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Protection and restoration of water-related ecosystems under SDG 6.6: a global systematic review

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Introduction: The conservation and restoration of water-related ecosystems are central to achieving Sustainable Development Goal 6 (SDG 6), particularly Target 6.6. Despite the growing body of research on water resource management, the extent to which conservation strategies are being studied, implemented, and aligned with SDG 6.6 remains insufficiently synthesized. This study aims to systematically review the protection methodologies applied to conserve and restore water-related ecosystems and to identify research trends, policy approaches, and existing knowledge gaps.

Methods: A systematic review was conducted following the PRISMA framework. A total of 75 articles were initially retrieved from the Web of Science, Scopus, and ScienceDirect databases. After applying inclusion and exclusion criteria, 40 peer-reviewed studies were selected for detailed analysis. The selected literature was examined through a structured comparative synthesis focusing on ecosystem types, conservation strategies, governance and policy instruments, and the use of technologies and monitoring tools.

Results: The results show that conservation efforts are unevenly distributed across ecosystem types, with forests and wetlands receiving the greatest research attention, while aquifers and river systems remain significantly underrepresented. Commonly reported strategies include watershed reforestation, wetland restoration, environmental education initiatives, and remote monitoring technologies. However, many studies show limited alignment with specific SDG 6 targets and frequently lack detailed water quality assessment and monitoring indicators.

Discussion: The review reveals persistent structural challenges affecting the implementation of conservation strategies, including governance limitations, insufficient funding, technological gaps, and global inequalities influencing water resource management outcomes. These findings highlight the need to strengthen integrated planning, improve monitoring systems, and promote more balanced research attention across all water-related ecosystems. This study synthesizes current conservation approaches within the SDG 6.6 framework and identifies key knowledge gaps that can inform future research, policy development, and decision-making in water resource management.

KEYWORDS

aquatic ecosystems, conservation strategies, SDG 6, systematic review, water resource management

1 Introduction

Sustainable water management and ecosystem conservation are critical for achieving the Sustainable Development Goals (SDGs) and fostering equitable, global development. A wide range of research explores the intricate connections between these elements across diverse contexts, highlighting their mutual dependence. Sustainable development extends beyond policies and statistics. It embraces a profoundly human vision that seeks to reduce inequalities and promote a fair distribution of development's benefits. This means ensuring that the most vulnerable populations have access to equitable opportunities and that progress is not confined to a privileged few. Innovation, collaboration, and a fundamental shift in consumption and production patterns are essential for building a future where everyone can thrive without jeopardizing our shared planet (Eyzaguirre et al., 2023).

The Millennium Development Goals (MDGs), established in 2000, represented a major global commitment to improving the lives of the world's most vulnerable people. With clear and ambitious targets, these goals focused on combating critical issues like extreme poverty, limited access to education, and gender inequality, particularly in countries in the Global South where these challenges were most pronounced. While the MDGs initially prioritized social issues, such as health improvements and a reduction in child mortality, they also addressed crucial environmental concerns, including access to clean drinking water and sanitation. One of the most notable targets was MDG 7C, which aimed to ensure sustainable access to safe drinking water and sanitation by 2015. While the original goal only included drinking water, sanitation was later added in 2002, a recognition of its critical role in overall health and well-being. Over the 15-year implementation period, the MDGs achieved significant progress: millions more people, particularly in rural areas, gained access to clean water and secure sanitation systems, which helped reduce diseases and substantially improve living conditions (Mujtaba et al., 2024).

At the end of the MDG period in 2015, there was a widespread recognition that, despite significant achievements, the world needed a more comprehensive agenda. This led to the creation of the Sustainable Development Goals (SDGs), which broadened the focus of the MDGs by fully integrating environmental and social challenges. These new goals were designed to holistically address poverty, climate change, and sustainability, ensuring balanced and fair development for present and future generations (Wiegand and Bruns, 2018).

In 2015, the UN General Assembly made a historic decision to launch the 2030 Agenda, a universal plan consisting of 17 Sustainable Development Goals (SDGs). These goals are designed to tackle the most pressing contemporary challenges, from ending poverty and hunger to protecting the environment and fostering peaceful, equitable societies. The SDGs are not just abstract targets; they represent a collective hope for a better future, emphasizing the profound interconnection between human well-being, the natural world, and economic development (Aguayo Lopes da Silva et al., 2024; Dickens et al., 2020; Grazule et al., 2022; Katila et al., 2020; Mujtaba et al., 2024; Wiegand et al., 2024; Yang et al., 2023).

A core principle of the SDGs is their integrated approach, which means progress in one area inevitably influences others. For example, universal access to clean water, outlined in SDG 6, is fundamental to combating poverty, safeguarding public health, and preserving ecosystems. However, this goal faces significant obstacles, as many nations still struggle to ensure access to clean water and adequate sanitation for all their citizens (Aguayo Lopes da Silva et al., 2024; Dickens et al.,

2020; Grazule et al., 2022; Katila et al., 2020; Mujtaba et al., 2024; Wiegand et al., 2024; Yang et al., 2023).

SDG 6 from the United Nations aims to ensure that all people have access to safe drinking water and sanitation, while promoting the sustainable management of water resources. This goal is vital not only for human health and well-being but also for the preservation of water-dependent ecosystems. As such, SDG 6 is a cornerstone for the success of most of the other SDGs, since without clean water and adequate sanitation, progress in areas like health, education, and poverty reduction is severely compromised (Grazule et al., 2022; Mujtaba et al., 2024). This global commitment is an integral part of the 2030 Agenda, an ambitious international strategy that places water at the heart of sustainable development. The international community has recognized the importance of water issues since the 1970s. In 1992, the "Dublin Principles" further highlighted the need for an integrated approach to managing the entire water cycle, including aspects like quantity, quality, and the protection of aquatic ecosystems (Grazule et al., 2022; Mujtaba et al., 2024).

In recent decades, a growing body of scientific research has addressed water conservation, watershed management, ecological restoration, and ecosystem services across different regions of the world (Vörösmarty et al., 2018; Grazule et al., 2022; Dickens et al., 2020). However, much of this research is fragmented across disciplines and geographical contexts, and it is not always explicitly framed within the SDG perspective (Wiegand and Bruns, 2018; Ait-Kadi, 2016). As a result, the extent to which existing knowledge contributes to understanding progress, priorities, and gaps related to SDG 6 Target 6.6 remains insufficiently synthesized. This situation may also lead to the underrepresentation of relevant scientific contributions to water-related ecosystem conservation but do not explicitly refer to the SDG framework (Dickens et al., 2020; Wiegand et al., 2024). At the same time, the challenges associated with achieving SDG 6.6 are not only scientific. The implementation of conservation strategies is strongly influenced by governance structures, institutional capacity, financial investment, technological development, and education (Ait-Kadi, 2016; Vörösmarty et al., 2018; Katila et al., 2020). In many regions—particularly in countries of the Global South—limitations in infrastructure, monitoring systems, and long-term environmental planning continue to constrain effective water resource management (Grazule et al., 2022; Mujtaba et al., 2024). These structural conditions are closely linked to global inequalities, which shape both the production of scientific knowledge and the capacity to implement conservation initiatives on the ground (Eyzaguirre et al., 2023; Wiegand et al., 2024).

Another important dimension concerns the geographical distribution of research. A significant portion of the literature is produced by institutions located in the Global North, often focusing on ecosystems situated in developing regions. This creates an asymmetry between knowledge production and local implementation contexts, which may influence the types of strategies proposed, the priorities addressed, and the interpretation of conservation challenges (Wiegand and Bruns, 2018; Katila et al., 2020). Recognizing these differences is essential for understanding how scientific knowledge contributes to policy development and decision-making in water resource management (Ait-Kadi, 2016; Vörösmarty et al., 2018).

Despite the large volume of studies related to water conservation and ecosystem protection, there is still a lack of integrative syntheses that identify which conservation strategies are most frequently implemented, which ecosystems receive the greatest research attention, and

where the main knowledge gaps persist. This is particularly relevant for less visible systems such as aquifers and river networks, which play a fundamental role in water security but often receive less attention in applied conservation research and monitoring efforts (Dickens et al., 2020; Hakimdavar et al., 2020). In this context, a systematic review provides an opportunity to organize and synthesize the available scientific evidence on conservation strategies for water-related ecosystems, identify research trends, and highlight gaps that are relevant for the management and protection of water resources (Liberati et al., 2009; Moher et al., 2009).

Therefore, the main objective of this study is to systematically review the protection and conservation methodologies applied to water-related ecosystems within the framework of Sustainable Development Goal 6, Target 6.6. Specifically, this research aims to: (i) identify the main conservation strategies implemented across different ecosystem types; (ii) examine the policy, governance, and management dimensions associated with these strategies; and (iii) detect knowledge gaps and research imbalances that may affect the effective achievement of SDG 6.6.

By providing an integrated synthesis of existing research, this study seeks to contribute to a better understanding of how current scientific knowledge supports water resource management and to identify priority areas for future research and policy action (Ait-Kadi, 2016; Vörösmarty et al., 2018; Wiegant et al., 2024).

2 Materials and methods

This study was conducted as a systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which provides a structured and transparent approach for identifying, selecting, and analyzing relevant scientific literature (Moher et al., 2009; Liberati et al., 2009). The aim was to synthesize existing research on conservation strategies for water-related ecosystems within the context of SDG 6, Target 6.6, and to identify trends, approaches, and knowledge gaps in the field.

The review considered scientific literature published between 1990 and 2024. This time frame was selected to capture the evolution of research on water resource management and ecosystem conservation, including both early studies prior to the MDGs and more recent research developed within the SDG framework.

2.1 Research questions

The study was guided by a set of research questions structured using the PICOC framework (Population, Intervention, Comparison, Outcome, Context), which helped define the scope and focus of the review (Cumpston et al., 2021).

The PICOC elements were defined as follows:

- Population: SDG 6 (Clean Water and Sanitation)
- Intervention: Target 6.6, focused on the protection and restoration of water-related ecosystems, including forests, mountains, wetlands, rivers, aquifers, and lakes
- Comparison: Millennium Development Goal 7 (Ensure Environmental Sustainability)
- Outcome: Research progress and conservation strategies related to SDG 6 Target 6.6

- Context: Scientific research on water-related ecosystem conservation

Based on this framework, the following research questions (QR) were established:

- QR1: What protection methodologies have been implemented to conserve and restore water-related ecosystems such as forests, mountains, wetlands, rivers, aquifers, and lakes since the emergence of global sustainability agendas?
- QR2: What types of ecosystems and conservation strategies have been applied for water conservation, biodiversity protection, human well-being, and sustainable development?
- QR3: What types of research approaches, tools, and policy instruments are used to support the protection of water-related ecosystems?

These general questions were complemented by a set of specific analytical criteria used to examine the selected studies and identify patterns in conservation strategies, governance dimensions, and research gaps.

2.2 Source identification and search strategy

To identify relevant literature, a structured search strategy was developed using selected keywords and Boolean operators across major scientific databases.

In the second stage, after question formulation, two methods were used: database searching and the use of Boolean operators. The database search involved using keywords to identify and retrieve relevant articles related to the research questions. The selected keywords were: “Aquifers, Forests, Lakes, SDG 6, Clean Water and Sanitation, Sustainable Development, Water” (Grant and Booth, 2009).

The Boolean operator approach was also used to combine search terms to broaden or narrow the results. For example, using the keywords “aquatic ecosystems” would return almost all articles related to wastewater treatment, thus broadening the search. However, using combined keywords like “forest” AND “sdg” OR “sdgs” OR “sustainable AND development” limits the search results by primarily returning articles focused on sustainability.

Boolean operators were effective in limiting search results to specific terms consistent with the research topic, in this case, the aquatic ecosystems of Target 6.6. These operators can also be used to limit the databases or journals from which results should come. They played a significant role in narrowing down search results based on specific inclusion and exclusion criteria (Borenstein et al., 2021).

The search was conducted using three major scientific databases:

- Web of Science
- Scopus
- ScienceDirect

2.3 Inclusion and exclusion criteria

The selection of studies was carried out through a two-stage evaluation process designed to ensure consistency and relevance in relation to the objectives of the review. In the first stage, the abstracts of all identified articles were examined to determine their suitability for

inclusion. A study was considered potentially relevant when its abstract clearly presented three essential elements: the background or context of the research, the methodology applied, and the main results or findings. This initial screening allowed the identification of studies closely aligned with the conservation and management of water-related ecosystems.

In the second stage, the full-text versions of the preselected articles were assessed using predefined inclusion and exclusion criteria. Only peer-reviewed scientific articles were considered, focusing on studies related to MDG 7, SDG 6, or the conservation and management of water-related ecosystems. Publications written in English or Spanish were included, particularly those addressing conservation strategies, ecosystem protection, environmental management approaches, or policy-related dimensions associated with water resource management.

Studies were excluded if they consisted of conference proceedings, if their content was not directly related to water resource management or ecosystem conservation, or if they did not align with the objectives of the review. This filtering process ensured that the final selection was composed of studies providing relevant and reliable scientific contributions to the analysis of conservation methodologies within the framework of SDG 6 Target 6.6.

2.4 Study selection process

The study selection process was conducted in accordance with the PRISMA model to ensure transparency and traceability in the identification, screening, and inclusion of relevant literature. A total of 75 articles were initially retrieved from the three selected

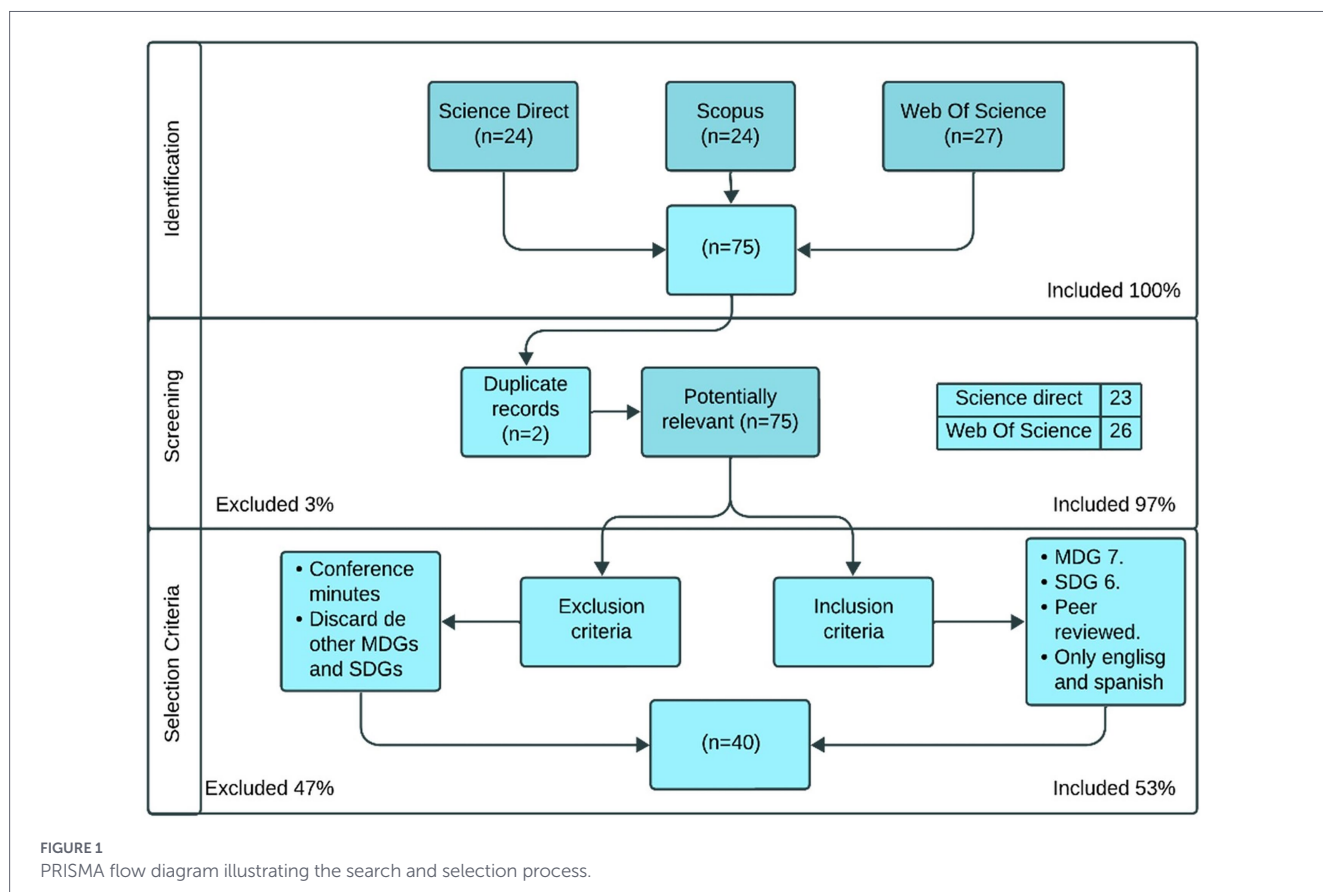
databases: 27 from Web of Science, 24 from Scopus, and 24 from ScienceDirect. Following the initial identification stage, the inclusion and exclusion criteria were applied to remove studies that did not meet the objectives of the review. This screening process involved both abstract evaluation and full-text assessment, allowing for the progressive refinement of the sample. As a result, 40 articles were selected for detailed analysis.

The distribution of selected studies varied across databases. Web of Science yielded the highest number of relevant publications, with 20 articles selected from the 27 initially identified. From Scopus, 11 articles were included out of the 24 retrieved, while ScienceDirect contributed 9 selected studies from an initial pool of 24. This process ensured that the final dataset was composed of peer-reviewed research directly aligned with water-related ecosystem conservation and the objectives of SDG 6 Target 6.6.

The overall selection procedure is illustrated in Figure 1, which presents the PRISMA flow diagram detailing the stages of identification, screening, eligibility, and final inclusion of the studies considered in this systematic review.

2.5 Data extraction and analysis

Each of the selected articles was carefully reviewed to extract relevant information related to the objectives of the study. The analysis focused on identifying key aspects such as the type of ecosystem addressed, the conservation strategies implemented, the policy and governance dimensions involved, the research approaches and tools used, and the reported impacts or outcomes associated with ecosystem protection and management.



To support a structured and comparative synthesis of the literature, a qualitative relevance assessment was applied to each study. This process allowed for the classification of articles according to their level of contribution to the understanding of conservation strategies within the framework of SDG 6 Target 6.6. Studies considered highly relevant to the research objectives were assigned a value of 1.0, those with partial relevance were assigned 0.5, and those with no direct relevance were assigned 0.0.

This approach facilitated the prioritization of key contributions and enabled a more organized interpretation of the evidence. By systematically categorizing the selected studies, it was possible to identify dominant research trends, commonly applied conservation methodologies, governance-related dimensions, and existing knowledge gaps associated with the protection and restoration of water-related ecosystems.

3 Results

The results of the systematic review are presented in two main sections. Section 3.1 describes the protection methodologies identified across different types of water-related ecosystems, including forests, wetlands, rivers, lakes, mountains, and aquifers. Section 3.2 provides an integrated perspective on aquatic ecosystem conservation, focusing on governance dimensions, policy approaches, research trends, and the main gaps identified in the literature. This structure allows for a comprehensive understanding of both the practical strategies implemented and the broader management context associated with SDG 6 Target 6.6.

The relationship between watershed reforestation efforts and the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) was a primary focus of this analysis. The reviewed literature was first assessed to determine if reforestation successfully achieves its core objectives of improving water quality and reducing soil erosion. The results reveal a mixed outcome: 19 articles indicate these objectives were not achieved, 11 report success, and 10 describe partial fulfillment. This indicates that while reforestation is a widely implemented strategy, its effectiveness is limited and highly contingent on local factors such as soil characteristics, vegetation type, and climatic conditions.

Subsequently, the alignment of these studies with SDG 6 (Clean Water and Sanitation) was evaluated. This analysis enabled the identification of the specific SDG 6 targets prioritized within the literature. The majority of works (26%, or 16 articles) were associated with Target 6.6 (protect and restore water-related ecosystems). A significant portion (24%, or 15 articles) did not specify a concrete target. Targets 6.3 (improve water quality) and 6.4 (increase water-use efficiency) were each addressed by 11% (7 articles), while Targets 6.1 (safe drinking water), 6.2 (sanitation and hygiene), and 6.5 (implement integrated water resources management) were each covered by 8% (5 articles). Targets 6.a and 6.b (international cooperation and community participation) were only marginally represented, appearing in just 2% (1 article) of the sample.

These findings demonstrate a strong thematic orientation toward protecting and restoring aquatic ecosystems (Target 6.6), which is consistent with the focus on watershed reforestation. However, the fact that nearly a quarter of the articles failed to specify a target highlights

a significant weakness in explicitly linking research to the SDG 6 framework.

The analysis also explored references to Millennium Development Goal 7 (MDG 7), the direct precursor to SDG 6. Seven articles referenced this goal, often to contextualize the evolution of international water agendas. Several authors highlighted the conceptual transition between the MDGs and SDGs, noting that while MDG 7 made significant progress in access to drinking water, it fell short of its basic sanitation target (Wiegand and Bruns, 2018). Other scholars emphasized that the SDGs broadened the MDG agenda to address a wider range of economic, social, and environmental challenges (Aguayo Lopes da Silva et al., 2023; Mugagga and Nabaasa, 2016; Eyzaguirre et al., 2023). Within this transition, SDG 6 is explicitly recognized as the direct heir of MDG 7C, thereby consolidating the intrinsic connection between water, sanitation, and sustainable development (Amezaga et al., 2019; Ait-Kadi, 2016).

Together, these results illustrate how reforestation strategies, their classification under SDG 6, and their historical roots in MDG 7 form a coherent narrative. This narrative reflects both the continuity of international development agendas and the persistent challenges in achieving sustainable water and ecosystem management.

3.1 Protection methodologies for water-related ecosystems

Regarding the strategies implemented for the sustainable management of aquifers, it was determined that 87.5% of the articles do not mention strategies related to aquifer protection. This suggests that research focusing on these aquatic systems remains scarce. The few strategies reported include educational campaigns for the protection and recovery of recharge zones, each represented by one article, accounting for 4% in total. Additionally, 10% of the articles ($n = 4$) mention strategies such as progressive monitoring of groundwater quality and quantity within aquifers (Hakimdarav et al., 2020), policy support systems, financing plans, and disaster risk reduction (Mujtaba et al., 2024), stress event monitoring, laws regulating drilling in areas with shallow aquifers, and the adoption of wastewater treatment techniques for aquifer recharge (Dadebo et al., 2023).

With respect to the synergy between forest protection and water resources, 59% of the articles did not report any strategy in this regard. In contrast, 13 articles (32%) presented specific conservation or forest protection strategies related to aquifer recharge zones or directly linked to water resources, as shown in Table 1. Furthermore, 10% of the articles highlighted strategies such as “sustainable forestry practices,” “soil restoration,” “combating deforestation,” and the establishment or strengthening of “protected areas.”

Regarding wetlands, the articles were analyzed in relation to strategies implemented for their protection and their importance for water quality. It was found that 62% (31 articles) provided no information on strategies for these ecosystems. In contrast, 14% of the articles reported different strategies emphasizing the importance of wetlands and successful protection practices, as shown in Table 2. General strategies such as sustainable management and wetland restoration, implementation of public policies, and continuous monitoring were identified in 24% of the articles.

In the analysis of the articles, the focus was on the specific challenges faced by lakes, particularly regarding their protection. The aim was to identify the most evident obstacles to effective lake conservation. The analysis revealed that 36% of the studies reported various

TABLE 1 Approaches to forest protection.

Main approach	Key contributions	References
Conservation and reforestation	Conservation as an ecological solution; reforestation of agricultural lands and pastures; watershed afforestation; restoration of degraded forests.	Vörösmarty et al. (2018), Ahmad et al. (1990), Wang (2020), and Wiegant et al. (2024)
Ecosystem services and water regulation	Forests regulate freshwater flows, reduce flooding, conserve soil, and improve air quality; critical role in water availability and climate resilience.	Ma et al. (2022), Amezaga et al. (2019), Zaizhi and Haishui (2004), and Wan Mahari et al. (2020)
Climate change and sustainability	Forests as climate change mitigators and providers of key ecosystem services for the SDGs; successful reforestation cases (Korea).	Biswas et al. (2020) and Aguayo Lopes da Silva et al. (2023)
Forest management and policies	Sustainable management plans; protection of areas through use and tenure rights; joint forest management with local communities (India).	Katila et al. (2020) and Dandabathula et al. (2021)
Innovation and forest economy	Large-scale monitoring maps; forests as an economic resource (Myanmar); forest tourism and sustainable markets.	Biswas et al. (2020) and Ma et al. (2022)
Education and community participation	Government-supported planting programs; incentives for women and schools in afforestation; cooperation from local communities.	Ahmad et al. (1990) and Dandabathula et al. (2021)
Ecological protection and restoration	Conservation and restoration projects; mountain protection plans; forest-water-food-energy nexus.	Yang et al. (2023) and Zhang et al. (2022)

TABLE 2 Wetland protection strategies.

Main approach	Key contributions	References
Restoration and conservation	Wetland restoration; elimination of human pollution; conservation and management standards; expansion of Ramsar Sites; adaptive management frameworks.	Vörösmarty et al. (2018) and Dandabathula et al. (2021)
Water and ecosystem services	Maintaining water flows and quality; agricultural land reforestation; replacement of exotic tree plantations with native species; protection of mangrove ecosystem services.	Amezaga et al. (2019) and Eyzaguirre et al. (2023)
Monitoring and observation systems	Global Wetland Observation System (GWOS); Satellite-based Wetland Observation Service (SWOS); Landsat and Sentinel data mapping; GEO-Wetlands initiative for global coordination.	Vörösmarty et al. (2018) and Hakimdavar et al. (2020)
Sustainability indicators and policy tools	Environmental Performance Index (EPI), Human Development Index (HDI), and SDG Index (SDGI) as drivers for wetland conservation and policy actions.	Kundu et al. (2024)
Community and governance	Local community involvement in decision-making; addressing corruption risks in REDD+ restoration contracts; adaptive governance frameworks.	Dandabathula et al. (2021) and Eyzaguirre et al. (2023)
Education, tourism, and awareness	Sustainable tourism through education and creative economy; Ocean Literacy programs building science around marine-coastal ecosystems (e.g., mangroves).	Eyzaguirre et al. (2023)

problems or challenges, which are summarized in Table 3. To provide a broader perspective, nine categories were created to classify these issues, linking them to major environmental problems such as pollution, anthropogenic pressure, and the regulation or enforcement of laws.

The analysis of protection methodologies applicable to improve river water quality, based on the reviewed articles, revealed that the vast majority (82.5%) did not mention specific methodologies for these ecosystems. In contrast, the remaining articles proposed

initiatives such as creating green spaces along rivers; tools for companies to raise awareness and understanding of water risks (Vörösmarty et al., 2018); introducing protective forest strips in riparian zones (Amezaga et al., 2019); United Nations environmental monitoring methodologies mapped with available data, and progressive monitoring of water quantity or discharge (Hakimdavar et al., 2020); as well as water quality plans and frameworks, along with extraction and discharge permit controls (Zaneti et al., 2023). Monitoring strategies and the construction of barriers and dams were each selected twice, while

TABLE 3 Challenges to lake protection.

Specific challenge	Category	Mentions (%)
Presence of cyanotoxins produced by algae in Lake Erie	Pollution	18.2%
Migratory species/birds	Anthropogenic pressure	18.2%
Unregulated agriculture, deforestation, illegal discharges	Anthropogenic pressure	9.1%
Lake Guaiba requires advanced treatment	Anthropogenic pressure	9.1%
Lack of a strong monitoring plan and no charges for water use	Regulation	9.1%
Indiscriminate fishing	Regulation	9.1%
Water conservation periods	Regulation	9.1%
Increasing eutrophication of lakes	Pollution	9.1%
Enforcement of Article 51A of the Indian Constitution	Regulation	9.1%

riparian zone restoration and citizen science appeared once. The control of invasive species was not selected at all.

As for sustainable practices contributing to the conservation of mountain water resources, the results showed that the option “Not applicable” was the most frequent, with 31 mentions (69%). The second most relevant category was “Other” practices, with five mentions (11%), including: the role of cloud forests in intercepting fog and cloud droplets to increase annual water yields; UNESCO’s Man and the Biosphere Programme, focused on the impact of human activities on mountain and tundra ecosystems for their management and sustainable development; and measures such as converting farmland back to forest to improve the ecological environment, transferring labor to reduce demographic pressure, and controlling population growth. “Watershed protection” and “reforestation” each received three mentions (9.7%). “Integrated watershed management” obtained two mentions (6.4%), and “restoration of mountain wetlands” was mentioned once (3.2%).

3.2 Integrated perspectives on aquatic ecosystem conservation: sustainability, governance, and socioeconomic development

Beyond the identification of specific conservation methodologies, the reviewed literature also reveals broader governance, policy, and institutional dimensions that influence the implementation of ecosystem protection strategies across different regions.

Another axis of the research focused on the strategies implemented in different types of aquatic ecosystems, aimed at promoting the conservation of water, biodiversity, human well-being, and sustainable development. In this context, the most frequently applied conservation criteria in the reviewed articles were sustainability (20.90%), ecosystem services (11.94%), water quality (10.45%), biodiversity (7.46%), ecological balance, and other complementary criteria grouped in Table 4.

Overall, the contributions derived from the remaining criteria (46.27%) reveal an evolution in academic discussions toward integrated approaches, where social, economic, environmental, and governance dimensions converge. For instance, Ait-Kadi (2016) and Wang et al. (2024) highlight the importance of linking economic development with social well-being and ecological sustainability, proposing that socioeconomic progress can only be considered legitimate when accompanied by environmental balance.

Within this perspective, the field of governance and decision-making emerges as a key dimension. Vörösmarty et al. (2018) stress the relevance of monitoring networks, ecosystem valuation, and technical capacity building as essential foundations for effective decision-making. Along the same lines, Wiegand and Bruns (2018) argue that SDG 6 represents an opportunity to redirect global water governance toward water security scenarios, which requires acknowledging the critical role of institutions and international cooperation in sustainability.

At the same time, forest ecosystems are highlighted in the literature as central actors in water regulation and climate change mitigation. Ma et al. (2022) emphasizes their role in water purification, while Aguayo Lopes da Silva et al. (2023, 2024) argue that the forestry sector contributes not only to emission reduction and the strengthening of carbon sinks, but also to the consolidation of sustainability strategies. These perspectives converge in recognizing the multifunctional role of forests, essential for sustaining ecosystem services and advancing sustainable development.

Complementarily, several studies focus on strategic ecosystems such as mangroves and wetlands. Hakimdavar et al. (2020) and Eyzaguirre et al. (2023) emphasize that, due to their high productivity, these ecosystems provide essential services to local communities, underscoring the need for collaborative management models that ensure community participation. Kundu et al. (2024) expand this view by highlighting the central role of wetlands in achieving multiple SDGs, as they deliver ecological, social, and cultural benefits. These findings suggest that the sustainable management of wetlands and mangroves constitutes a direct bridge between ecological conservation and human well-being.

Some authors examine the challenges to sustainability posed by anthropogenic pressures and global dynamics. Zhang et al. (2022) warn that hydropower projects may significantly disrupt aquatic ecosystems and biodiversity. Similarly, Huang et al. (2023) analyze the impacts of urban expansion, pollution, and habitat loss, proposing the creation of cross-sectoral synergies to counteract these effects. In the same direction, Wiegand et al. (2024) draw attention to the lack of environmental criteria in reporting processes, which hinders accurate monitoring of progress toward sustainability.

Furthermore, the study quantified the types of ecosystems in which protection methodologies have been applied to safeguard aquatic ecosystems in line with SDG 6, Target 6.6. The review was designed to identify articles that reported one or more methodologies implemented within one or two ecosystems.

TABLE 4 Main approaches and criteria proposed by the literature for sustainable development and ecosystem conservation.

Thematic axis	Main criteria	References
Socioeconomic dimension	<ul style="list-style-type: none"> • Socioeconomic development and social impact • Social well-being and environmental balance • Sustainable economic growth (natural, economic, social, and environmental resources) • Social environment and economic factors 	Ait-Kadi (2016), Wang et al. (2024), Grazule et al. (2022), and Frone and Frone (2021)
Governance and policies	<ul style="list-style-type: none"> • Measurement, valuation, and decision-making • Monitoring networks and technical capacity building • Global water governance and SDG 6 • Lack of compliance in environmental reporting • Environmental and sustainability strategies 	Vörösmarty et al. (2018), Wiegleb and Bruns (2018), Wiegant et al. (2024), and Aguayo Lopes da Silva et al. (2024)
Forest ecosystems	<ul style="list-style-type: none"> • Sustainable forestry and rational forest management • Forests as water purifiers • Emission reduction and strengthening of carbon sinks • Continuous flow of ecosystem services 	Ma et al. (2022) and Aguayo Lopes da Silva et al. (2023)
Aquatic ecosystems and wetlands	<ul style="list-style-type: none"> • Multiple ecosystem services (water, carbon, biodiversity, recreation) • Role of wetlands in achieving SDGs • Conservation and sustainable management of mangroves • Community participation in management 	Hakimdavar et al. (2020), Kundu et al. (2024), and Eyzaguirre et al. (2023)
Environmental and technological factors	<ul style="list-style-type: none"> • Precipitation, ecological flows, and technological advances • Climate, disturbances, anthropogenic pressures, and topography • Indicators for natural resource protection • Sustainability challenges: pollution, urbanization, habitat loss 	Ge and Wang (2024), Randin et al. (2020), Dickens et al. (2020), and Huang et al. (2023)
Infrastructure impacts	<ul style="list-style-type: none"> • Hydropower construction and alteration of aquatic ecosystems 	Zhang et al. (2022)

Another relevant aspect identified in the review concerns the policies implemented for the protection of aquatic ecosystems. As shown in Table 5, the category with the highest number of documented examples was integrated water management, followed by biodiversity and ecosystem services policies, international collaboration, governance and regulations, and international programs, each with three records. In contrast, the categories of national sustainability plans and global perspectives and studies included two and three examples, respectively, while monitoring and data was the least represented, with only one case. Table 5 also provides details on specific policies, case studies, and international agreements that were not included among the main analytical categories, thereby highlighting the diversity of approaches employed across different contexts to ensure the sustainable management of water resources and the conservation of ecosystems.

The analysis of the social and economic impacts of protection methodologies applied in aquatic ecosystems indicates that the majority of studies (60%, $n = 24$) reported a moderate impact, characterized by visible improvements in management and conservation, although accompanied by persistent challenges that limit their overall effectiveness. In contrast, only 2.5% ($n = 1$) of the articles documented a clearly positive impact, with significant improvements in both social conditions and economic benefits, while 5% ($n = 2$) reported negative impacts associated with deteriorating living conditions or adverse economic effects. Finally, 32.5% ($n = 13$) did not explicitly assess these dimensions, mainly

due to limited data availability or the absence of dedicated analyses addressing social and economic outcomes.

Regarding water quality assessment, there is limited consideration of physicochemical parameters. Seventy-nine percent of the articles do not mention specific indicators, and only a small group refer to variables such as pH, turbidity, apparent color, coliforms, conductivity, and other advanced parameters (e.g., dissolved oxygen, nutrients, suspended solids, and ecological flow).

Regarding the methods employed to analyze the chemical and biological composition of water for pollutant detection, the vast majority of studies (85%) indicated that such evaluation was not applicable. Only 10% incorporated water quality monitoring techniques, while laboratory tests and field measurements were reported only marginally.

In terms of technologies and tools applied for the protection and restoration of aquatic ecosystems, the category “Non-Specific Technologies and Tools for Protection and Restoration” that shows in Table 6, was the most prevalent (44%), followed by “not applicable” (29%). Sensor- and remote monitoring-based tools (11%) and modeling and simulation (10%) were also reported, though to a lesser extent. The use of green technologies was scarce (4%), and no applications of biotechnology were identified.

These findings highlight significant methodological gaps in the recent literature, underscoring the need to strengthen the technical and multidimensional rigor of research, particularly within the framework of SDG 6, Target 6.6, which is aimed at protecting and restoring water-related ecosystems.

TABLE 5 Policies implemented for the protection of aquatic ecosystems.

Policy category	Examples	References
Integrated water management	Integrated water management strategies; 14 of 108 countries set IWRM targets; national cooperation in research; public interest in Rio + 20 consultations	Ait-Kadi (2016), Vörösmarty et al. (2018), and Ma et al. (2022)
Biodiversity and Ecosystem services	Biodiversity policies; REDD+ action plans; national biodiversity strategies; forest and wetland conservation	Biswas et al. (2020), Zaizhi and Haishui (2004), and Yang et al. (2023)
International collaboration	UNFCCC; UN-GEMI Initiative; Ramsar Convention; UN-REDD Programme; EU agreements (Romania)	Wiegand and Bruns (2018), Frone and Frone (2021), and Eyzaguirre et al. (2023)
Governance and regulations	Resolution 91/2008 of CNRH (Brazil); Constitution of India; economic development policies aligned with Agenda 2030	Zaneti et al. (2023), Dandabathula et al. (2021), and Wiegand et al. (2024)
National sustainability plans	Myanmar Sustainable Development Plan (MSDP); National Forest Master Plan; Guangdong-Hong Kong-Macao Greater Bay Plan	Biswas et al. (2020) and Huang et al. (2023)
International programs	Natural Forest Conservation Program (NFCP, China); UN-REDD Programme; UNEP initiatives	Wan Mahari et al. (2020) and Hakimdavar et al. (2020)
Monitoring and data	Global Water Data Initiative; OECD governance and financing of water infrastructure	Amezaga et al. (2019)
Global perspectives and studies	Global reports; Global Reporting Initiative (GRI); forest–water nexus studies; environmental impact assessment in the Himalayas	Aguayo Lopes da Silva et al. (2023) and Rawat and Rai (1990)

TABLE 6 Classification of non-specific technologies and tools for protection and restoration.

Tool category	Specific examples of tools and data	References
I. Remote sensing and observation platforms	Landsat, MODIS, Sentinel, Global Mangrove Watch (GMW), Google Earth Engine (GEE), Earth Observations (EOs)	Biswas et al. (2020), Hakimdavar et al. (2020), Aguayo Lopes da Silva et al. (2023), and Eyzaguirre et al. (2023)
II. Geographic information systems (GIS) & software	Q-GIS, ArcView GIS, Google Earth, Python 3.6	Aguayo Lopes da Silva et al. (2023) and Dadebo et al. (2023)
III. Modeling and simulation	EPANET, System Dynamics Models (population, agriculture), Remote Sensing Models, Driver-Pressure-State-Impact-Response (DPSIR) Model	Peng et al. (2013), Huang et al. (2023), Dadebo et al. (2023), and Randin et al. (2020)
IV. Machine learning (ML) and statistics	Random Forest (RF) algorithm, Artificial Neural Network (ANN), Support Vector Machine (SVM), Discriminant analysis, Logistic regression, Pearson method, Panel Vector Autoregressive Model (PVAR)	Biswas et al. (2020), Shen et al. (2020), Zhang et al. (2022), and Kundu et al. (2024)
V. Specific monitoring and <i>in situ</i> tools	Secchi depth (Zsd) low-cost clarity measure, Environmental detection systems, WHO/UNICEF Joint Monitoring Programme	Amezaga et al. (2019) and Shen et al. (2020)
VI. Development and restoration practices	Low Impact Development (LID) technologies, Composting, Vermiculture, Biofertilizer, Poly-pit/trench/house	Vörösmarty et al. (2018) and Samal et al. (2003)

4 Discussion

The United Nations (UN) 2030 Agenda for Sustainable Development places water management as a central pillar for global development (Ait-Kadi, 2016). It is not an isolated goal, but rather the foundation upon which public health, food security, and economic stability are constructed. As Frone and Frone (2021) assert, the rational management of

water resources is a prerequisite for sustainable development. The availability of renewable and reliable water is the key to human water security (Vörösmarty et al., 2018), an existential challenge in a context where scarcity already affects over 40% of the world's population (Amezaga et al., 2019). The water stress indicator—which (Liu, 2021) defines as “the ratio between total freshwater withdrawal by all major sectors and total renewable freshwater resources”—is not merely an environmental

metric; it is a direct indicator of social vulnerability, positively linked with poverty in developing countries (Liu, 2021).

The results, extracted from 40 selected articles, reveal a complex and fragmented landscape. Progress toward Target 6.6 is non-uniform; it is characterized by profound knowledge gaps, thematic imbalances, and a chronic disconnect between policy and practice. The discussion of these findings is articulated along four critical axes: (1) the marked imbalance in research focus among the ecosystems of Target 6.6; (2) the ambiguity surrounding the effectiveness of strategies and the weak linkage with the SDG framework; (3) the persistent gap between the discourse of integrated policies and their tangible implementation; and (4) the systemic interconnectedness of the SDGs and the risk of trade-offs.

The most compelling finding of this review is the extreme disparity in scientific attention. Forests emerge as undisputed protagonists (26.8% of articles), which is consistent with global literature recognizing the fundamental forest-water symbiosis. Forest ecosystems can conserve water, a function directly related to SDG 6 (Ma et al., 2022). The high research productivity of countries such as the United States, China, Germany (along with the UK, Australia, Austria, Italy, the Netherlands, Switzerland, and Sweden) in this area is vital (Ma et al., 2022), especially as regions like South America and Africa face rampant deforestation and have experienced the greatest net losses in forest area (Amezaga et al., 2019).

The geographical distribution of research also reveals an important imbalance between knowledge production and implementation contexts. A considerable portion of the scientific literature is generated by institutions located in the Global North, often focusing on ecosystems situated in developing regions. This asymmetry may influence research priorities, funding availability, and the types of conservation strategies proposed, reinforcing structural inequalities in water resource management.

Wetlands also receive significant attention (10.7%), justified by their role as “the planet’s kidneys” and their immense capacity for carbon sequestration and biodiversity provision. They are crucial ecosystems for conservation and sustainable management (Kundu et al., 2024). However, the research underscores their critical state of global degradation, with alarming rates of loss: in Africa, countries like Tanzania, Uganda, Ethiopia, and Nigeria have experienced high rates of loss; in Asia, India, Bangladesh, and China; and South America, specifically Brazil and Argentina, has exhibited moderate to high rates of degradation (Kundu et al., 2024).

This focus on forests and wetlands, though necessary, has created dangerous blind spots. The finding that 87.5% of articles failed to mention specific strategies for aquifers represents a critical knowledge vacuum. Similarly, the omission of methodologies for rivers (82.5%) and mountains (69%) is alarming. This confirms that Target 6.6 is being addressed in a fragmented manner, with a disproportionate focus on visible ecosystems (forests) while neglecting subterranean (aquifers) and source (mountains) systems that are fundamental to the complete water cycle. Beyond the thematic focus, the efficacy of implemented strategies is, at best, ambiguous. Reforestation, the most cited intervention, yielded mixed results: 19 articles reported non-compliance with objectives (water quality, erosion) compared to 11 reporting full compliance. A “moderate” socioeconomic impact (reported in 24 articles) suggests that, while interventions can generate improvements, they often fail to transform living conditions or resolve underlying economic pressures.

Equally problematic is the weak linkage of research with the SDG framework itself. That 24% of studies did not specify any concrete SDG target is a “weakness in explicitization.” This hinders the monitoring of

global progress, impedes data aggregation, and suggests that the scientific community is not always aligning its research with the objectives of policymakers. This finding is crucial in the transition from the Millennium Development Goals (MDGs) to the SDGs. The MDGs focused on social development issues and only marginally addressed environmental challenges (Wiegleb and Bruns, 2018). Although the drinking water target was considered a great success, being met five years ahead of schedule, the sanitation target was never achieved (Amezaga et al., 2019; Wiegleb and Bruns, 2018). In contrast, the SDGs are the blueprint for achieving a better and more sustainable future, explicitly confronting environmental degradation (Zhang et al., 2019). If the research evaluating Target 6.6 interventions does not even name it, there is a risk of repeating the failures of the MDGs.

The results identify the classic triad of factors that define the gap between the intent of Target 6.6 and its implementation: governance, financing, and technology. In governance, realizing the vision of the SDGs is, first and foremost, the responsibility of countries, national governments, and stakeholders (Ait-Kadi, 2016). Success requires an alignment of actors (government, academia, private sector, civil society) (Vörösmarty et al., 2018). Success stories, such as restoration in China (Yang et al., 2023) or the “Namami Gange” program in India (Dandabathula et al., 2021), demonstrate that strong governmental backing is a predictor of efficacy. However, governance systemically fails when data are inadequate or when policy formulation is centralized and “top-down.” It is crucial for governments to look beyond the global trend when reporting progress and collect data on natural resources to enable national-level sustainability assessment (Mondal et al., 2020; Dickens et al., 2020). The lack of local government and community involvement weakens long-term sustainability; measuring SDG progress is critical for defining achievement and informing local policies (Huang et al., 2023).

Beyond scientific and technical considerations, the reviewed literature highlights that the successful implementation of conservation strategies is strongly influenced by structural factors such as governance capacity, financial investment, institutional coordination, and access to monitoring technologies. In many regions, particularly in the Global South, limitations in infrastructure, environmental management systems, and long-term policy continuity represent significant barriers to achieving SDG 6.6. These challenges indicate that the gap is not only related to knowledge production, but also to the capacity to translate scientific findings into effective management actions.

In financing, the lack of financial support is not just a barrier, but an active inhibitor. In most countries, funding for ecosystem protection “is neither sufficient nor sustainable” (Vörösmarty et al., 2018). This has direct effects, such as the deterioration of water monitoring networks (Vörösmarty et al., 2018), creating a vicious cycle. Furthermore, deficient financial support affects the fulfillment of SDG 6 (Zhang et al., 2019), as low-resource communities struggle to achieve universal access to adequate services, and low-income countries find it difficult to reach the targets (Dadebo et al., 2023). The success of the program in the Himalayas, with 100% financial assistance (Shaheen et al., 2023), confirms this.

The results show an extensive use of diagnostic technologies (Landsat, Sentinel, GIS), but a low specification of laboratory methods for contaminants (35 articles). The literature highlights the potential of tools like cloud services, mentioning the use of Amazon Web Service to help calculate how to use water more efficiently (Yu et al., 2022). This suggests that advanced technology is being used far more to describe the problem (mapping deforestation) than to evaluate the efficacy of solutions. However, the need for more science and synthesized analysis of

existing global datasets has been named to meet the ambitious reporting goals set by SDG 6 (Hakimdavar et al., 2020).

There exists a profound interconnection of Target 6.6 with the entire 2030 Agenda. SDGs 2 (Zero Hunger), 6 (Water), 7 (Energy), and 15 (Life on Land) are considered the “essential needs” that humans obtain from ecosystems for sustenance (Zhang et al., 2022). Synergies are evident: protecting a watershed (Target 6.6) improves water and food security (SDGs 2 and 6) and reinforces growth, as water security and economic growth (SDG 8) can be mutually reinforcing (Zhang et al., 2022). However, this synergy is not automatic, and the literature is often overly optimistic. The reality of development is fraught with “trade-offs.” In contrast, the policies, practices, and investments needed to achieve SDG 6 may not be coordinated with those of other SDGs, thereby failing to guarantee positive outcomes for people (Amezaga et al., 2019). The pursuit of SDG 7 (Energy) through large hydroelectric dams can destroy river ecosystems (Target 6.6). Agricultural expansion for SDG 2 (Zero Hunger) is the primary cause of aquifer overexploitation and nitrate contamination (Targets 6.3 and 6.6).

The risk, as demonstrated by the findings of this review, is that the policies, practices, and investments required to achieve SDG 6 are not coordinated. The fact that 65% of biodiversity and ecosystem conditions in the Americas are declining (Vörösmarty et al., 2018) is proof that “trade-offs” are winning over synergies. The fulfillment of Target 6.6 is, therefore, not an isolated objective. It is the pillar that must manage these trade-offs. Failing Target 6.6 means not only losing ecosystems but also jeopardizing the long-term viability of the entire 2030 Agenda, by undermining the very resource base on which the other SDGs depend.

5 Conclusion

The findings of this systematic review reveal a significant imbalance in the scientific attention given to water-related ecosystems. Forests dominate the research landscape, while aquifers, rivers, and mountain systems remain critically understudied despite their fundamental role in the hydrological cycle. This fragmented focus limits the comprehensive protection of water-related ecosystems and constrains effective progress toward SDG 6, particularly Target 6.6.

The analysis also highlights the uncertain effectiveness of widely implemented interventions, such as watershed reforestation. Mixed outcomes and predominantly moderate socioeconomic impacts suggest that conservation strategies are highly context-dependent and cannot be universally applied without considering local environmental, institutional, and social conditions.

A critical gap identified in the literature is the weak explicit alignment between research outputs and the SDG framework. The absence of clear references to specific SDG targets in a considerable portion of studies complicates the monitoring of global progress and reduces the potential for translating scientific knowledge into policy-relevant evidence.

Beyond technical and ecological dimensions, the results point to persistent structural barriers related to governance, financing, and technological application. The lack of institutional coordination, long-term financial support, and robust monitoring systems continues to limit the effectiveness and sustainability of conservation initiatives, particularly in regions with lower management capacity.

Finally, the findings underscore the strong interconnections between Target 6.6 and other development goals, especially those related to food security and economic growth. However, the prevalence of tradeoffs,

such as hydropower expansion affecting river ecosystems or agricultural intensification contributing to aquifer degradation—suggests that achieving SDG 6.6 requires more integrated and coordinated policy frameworks. Protecting water-related ecosystems is not only an environmental priority, but a structural condition for sustaining the broader objectives of the 2030 Agenda.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

PA-C: Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. KL: Data curation, Formal analysis, Investigation, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. HG-S: Writing – original draft, Writing – review & editing. LA-C: Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

- Aguayo Lopes da Silva, R., Cesar Gonçalves Robert, R., and Purfürst, T. (2023). How is the forest sector's contribution to the sustainable development goals (SDGs) being addressed? A systematic review of the methods. *Sustainability* 15:8988. doi: 10.3390/su15118988
- Aguayo Lopes da Silva, R., Duarte dos Santos, L., Gonçalves Robert, R. C., and Purfürst, T. (2024). Brazilian forest-based sector perceptions and contributions to the sustainable development goals (SDGs)—developing strategies using the strategic options development and analysis (SODA) approach. *Forests* 15:198. doi: 10.3390/f15010198
- Ahmad, A., Rawat, J. S., and Rai, S. C. (1990). An analysis of the himalayan environment and guidelines for its management and ecologically sustainable development. *Environmentalist* 10, 281–298. doi: 10.1007/BF02239722
- Ait-Kadi, M. (2016). Water for development and development for water: realizing the sustainable development goals (SDGs) vision. *Aquat. Procedia* 6, 106–110. doi: 10.1016/j.aqpro.2016.06.013
- Amezaga, J., Bathurst, J., Iroumé, A., Jones, J., Kotru, R., Dutt Bhatta, L., et al. (2019). "SDG 6: clean water and sanitation – forest-related targets and their impacts on forests and people", in Sustainable Development Goals: Their Impacts on Forests and People Eds. P. Katila, C. J. Pierce Colfer, W. de Jong, G. Galloway, P. Pacheco, and G. Winkel (Cambridge: Cambridge University Press), 178–205.
- Biswas, S., Huang, Q., Anand, A., Mon, M. S., Arnold, F. E., and Leimgruber, P. (2020). A multi sensor approach to forest type mapping for advancing monitoring of sustainable development goals (SDG) in Myanmar. *Remote Sens.* 12:3220. doi: 10.3390/rs12193220
- Borenstein, M., Hedges, L. V., Higgins, J. P., and Rothstein, H. R. (2021). *Introduction to Meta-Analysis*. 2nd edn. Wiley.
- Cumpston, M. S., McKenzie, J. E., Thomas, J., and Brennan, S. E. (2021). The use of 'PICO for synthesis' and methods for synthesis without meta-analysis: protocol for a survey of current practice in systematic reviews of health interventions. *F1000Res.* 9, 678. doi: 10.12688/f1000research.24469.2
- Dadebo, D., Obura, D., and Kimera, D. (2023). Hydraulic modeling and prediction of performance for a drinking water supply system towards the achievement of sustainable development goals (SDGs): a system case study from Uganda. *Groundw. Sustain. Dev.* 22:100951. doi: 10.1016/j.gsd.2023.100951
- Dandabathula, G., Chintala, S. R., Ghosh, S., Balakrishnan, P., and Jha, C. S. (2021). Exploring the nexus between Indian forestry and the sustainable development goals. *Reg. Sustain.* 2, 308–323. doi: 10.1016/j.regus.2022.01.002
- Dickens, C., McCartney, M., Tickner, D., Harrison, I. J., Pacheco, P., and Ndhlovu, B. (2020). Evaluating the global state of ecosystems and natural resources: within and beyond the SDGs. *Sustainability* 12:7381. doi: 10.3390/SU12187381
- Eyzaguirre, I. A. L., Iwama, A. Y., and Fernandes, M. E. B. (2023). Integrating a conceptual framework for the sustainable development goals in the mangrove ecosystem: a systematic review. *Environ. Dev.* 47:100895. doi: 10.1016/j.envdev.2023.100895
- Frone, D. F., and Frone, S. (2021). Aspects concerning contribution of water supply and sanitation networks (WSS) investments to sustainable development goals (SDGs) in Romania. *Sci. Papers, Ser. Manag. Econom. Eng. Agric. Rural Dev.* 21, 255–266.
- Ge, Y., and Wang, J. (2024). The water resources rebound effect threatening the achievement of sustainable development goal 6 (SDG 6). *Sustainability* 16:4155. doi: 10.3390/su16104155
- Grant, M. J., and Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Info. Libr. J.* 26, 91–108. doi: 10.1111/j.1471-1842.2009.00848.x
- Grazule, D., Grinfelde, I., Bakute, A., Pilecka-Ulcugaceva, J., Burlakovs, J., and Siltumens, K. (2022). Challenges for the development of lowland rivers ecosystem services in the context of sustainable development goals. *Res. Rural Dev.* 37, 259–265. doi: 10.22616/rrd.28.2022.037
- Hakimdar, R., Hubbard, A., Policelli, F., Pickens, A., Hansen, M., Fatoyinbo, T., et al. (2020). Monitoring water-related ecosystems with earth observation data in support of sustainable development goal (SDG) 6 reporting. *Remote Sens.* 12:1634. doi: 10.3390/rs12101634
- Huang, J., Nitivattananon, V., Lin, D., and Gong, W. (2023). Integrated assessment for sustainable development goals of metropolitan regions: a case study of the Pearl River Delta region, China. *Environ. Sustain. Indic.* 20:100299. doi: 10.1016/j.indic.2023.100299
- Katila, P., McDermott, C., Larson, A., Aggarwal, S., and Giessen, L. (2020). Forest tenure and the sustainable development goals—a critical view. *Forest Policy Econ.* 120:102294. doi: 10.1016/j.forpol.2020.102294
- Kundu, S., Kundu, B., Rana, N. K., and Mahato, S. (2024). Wetland degradation and its impacts on livelihoods and sustainable development goals: an overview. *Sustainable Prod. Consumption* 48, 419–434. doi: 10.1016/j.spc.2024.05.024
- Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gotzsche, P. C., Ioannidis, J. P., et al. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J. Clin. Epidemiol.* 62, e1–e34. doi: 10.1016/j.jclinepi.2009.06.006
- Liu, S. (2021). Child mortality and water stress under the framework of sustainable development goals (SDGs): evidence from twenty developing countries. *Present Environ. Sustain. Dev.* 15, 49–58. doi: 10.15551/pesd2021151004
- Ma, Z., Hu, C., Huang, J., Li, T., and Lei, J. (2022). Forests and forestry in support of sustainable development goals (SDGs): a bibliometric analysis. *Forests* 13:1960. doi: 10.3390/f13111960
- Moher, D., Liberati, A., Tetzlaff, J., and Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 6:e1000097. doi: 10.1371/journal.pmed.1000097
- Mondal, P., McDermid, S. S., and Qadir, A. (2020). A reporting framework for sustainable development goal 15: multi-scale monitoring of forest degradation using MODIS, Landsat and sentinel data. *Remote Sens. Environ.* 237:111592. doi: 10.1016/j.rse.2019.111592
- Mugagga, F., and Nabaasa, B. B. (2016). The centrality of water resources to the realization of sustainable development goals (SDG). A review of potentials and constraints on the African continent. *Int. Soil Water Conserv. Res.* 4, 215–223. doi: 10.1016/j.iswcr.2016.05.004
- Mujtaba, G., Shah, M. U. H., Hai, A., Daud, M., and Hayat, M. (2024). A holistic approach to embracing the united nation's sustainable development goal (SDG-6) towards water security in Pakistan. *J. Water Process Eng.* 57:104691. doi: 10.1016/j.jwpe.2023.104691
- Peng, Y., Ai, N. S., and Liu, G. D. (2013). Analysis on sustainable development of small watershed in mountain area by system dynamics. *Adv. Mater. Res.* 807–809, 919–922. doi: 10.4028/www.scientific.net/AMR.807-809.919
- Randin, C. F., Ashcroft, M. B., Bolliger, J., Cavender-Bares, J., Coops, N. C., Dullinger, S., et al. (2020). Monitoring biodiversity in the Anthropocene using remote sensing in species distribution models. *Remote Sens. Environ.* 239:111626. doi: 10.1016/j.rse.2019.111626
- Rawat, A. J. S., and Rai, S. C. (1990). An analysis of the Himalayan environment and guidelines for its management and ecologically sustainable development. *Environmentalist* 10, 281–298. doi: 10.1007/BF02239722
- Samal, P. K., Palni, L. M. S., and Agrawal, D. K. (2003). Ecology, ecological poverty and sustainable development in central Himalayan region of India. *Int. J. Sustain. Dev. World Ecol.* 10, 157–168. doi: 10.1080/13504500309469794
- Shaheen, F. A., Wani, M. H., and Baba, S. H. (2023). Sustainable hill agricultural practices through watershed development programmes and their impact in Himalayan states. *J. Agric. Econ.* 65. Available online at: <http://ageconsearch.umn.edu> (Accessed February 15, 2025).
- Shen, M., Duan, H., Cao, Z., Xue, K., Qi, T., Ma, J., et al. (2020). Sentinel-3 OLCI observations of water clarity in large lakes in eastern China: implications for SDG 6.3.2 evaluation. *Remote Sens. Environ.* 247:111950. doi: 10.1016/j.rse.2020.111950
- Vörösmarty, C. J., Rodríguez Osuna, V., Cak, A. D., Bhaduri, A., Bunn, S. E., Corsi, F., et al. (2018). Ecosystem-based water security and the sustainable development goals (SDGs). *Ecohydrol. Hydrobiol.* 18, 317–333. doi: 10.1016/j.ecohyd.2018.07.004
- Wan Mahari, W. A., Azwar, E., Li, Y., Wang, Y., Peng, W., Ma, N. L., et al. (2020). Deforestation of rainforests requires active use of UN's sustainable development goals. *Sci. Total Environ.* 742:140681. doi: 10.1016/j.scitotenv.2020.140681
- Wang, T. (2020). Environmental protection and sustainable development in ecological functional zones. *IOP Conf. Ser.: Earth Environ. Sci.* 514:032061. doi: 10.1088/1755-1315/514/3/032061
- Wang, T., Zhou, D., and Fan, J. (2024). Spatial differences of sustainable development goals (SDGs) among counties (cities) on the northern slope of the Kunlun Mountains. *Reg. Sustain.* 5:100108. doi: 10.1016/j.regus.2024.03.002
- Wiegand, D., Dewulf, A., and Van Zeben, J. (2024). Alignment mechanisms to effectively govern the sustainable development goals. *World Dev.* 182:106721. doi: 10.1016/j.worlddev.2024.106721
- Wiegand, V., and Bruns, A. (2018). Hydro-social arrangements and paradigmatic change in water governance: an analysis of the sustainable development goals (SDGs). *Sustain. Sci.* 13, 1155–1166. doi: 10.1007/s11625-017-0518-1

- Yang, H., Gou, X., Xue, B., Ma, W., Kuang, W., Tu, Z., et al. (2023). Research on the change of alpine ecosystem service value and its sustainable development path. *Ecol. Indic.* 146:109893. doi: 10.1016/j.ecolind.2023.109893
- Yu, W., Hassan, A., and Adhikariparajuli, M. (2022). How did Amazon achieve CSR and some sustainable development goals (SDGs)—climate change, circular economy, water resources and employee rights during COVID-19? *J. Risk Financ. Manag.* 15:364. doi: 10.3390/jrfm15080364
- Zaizhi, Z., and Haishui, Z. (2004). Development of socio-economic and ecological alternatives for sustainable management of mountain secondary forest in tropical China. *Int. J. Sustain. Dev. World Ecol.* 11, 63–68. doi: 10.1080/13504500409469812
- Zaneti, R. N., Fernandes, C. V. S., and Etchepare, R. G. (2023). Urban water quality in Porto Alegre (Brazil) in light of the sustainable development goal (SDG) 6 and the new national sanitation policy. *Urban Water J.* 20, 1608–1617. doi: 10.1080/1573062X.2022.2056489
- Zhang, Q., Liu, S., Wang, T., Dai, X., Baninla, Y., Nakatani, J., et al. (2019). Urbanization impacts on greenhouse gas (GHG) emissions of the water infrastructure in China: trade-offs among sustainable development goals (SDGs). *J. Clean. Prod.* 232, 474–486. doi: 10.1016/j.jclepro.2019.05.333
- Zhang, J., Wang, S., Pradhan, P., Zhao, W., and Fu, B. (2022). Mapping the complexity of the food-energy-water nexus from the lens of sustainable development goals in China. *Resour. Conserv. Recycl.* 183:106357. doi: 10.1016/j.resconrec.2022.106357