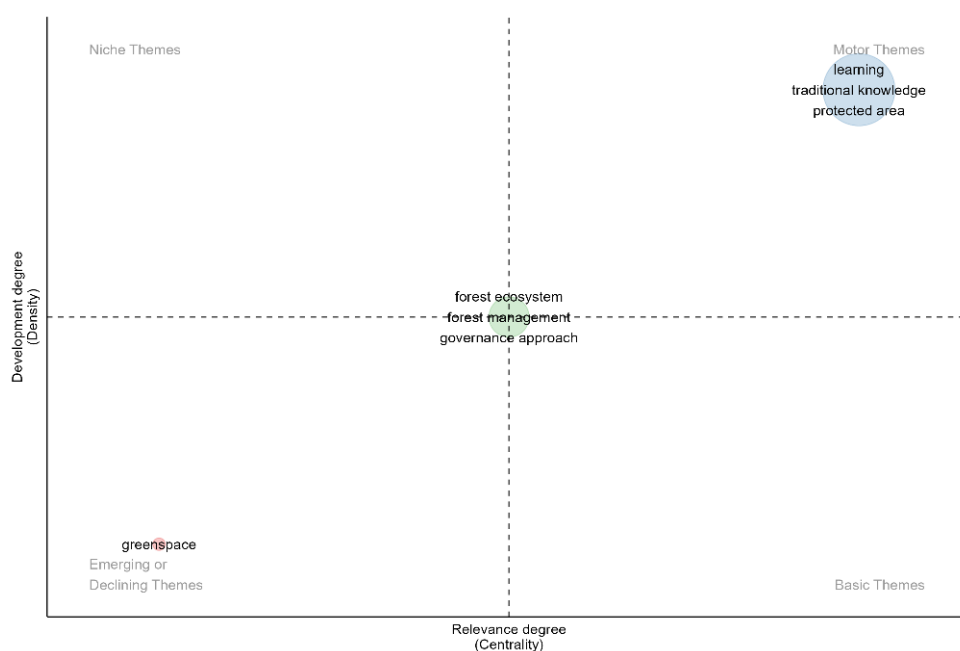


Figure 2. Thematic Map. Bibliometrix.

3.2. Bibliometric Review: Thematic Analysis and Description of Common Content

To address the research questions: What studies exist, and how are adaptive management, co-learning, and traditional knowledge jointly approached? What are the main thematic components and key contributions? What research gaps can be identified? The studies identified were systematized. Table 1 summarizes this systematization, presenting the main contributions of each study and the degree of integration of the three approaches analyzed: adaptive management, co-learning, and traditional knowledge. These approaches were classified according to their explicit or implicit presence in the studies and organized thematically into six recurring components: social, ecological, cultural, economic, political, and technological.

Table 1. Bibliometric Review: Thematic Analysis and Description of Common Content.

Thematic Components	Main Contributions	Authors	Research Gap
Social	- A focus on community participation as a fundamental pillar to implement effective socio-ecological management in the face of natural disasters or climate change. - Participatory Action Research (PAR) promotes the empowerment and active participation of communities in decision-making processes, enabling them to influence their territories and governance processes.	[21–37]	Limited systematization of experiences integrating co-learning and traditional knowledge in adaptive water management. Furthermore, there remains a notable absence of adequately developed frameworks that effectively articulate local and scientific knowledge within socio-ecological systems (SES), particularly considering their inherent complexity. There is a need to move towards more equitable and culturally contextualized collaborative approaches. Traditional knowledge remains insufficiently integrated as a legitimate source of learning within institutional frameworks. Adaptive management and co-learning are present, but with little articulation with economic and technological systems (economic-technological) Weak connection with formal political structures and absence of longitudinal evaluations (political-ecological).
Ecological	Water and Fisheries Resources Protection—Safeguarding Biodiversity in Community Contexts. Redesign of Agricultural Systems Towards Sustainable Models That Regenerate Ecosystems and Strengthen Resilience. Integration of Ecological and Political Dimensions as a Foundation for Achieving Sustainability.	[38–40]	Limited integration of traditional and local knowledge into scientific approaches to adaptive water management and governance. There remains a need for deeper exploration of how co-learning between local communities and scientific communities can strengthen Social-Ecological Systems (SES). Limited and uneven integration of participatory approaches (social, cultural, political). Weak research integrating economic and technological aspects into ecological transition strategies based on local knowledge. Poor assessment of the impact of integrative approaches on long-term processes (social-ecological-political).
Cultural	Cases illustrating how communities draw upon traditional knowledge and cultural practices in response to climate change, particularly within urban contexts. The significance of traditional knowledge and the cultural identity of Indigenous communities in the management and conservation of cultural heritage.	[41–44]	Development of approaches that acknowledge and integrate both traditional knowledge and scientific advancements in water management. There remains a need to explore the intersections between traditional and Indigenous knowledge systems and technological innovations in order to enhance resilience within changing and dynamic socio-ecological contexts. There is a continuing need to explore the intersections between traditional and indigenous knowledge systems and technological innovations in order to improve resilience in changing and dynamic socio-ecological contexts. Co-learning is present, but there are still limitations in intercultural methodologies and impact assessment (cultural-social-technological). Research is needed that integrates local economic strategies with cultural and ecological conservation to strengthen the viability and resilience of these adaptive practices.
Politics	Governance Processes and Community-Based Planning for Climate Change Adaptation. The Importance of Inclusive and Adaptive Policies The Design of Scenarios as a Strategic Tool for Planning Responses to Climate Change. Participatory Development of Public Policies for the Recognition of Indigenous Rights in Territorial Contexts	[45–48]	From the perspective of socio-ecological systems (SES), there is a lack of effective integration between public policies, joint learning, and traditional knowledge in adaptive water management. Governance is limited by the exclusion of traditional knowledge and technical approaches through genuine joint learning processes within sociocultural contexts. There is a lack of applied research on how to structure and sustain multisectoral co-learning processes with technological support and adaptive methodologies, especially in contexts of high sociopolitical complexity. Explore how to integrate traditional knowledge into public policy in a structural way, including its economic value and its role in decision-making.

Table 1. *Cont.*

Thematic Components	Main Contributions	Authors	Research Gap
Technological	Case studies in agriculture on the use of community-based climate information platforms to enhance adaptive capacity. There is a recognition that the deployment of technological tools and methodologies enhances data integration and supports the formulation of practical solutions in response to potential environmental impacts and the need for climate change adaptation.	[49,50]	Explore in depth the articulation of technologies and collaborative approaches with local knowledge, conceived as strategies for joint learning. There is limited integration between traditional knowledge systems and technological approaches in the context of adaptive water management. It shows how technology can strengthen adaptive capacity through localized climate services and shared information systems. However, the cases show little formal articulation between technological innovations and existing governance structures, which limits the institutionalization of adaptive management based on these technologies.

A comparative qualitative approach was used for the analysis, identifying patterns of thematic integration and gaps in the treatment of the aforementioned approaches. For example, if a study addressed community resilience through participatory water management processes, it was coded as integrating the social and ecological components, with the presence of co-learning and adaptive management, but without evidence of the use of traditional knowledge, which was noted as a gap.

It was observed that most studies address two of the three approaches, but few achieve a holistic integration of all three. Thematically, the social component emerges as the most prominent, particularly in relation to water resource management and community resilience. However, the analysis also reveals significant gaps in the systematic incorporation of traditional knowledge, suggesting a need for greater attention to this aspect in future research.

3.3. Identification of Research Opportunities Based on Existing Knowledge Gaps

The identified research opportunities include: (i) the potential to conduct long-term impact assessments of participatory projects, as few studies report outcomes over extended timeframes; (ii) the need to consider the intersections of gender, power, and participation, given the limited attention paid to how inequalities shape participatory processes; (iii) the integration of global and local scales, as there is still insufficient analysis of how local actions may influence change and inform regional, national, and global policies; (iv) the role of technology and digitalisation in rural contexts, since the contribution of digital tools to the co-production of knowledge remains underexplored; and (v) design and apply techniques for monitoring and evaluating adaptive management processes using social, ecological, political, and cultural indicators.

3.4. Promoting Adaptive Water Management Through Co-Learning

In addressing the question, how can an SES-based approach promote adaptive water management through co-learning between local communities and institutional actors? This analysis identifies various contributions aligned with SES-based frameworks, which offer an integrative perspective by acknowledging the interplay between social, ecological, and economic components. Some of the main contributions relate to: the recognition of complexity and interdependencies, emphasizing that water-related decisions must adopt a more holistic understanding and take into account all social and ecological dimensions [26]; the promotion of resilience and adaptability, by focusing on the capacity of systems to absorb and respond to change [24,27,43,44,46]; the advancement of nature-based solutions [29,39,49], which include strategies to enhance water quality, availability,

and regulation; and community engagement and governance [27,29,35,40,47,49], which involve inclusive decision-making processes tailored to local needs. The contributions of Social-Ecological Systems (SES) to adaptive water management involve the implementation of flexible actions and continuous evaluation to adjust strategies in accordance with observed outcomes.

In fact, participatory action research (PAR) is a fundamental methodological and interdisciplinary tool in various studies [21,25,27,28,34,41]. This approach is characterized by promoting active collaboration between researchers and local actors throughout the research process, from the formulation of questions to the interpretation of results and the implementation of actions. In the context of environmental sciences, PAR allows for the construction of contextualized knowledge that is tailored to the realities of the territory and useful for decision-making, integrating scientific perspectives and local or traditional knowledge to address complex issues in socio-ecological environments, such as adaptation to climate change. Due to its iterative and reflective approach, it facilitates co-learning, promotes community empowerment, and reinforces the legitimacy of decision-making processes.

Similarly, the concept of adaptive governance is recurrent in ecological studies, urban planning, and climate risk management, fostering shared decision-making among local stakeholders, scientists, governmental bodies, and non-governmental organizations (NGOs).

Resilience and adaptation to climate change are recurrent themes in the bibliometric analysis, as evidenced in studies concerning Pacific islands [42], rural communities in Asia and Africa [34,46,47], and agricultural systems [23]. Accordingly, this concept is closely associated with the strengthening of local capacities. Furthermore, local, traditional, Indigenous, or endogenous knowledge is identified as fundamental in generating conceptual and sustainable solutions [40,44,47].

It is also essential to emphasize that community education and communication emerge as key processes to facilitate learning and enhance resilience to climate change [27,28].

4. Discussion

The importance of traditional and indigenous knowledge is valued as a strategic component in adaptive water management, particularly in rural and agroecological contexts. This integration enables not only effective adaptation to climate change, but also a transformation of governance practices toward more inclusive, resilient, and culturally relevant models.

Reviewing other studies [51–53], they reveal how communities in Ghana and Colombia have reactivated or sustained traditional forms of water management, demonstrating that local knowledge can be a source of adaptive innovation. In these contexts, water is not managed exclusively as a physical resource, but as a socio-ecological good, laden with symbolic and cultural values.

This narrative has also been analyzed in more recent international studies. For example, in the Philippines [21] demonstrate how participatory action research has improved adaptive governance of clam fisheries by fostering collective learning among diverse actors. In a similar approach, in Thailand [22] proposes community-based adaptive planning based on social learning and the recognition of local knowledge.

Other authors have synthesized empirical evidence on the benefits of co-learning, highlighting that the adaptive capacity of small-scale agriculture depends largely on collective learning processes and knowledge dialogue [23]. It is also shown how traditional knowledge in Fiji [24] has been key to identifying vulnerabilities made invisible by conventional assessment tools.

Beyond individual cases, various studies on participatory approaches, social learning, and transdisciplinarity [26,27,30], are evidenced as vehicles for incorporating local knowledge into adaptive policies. These approaches are essential to facilitating just and sustainable socio-ecological transitions.

The literature review reveals regional overrepresentation in studies on adaptive water management, with a strong emphasis on Southeast Asia [22], India [29,50], the Andes [38], and the insular Pacific [24,42]. These regions have a literature base on collaborative and participatory approaches. However, other highly vulnerable areas, such as the Caribbean, North Africa, and the Middle East, are significantly underexplored [33,48]. Furthermore, the literature is dominated by English-language publications, which limits the visibility of knowledge generated in other languages and restricts the integration of locally documented traditional knowledge [44,45].

From a methodological approach, studies are mostly based on participatory action research (PAR), with an emphasis on community scales [32,35], highlighting local adaptation experiences, but with little attention to their articulation with public policies or multi-level governance structures [46,47]. Furthermore, the approach is centred on successful cases, which may hide conflicts, institutional limitations or power asymmetries that condition the effectiveness of these initiatives [36,40]. Experiences that combine participatory tools with long-term strategic planning are less common, although notable progress has been made [20,49].

Furthermore, many of the gaps identified in the literature can be explained by difficulties inherent to empirical research in marginalized contexts: financial limitations, language barriers, lack of institutional continuity, or the absence of historiographical traditions documenting Indigenous knowledge [37,43]. In several cases, the pressure to adapt local knowledge to international technical standards dilutes its contextual meaning or depoliticizes its content [25,39]. Recognizing these structural limitations not only explains why certain gaps persist but also provides a critical perspective on the challenges of building a more inclusive, transdisciplinary, and situated research agenda.

Proposed Conceptual Model

A conceptual model of adaptive water management is proposed from the perspective of socio-ecological systems, illustrating the interconnection among the main identified components. This model encompasses the dynamic interaction between systems, integrating the social and ecological subsystems into a unified framework “the human-in-nature” system a complex structure in which, for example, the social subsystem includes diverse human perceptions, behaviours, and ideas (values, knowledge, ideology, spirituality, arts, and culture), where social, institutional, economic, and political dimensions are intricately interwoven. In turn, the ecological subsystem encompasses all ecosystems (water, energy, air, soil, minerals, hydrology, climate, and the physical, chemical, and biological processes of the biosphere) [54,55]. Understanding the dynamics of a socio-ecological system entails recognizing its state and regime shifts.

The conceptual analysis conducted enabled the identification of five fundamental concepts that structure the theoretical framework of adaptive water management from a socio-ecological perspective.

Concept 1. Adaptive Governance is essential for addressing complexity, particularly in contexts of uncertainty such as climate change. Flexible and collaborative governance systems enhance adaptability through mutual learning, experimentation, and the coordinated management of natural resources. “Uncertainty in water availability demands polycentric, collaborative, and adaptive approaches” [7,56]. Adaptive governance strengthens the capacity to respond to hydrological uncertainties. It is thus well suited to water management

in the context of climate change, as it fosters continuous monitoring, institutional flexibility, and the integration of diverse knowledge systems.

Concept 2. Local and indigenous knowledge provides an indispensable epistemological source for culturally relevant and ecologically resilient water management strategies. These knowledge systems, built up over generations through direct observation of the environment, not only provide valuable information on hydrological cycles, land use, and water sources, but also reflect social and spiritual values deeply linked to water [57]. Integrating this knowledge into planning and decision-making frameworks improves social acceptance of the actions implemented, encourages local participation, and promotes the formulation of adaptive strategies consistent with territorial realities.

Several studies have documented that, in indigenous and rural territories, practices such as rainwater harvesting, traditional irrigation systems, and knowledge of local weather patterns have been essential for resilience in the face of extreme events and water scarcity. Likewise, in the Andean region and other territories of the Global South, the recognition of indigenous epistemologies has been central to advancing toward approaches to water justice that address not only the distribution of the resource, but also the cultural and territorial rights associated with its use [58]. This integration of multiple forms of knowledge promotes a more equitable, inclusive, and sustainable approach to water management.

Concept 3. Co-learning and community participation are fundamental pillars for promoting innovation and adaptability in water management within complex socio-ecological systems. Understood as a collective process of horizontal exchange between diverse actors (local, institutional, academic, and political), co-learning allows for the sharing of experiences, knowledge, and values, generating consensus and promoting adaptive and innovative solutions [59]. This approach helps different actors recognize different perspectives, which strengthens the co-creation of resilient alternatives.

From this perspective, it is key to differentiate and at the same time articulate co-learning with social learning, given that although both processes are complementary, they have different scopes in socio-ecological transformation. Co-learning is centred on active and symmetrical interaction between actors, where there are no predefined hierarchies between those who teach and those who learn. Its objective is the co-construction of knowledge through egalitarian dialogue, favouring the development of collective competencies, the appropriation of knowledge, and the strengthening of collaborative networks [60]. Social learning refers to collective processes of meaning-making and action among diverse actors facing common challenges such as water management. This learning, facilitated by Participatory Action Research (PAR), integrates community knowledge into decision-making, improves the legitimacy of policies, and strengthens sustainability through social appropriation of the process [51,60,61]. Thus, while co-learning provides a transformative educational methodology focused on individual and group empowerment through shared knowledge, social learning acts at the systemic level, strengthening adaptive governance through collaboration and co-responsibility. Together, both approaches offer a solid foundation for socio-ecological transformation by articulating scientific and traditional knowledge, encouraging collective action, and increasing the capacity to adapt to scenarios of change and uncertainty.

Concept 4. Resilience from a socio-ecological systems perspective involves the integration of all stakeholders, as it aims to enhance the capacity of territories to adapt to and transform in the face of disturbances. “Water resilience is the outcome of systems that link ecological health with the capacity for social organisation” [62,63]. Water resilience depends on the interconnections between social and ecological components; therefore, a socio-ecological approach to water management enables the analysis of how communi-

ties respond to, adapt to, and transform in the face of extreme events such as droughts and floods.

Concept 5. Sustainability understood as the search for lasting solutions that enable long-term conservation and well-being. In the literature, this concept is deeply linked to participatory processes that take place in specific local contexts and territories, where communities are not only recipients but also actively involved in the design and implementation of strategies adapted to their realities. This active participation is crucial because, without it, initiatives such as water management tend to fail or reproduce existing social inequalities [64,65].

Sustainability in water management is based on considering water a common good, whose conservation and efficient use require effective mechanisms of social control and community self-management [64,66]. In addition, it is important to strengthen the resilience of ecosystem services through principles that promote adaptation and collaboration between local actors, technicians, and politicians. Universal solutions or “panaceas” are insufficient, and success in water management depends on flexible and participatory institutional processes that recognize local particularities and the diversity of actors involved [66,67].

Together, these approaches underscore that sustainability is a dynamic social process that is built from the community level up.

Table 2 then identifies the main characteristics of the concepts and organizes them according to their epistemological, ontological, and methodological functions [68]. The table consists of three columns: the first presents the names of the concepts; the second indicates the main character of the research according to its function; and the third explains the justification for the selected characteristic.

Indeed, this conceptual model provides a comprehensive framework for inclusive water policies. The components of the model (governance, local knowledge, co-learning, resilience, and sustainability) do not function in isolation; rather, it is their synergy that enables the transition towards more equitable, sustainable, and resilient systems. “Integrated models allow knowledge to be translated into action and foster transformative changes in water management” [59,69–71].

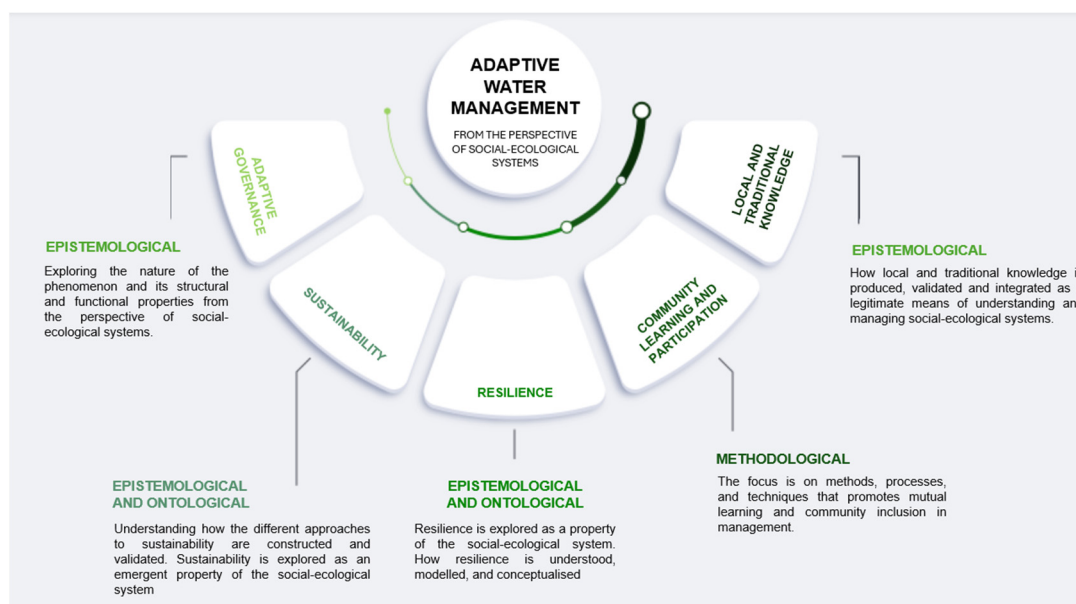
Figure 3 presents a conceptual synthesis that articulates the main theoretical components emerging from this research, which support adaptive water management from a socio-ecological approach. This representation integrates five key concepts—adaptive governance, sustainability, local knowledge, co-learning, and resilience—organized around three fundamental dimensions of scientific knowledge: ontological, epistemological, and methodological.

Adaptive governance is conceived as an approach that integrates diverse knowledge, flexible institutional capacities, and participatory mechanisms for decision-making under uncertainty. Sustainability represents the desired condition toward which the socio-ecological system converges, in dynamic equilibrium between the ecological, social, and economic spheres. Local knowledge, derived from the historical interaction between communities and their territories, allows for the interpretation of the contextual dynamics of water and is directly linked to resilience, as it strengthens the adaptive capacities of systems in the face of external disturbances.

In turn, co-learning and community participation act as operational mechanisms that facilitate the collective construction of knowledge and the co-creation of solutions in water resource management. Within this framework, the aim is not only to identify these five concepts, but also to explain the specific mechanisms of interaction between them, such as how local knowledge enhances community resilience, or how co-learning contributes to more adaptive and equitable governance.

Table 2. Conceptual Framework of Adaptive Water Management and the Nature of the Research.

Related Concept	Nature of the Research	Characteristic
Adaptive Governance	Epistemological	Exploring the nature of the phenomenon and its structural properties within socio-ecological systems.
Local and Traditional Knowledge	Epistemological	How local and traditional knowledge is produced, validated, and integrated as a legitimate way of understanding and managing socio-ecological systems.
Co-learning and Community Participation	Methodological	The emphasis is placed on methods, processes, and techniques aimed at fostering mutual learning and community inclusion in management practices.
Resilience	Ontological—Epistemological	Resilience is explored as an inherent property of the socio-ecological system. The ways in which resilience is understood, modelled, and conceptualized are examined. Resilience in socio-ecological systems has a dual epistemological and ontological nature. Ontologically, it recognizes the world as a complex and dynamic system where the social and ecological co-evolve. Epistemologically, it promotes non-linear, integrative, and adaptive forms of knowledge that allow for understanding uncertainty and change. This perspective redefines how resilience is conceived, modelled, and managed in complex socio-environmental contexts [60]
Sustainability	Epistemological, Ontological	To understand how different ways of knowing and validating sustainability are constructed. Sustainability is explored as an emergent property of the socio-ecological system.

**Figure 3.** Conceptual Model—Adaptive Water Management from a Socio-Ecological Systems Perspective.

This graphic representation allows us to visualize the conceptual and functional interdependence between these components, showing how they operate simultaneously as theoretical foundations, interpretive approaches, and practical strategies in contexts of high complexity and socio-environmental uncertainty.

5. Conclusions

The conceptual model proposes an adaptive water management approach grounded in the socio-ecological perspective, wherein resilience and sustainability emerge from the interaction among communities, ecosystems, and diverse forms of knowledge. It promotes co-learning among local actors, technical experts, and authorities, thereby fostering horizontal processes of adaptive governance. This perspective recognizes that traditional knowledge is not merely a complement but also a foundational pillar for designing water-related responses that are context-specific and culturally appropriate within territories.

Active participation in these processes fosters community empowerment, thereby strengthening the legitimacy of decision-making. In this way, socio-ecological systems become more flexible and better equipped to cope with climatic disturbances. In essence, the model advocates for a bottom-up transformation, in which the dialogue of knowledge drives social and ecological innovations. Water is thus managed as a common good, within a framework of justice and intergenerational equity.

Integrating traditional knowledge into water governance enables a shift from technocratic approaches to co-created systems, in which social learning plays a pivotal role in fostering adaptation and transformation. The model presented demonstrates that water resilience does not rely solely on infrastructure or scientific data, but rather on the collective capacity to learn from the environment and through interactions among diverse actors.

This systemic logic fosters trust-building, collaborative experimentation, and shared monitoring, all of which are essential to addressing climate uncertainty. Sustainability is not imposed from above, but rather constructed collectively, acknowledging the interdependence of social, ecological, and cultural elements. In this context, water management ceases to be merely technical and becomes a political and community-based practice. In doing so, pathways are opened towards a just, resilient, and life-centred water transition.

Going forward, this model offers a conceptual framework for understanding and addressing the complexity of adaptive water management in diverse contexts. It opens up new avenues of research for validation at various territorial and socio-environmental scales. Furthermore, its potential application as a decision-support tool for sustainable and participatory water planning is proposed, which could contribute to more equitable and resilient water management.

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