frontiers | Frontiers in Water

TYPE Review
PUBLISHED 09 May 2025
DOI 10.3389/frwa.2025.1511044

OPEN ACCESS

EDITED BY
Tamuka Nhiwatiwa,
University of Namibia, Namibia

REVIEWED BY
Rinku Singh,
Central Agroforestry Research Institute (CAFRI), India
Krasposy Kujinga,
WaterNet Trust, Botswana

*CORRESPONDENCE
Rajendrakumar S
✉ s_rajendrakumar@cb.amrita.edu
Tharanidevi N
✉ n_tharanidevi@cb.amrita.edu

RECEIVED 14 October 2024
ACCEPTED 20 March 2025
PUBLISHED 09 May 2025

CITATION
Damasco M, S R, N T, S S, Rahut DB and Timilsina RR (2025) Eco-profile approach in watershed and river basin management for addressing water rights and conflicts at micro scale.
Front. Water 7:1511044.
doi: 10.3389/frwa.2025.1511044

Eco-profile approach in watershed and river basin management for addressing water rights and conflicts at micro scale

Mavhaire Damasco[1], Rajendrakumar S[2]*, Tharanidevi N[3]*, Shimly S[4], Dil Bahadur Rahut[5] and Raja Rajendra Timilsina[5]

[1]Amrita School for Sustainable Futures, Amrita Vishwa Vidyapeetham, Amritapuri, India, [2]Department of Chemical Engineering and Materials Science, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India, [3]Department of Food Science, Amrita School of Physical Sciences, Coimbatore, Amrita Vishwa Vidyapeetham, India, [4]Department of Sciences, Amrita School of Physical Sciences, Coimbatore, Amrita Vishwa Vidyapeetham, India, [5]Asian Development Bank Institute, Chiyoda City, Tokyo, Japan

Eco-profile studies help in continuous assessment and monitoring of river basin functions; the planners, and decision-makers deploy study findings to address problems associated within river basins. In this paper, we reviewed the study covering the eco-profile based watershed and river basin management practices and the benefits of eco-profile in understanding and addressing water-related issues at the micro-level. The study uses a systematic literature review approach called the PRISMA framework (Preferred Reporting Items for Systematic reviews and Meta-Analyses) to collect and process the literature. Our study found that eco-profile based implementations improves the river basin functions and addresses the micro-level issues related to water rights and conflicts that are usually not addressed during water resources management. Through eco-profile study, the key ecological indicators at micro and macro scales can be identified that help to predict the continuous changes of biotic and abiotic conditions within the watershed and river basin regions. The present study discusses the advantage of eco-profile in the watershed, measures to comprehend river basin function, community role, and approach to solve the water rights and conflicts at the micro scale. The study also recommends the inclusion of eco-profile framework and eco-profile policy in integrated water resources management programs specific to river basin/watershed management activities.

KEYWORDS

eco-profile assessment, watershed, river basin management, water rights, water conflicts, ecological indicators, community wellbeing

1 Introduction

Eco-profile evaluation is a geographic-based instrument for planners and decision-makers, which presents the environmental quality and carrying capacity of a river basin region (Pomara and Lee, 2021; Peng et al., 2023). It describes the status of an ecological resource in the river basin and acts as a guide to implement a plan for watershed management, which is part of the river basin (Li and Wang, 2022). This evaluates results from integrating primary and secondary data on the watershed region, information on natural resources, anthropogenic activities, and associated environmental risks in this region (Siddig et al., 2016). Eco-profile

evaluation is complex due to constant regional and temporal changes, variations in flora and fauna, abiotic conditions, and disturbances in the river basin (Rowland et al., 2020). In addition, the river ecosystem is a lentic system; the water level increases or decreases due to seasons, land use in nearby ecosystems, and pollution waste dumping will affect the eco-profile evaluation.

The eco-profile study involves a multidimensional approach; the evaluation of physical, biological, socio-economic, and institutional components is crucial and must be included in this approach. Such ecological assessment practices helped in reduction in soil loss in the Abbay river basin (Khairy, 2022) and forestry interventions in the Ganga River (Singh et al., 2022). It improves the soil infiltration rate (Cai and Zhang, 2018), water holding capacity, and groundwater recharge (Woldearegay et al., 2023). The river function is enhanced through comprehensive eco-profile data on the ecological, hydrological, and socio-economic aspects of the watershed (Fenta et al., 2023; Gai et al., 2019). An eco-profile study carried out by the Foundation for Ecological Security (FES), proposed a measure to reduce a water crisis and conflicts in watersheds (Kandicuppa et al., 2016). Further, the study collates data on water quality and habitat health, which may prompt the implementation of regulations or incentives to reduce pollution or protect critical habitats. Fenta et al. (2023) stated that the information on ecosystem services provided by the watershed could guide land-use planning decisions to balance conservation with development needs and address the micro-level problems of the region.

Eco-profile assessments record the changes in the landscapes and specific stress on watersheds (Pomara and Lee, 2021). It helps develop models to predict ecosystems' response to human-induced stress (Savita and Kushwaha, 2018). Eco-profile assessments evaluate ecosystem processes in the context of a system that allows for the estimation of cumulative impacts across a larger region by combining various environmental data (Li and Wang, 2022). This approach helps identify degraded areas, vulnerable regions, and zones suitable for restoration. Such regional ecological assessments often provide the best available overview of ecological conditions, environmental stressors, and resource sustainability (Gain et al., 2020). Studies on eco-profile assessment processes build capacity for customized analysis. It will be necessary to repeat such analyses for future regional/sub-regional levels with the help of a geographical database. In the Sharavathi River basin, a study on the ecological profile focused on aquatic ecosystems such as water sediments, phytoplankton, zooplankton, and freshwater fish fisheries and addressed conflicts related to resource use (Ramachandra et al., 2012). The ecological profile in Madanapalle covered most of the southern part of Andhra Pradesh, focusing on aspects like climate, geology, soils, water, forests, and biodiversity (Foundation for Ecological Security, 2009). The multiple studies carried out by the FES (Kandicuppa et al., 2016) focused on water use planning, challenges in water conservation, methods to improve water quality, preserve water rights of the local community, and address the water use conflicts in these regions.

Research on the Amazon River basin aimed to develop an integrated eco-profile assessment framework focusing on ecosystem services, biodiversity conservation, and sustainable resource management. By utilizing remote sensing data and stakeholder consultations to characterize the basin's ecological functions and identify priority areas for conservation and restoration (Lessmann et al., 2019; Jezequel et al., 2022). Additionally, a study on the Yangtze River basin focused on integrating ecological health indicators with socio-economic development indicators by analyzing spatial and temporal trends in ecosystem services, water quality, water rights, and conflicts due to land use and human activities. The study aimed to inform decision-making processes for sustainable watershed management and economic development in the region (Yu et al., 2018).

In the Mekong river basin, an investigation was performed on the impacts of land use changes on ecosystem functions, with a particular emphasis on hydrological processes, sediment dynamics, and fisheries productivity. Using a combination of field surveys, remote sensing analysis, and hydrological modeling, the study assessed the vulnerability of different ecosystems to land use pressures and identified strategies for mitigating negative impacts on biodiversity and livelihoods (Ma et al., 2021). Another study of the Rhine River basin focused on integrating ecosystem service assessment into water resource management. The study aimed to enhance sustainable and resilient water management practices to address a regional water conflicts (Staentzel et al., 2019; Kuenzer et al., 2020).

The eco-profile assessment strategies assist in identifying critical areas of degradation attributed to deforestation and unsustainable agricultural practices (Cai and Zhang, 2018) and water rights and conflicts (Foundation for Ecological Security, 2009). However, without proper assessment and limited knowledge of watershed ecological and socio-economic dynamics, such intervention strategies could lead to unintended consequences of increased soil erosion, habitat loss, and water conflicts with local communities (Chandrakar et al., 2016), leading to long-term failure of the watershed management program. It is against this background to manage watersheds and river basins to address associated water rights and conflict issues at the micro-level. Therefore, it is in the interest of this paper to include an eco-profile assessment approach as an instrument to answer the following research questions:

1. What are the advantages of employing eco-profile in watershed management?
2. In what way does the eco-profile assessment help understand the river basin function?
3. How do eco-profile studies solve water rights and conflicts in river basins at the micro–macro scale?
4. Why should the community participate in eco-profile assessment to solve the water rights and conflicts?
5. How can river basin and watershed management practices be promoted based on eco-profile assessment frameworks and policies?

2 Methods

This study follows Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Shaffril et al., 2018; Dandadzi and Kothurkar, 2023) methodology to retrieve the peer-reviewed articles that focus on eco-profile based management of watershed and river basins. The sources were from "Google Scholar," "Web of Science," "PubMed" and "Scopus" academic databases. Retrieved articles were based on the following keywords: "eco-profile evaluation," "watershed management," "river basin functions," "ecosystem services," "hydrology," "biodiversity," "land use," "water quality,"

"socio-economic factors," "water policy," "water rights," "water conflicts," and "decision support." Then, citation chaining and snowballing techniques were used to identify additional relevant sources from the reference lists of retrieved articles.

2.1 Search strategy and selection criteria

The systematic review process involved (a) identification of similar articles using keywords from studies on watershed and river basin management from different online databases. (b) Read titles and abstracts for eligibility. (c) Elimination of articles that were not in English together with those without full-text. (d) Full-texts irrelevant articles removed. Finally, only relevant articles specific to watershed/river basin management that used the eco-profile approach to address water rights and conflicts were selected for this study (Figure 1).

2.1.1 Inclusion and exclusion papers

We included only those papers that primarily focused on watersheds, river basin management, and water rights and conflicts and published in peer-reviewed journals. Irrelevant articles that do not include eco-profile to manage watershed river basin management are excluded from this study (Figure 1).

3 Eco-profile in watershed and river basin management and its benefits

Eco-profile studies require inventory preparation of authentic scientific information elements of climate, landforms, plant and animal communities, and socio-economic systems of the regions. This helps to understand current baseline data, track changes over time, and evaluate the effectiveness of interventions in watershed

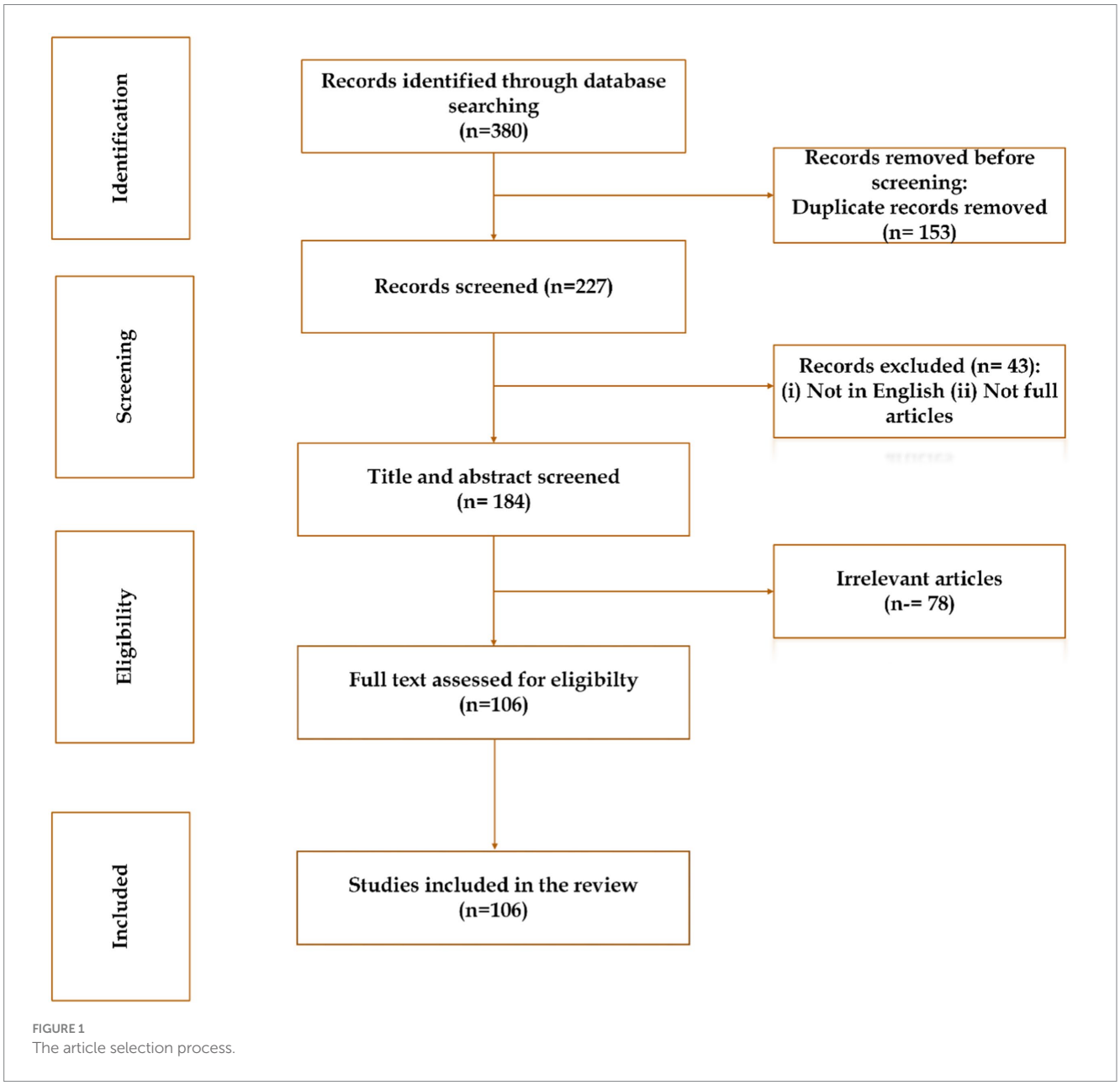

FIGURE 1
The article selection process.

management (Farid Ahmed et al., 2023). It acts as a pilot study in gathering available information and problems identified in the watersheds (Sonu and Bhagyanathan, 2022). The study explores valuable resources potentially at risk, stressors and exposure opportunities, and environmental effects (Zelenakova, 2009). Stakeholder engagement is crucial in the establishment of an intervention management plan to address the identified watershed challenges. However, the use of Geographical Information Systems (GIS) and Remote Sensing (RS) in eco-profile data collection and storage enhances the visual presentation of the stored data in an updated form (Baloch and Tanık, 2008). Regular watershed eco-profiling (Figure 2) helps to identify emerging threats or successes and allows for adaptive management approaches that can be adjusted as needed (Baloch and Tanık, 2008; Mostert, 2018).

In the river basin (constitute all watersheds), the river basin functions (Figure 3) are monitored through continuous eco-profile assessments of landscapes, which determine the quantity and quality of river flow in various catchment areas (Uereyen and Kuenzer, 2019). The ecological profile (Dale and Beyeler, 2001) information provides managers with insights into the conservation of critical habitats and endangered species of diverse flora and fauna, as well as the restoration of degraded ecosystems within the river basin (Farid Ahmed et al., 2023; den Haan et al., 2019).

3.1 Enhancing the river basin functions

3.1.1 River hydrology and river flow

The health of a river ecosystem is determined by its water flow. However, surface water and land properties of many major river basins remain largely unmonitored at basin scale (Uereyen and Kuenzer, 2019; Dwivedi et al., 2018). Several inventories exist, yet consistent spatial databases describing the status of major river basins at the global scale are lacking (Uereyen and Kuenzer, 2019). Eco-profile studies contribute to the protection of river hydrology and water flow through research that leads to the plan for improving the river basin functions (Figure 2) and regional ecology (McManamay et al., 2022). Globally, human activities have substantially affected the natural hydrologic cycles of rivers through land-use changes that directly affect river hydrology. Indirectly, urbanization creates impermeable surfaces that increase the volume and speed of storm runoff. River channels are often altered by the construction of dams, levees, and other channel modifications for flood protection, hydropower generation, and navigation. Strengthening of river courses facilitates navigation but reduces channel and flow complexity, thereby diminishing habitat diversity. The abstraction of the river basin affects the domestic water supply, agriculture irrigation channels, and water structures in the catchment regions.

Eco-profile studies contribute to preserving river hydrology and water flow by monitoring river flow. This helps to identify and understand the subsequent changes caused by human activities or environmental factors. River basin management requires the use of indicators to assess the health and alteration of hydrological systems at the basin scale. Eco-profile helps identify the indicators to evaluate the impact of human activities on river structure, disruption of longitudinal connectivity, and volumes of water within fluvial channels. This evaluation is crucial for the river basin ecosystem; it guides effective water resource management at the micro–macro scale (Lebel et al., 2013).

3.1.2 Geological structure

River basins are the most natural geomorphologic spatial units on the terrestrial landscape, which, if modified by humans, their soils and vegetation directly affect the delivery of water, sediments, and nutrients into these river drainage systems. Geological structures of rivers determine the geophysical and ecological processes related to surface water (Ghorbani Nejad et al., 2017; Fargnoli et al., 2013). Human activities such as mining, quarrying, and construction can significantly alter geological structures if the river basin is not monitored. To minimize the environmental impact of these activities, efficient resource extraction practices ensure proper restoration of disturbed sites. Eco-profile studies primarily focus on assessing ecological systems rather than geological structures, but they can be indirectly maintained by habitat preservation, land use planning, and erosion control.

3.1.3 Ecology and biodiversity

Eco-profile studies involve a comprehensive assessment of ecosystems, their structure, function, and interactions, which helps to identify key components and processes necessary for ecosystem health. The study delivers public awareness and practices such as sustainable agriculture, forestry, and fisheries to help minimize negative impacts on ecosystems while meeting human livelihood needs. Therefore, eco-profile studies contribute to the preservation of

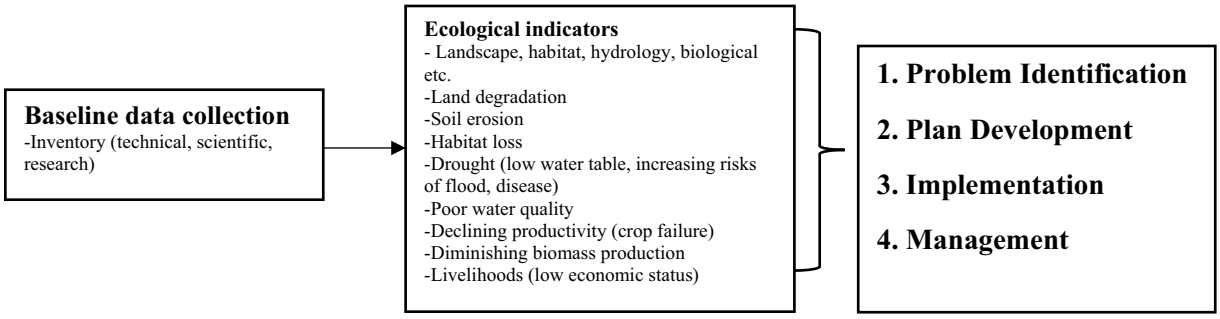

FIGURE 2
Flow chart of watershed eco-profiling and management.

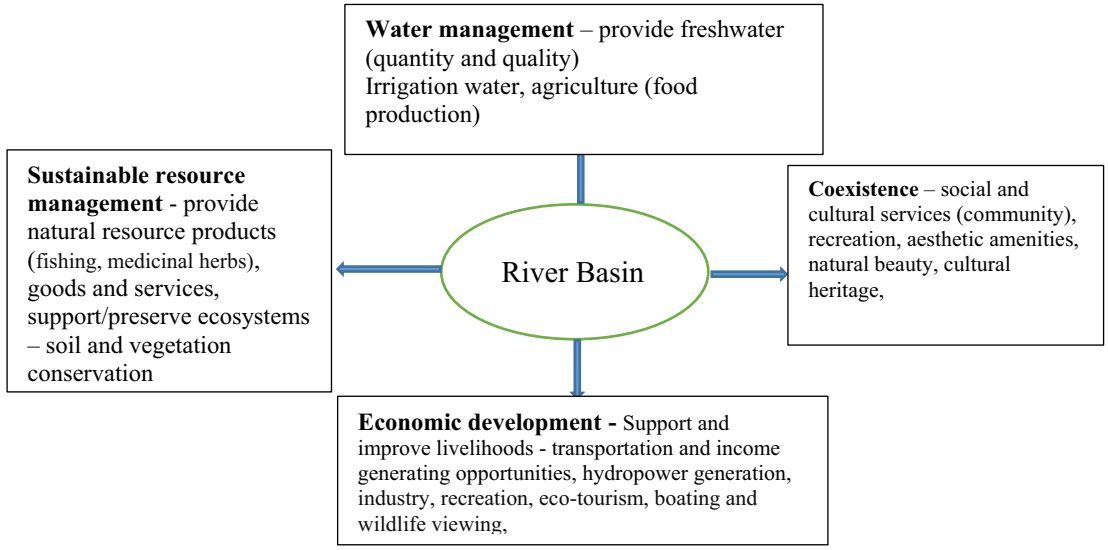

FIGURE 3
Community benefits and co-existence of River basin.

ecology and biodiversity by informing evidence-based conservation actions and promoting sustainable management practices. This necessitates species inventory and monitoring within a given ecosystem by tracking population size, distribution, and trends over time (Brauman, 2015; Finotto, 2011).

By eco-profile study, ecologists can detect changes that may indicate ecological imbalances or threats to biodiversity by identifying critical habitats for different species. Most of these threats are human-induced, including habitat destruction, pollution, climate change, and the introduction of invasive species (Ramakrishnan et al., 2024). Such threats to environmental conditions that influence river basin functions and watershed health (Angriani et al., 2018). Hence, there is a need to conserve and preserve the river basin biodiversity through policies and legislation and by a systematic approach.

3.1.4 Natural resources

Improper management approaches in watershed and river basin regions result in the degradation of river basins in many parts of the world (Molle et al., 2010). It seriously threatens the natural resources of river basins, like soil and water resources (Hafizan et al., 2023; Geetha and Soman, 2019), mainly in developing countries (Diop et al., 2022; Pradhan et al., 2023).

India, China, Brazil, and Turkey recorded natural resource degradation in watershed regions (Molle et al., 2018; Kanyagui and Viswanathan, 2022). The successful formulation of national policies at the watershed level reduces the problem of natural resource degradation. However, it faced challenges in Indonesia and Morocco due to uncertainties involved in a community-based approach in managing watershed (Darghouth et al., 2008). Therefore, applying eco-profile studies in watershed management helps in addressing the community conflict which arise in the catchment area owned by the different communities. In eco-profile based watershed practices such as terraces, dam construction helps control excess runoff and subsequently improve the livelihoods of communities through potential irrigation and fishing income-generating activities. This holistic approach improves the natural resources of the river basin and leads to sustainable development.

3.1.5 Fire protection

Improving river basin functions and regional ecology often involves community engagement and awareness initiatives to minimize the damage associated with fire (Neeraja et al., 2021). Communities can participate in such activities through prescribed burns, invasive species removal, vegetation pruning, habitat restoration, and protection of forests in the river basins (Metlen et al., 2021; Kanyagui et al., 2024). Eco-profile studies contribute positively to the protection of natural ecosystems by evaluating watershed environmental conditions and their role in giving early fire warning signals involving remote sensing technology necessary to conserve river basin resources. Hence, efficient forest protection through a properly built road network can protect water quality for longer.

3.2 Social and economic development

3.2.1 Agricultural sustainability

Historically, agricultural management practices mainly focused on crop yield rather than effects caused by nutrient load runoff into the water bodies (Ramakrishnan et al., 2024). Hence, agricultural practices require efficiency in order to reduce nutrient loads into rivers and protect the environment (European Environment Agency, 2020). Intensive farming practices may lead to land degradation (Maximillian et al., 2019; Khoiri et al., 2021), contributing to soil erosion, subsequent water siltation, and loss of ecosystem services (Scholes et al., 2018). Therefore, management practices proposed based on the eco-profile study in watershed regions, such as contour farming, zero tillage, and reforestation, contribute immensely (Marowa et al., 2023) and increase infiltration and reduce surface runoff (Khairy, 2022; Ricci et al., 2022). Eco-profile studies facilitates a better understanding of the changes

occurring in watersheds and river basins over time and improvement plans for sustainable agriculture.

3.2.2 Fodder management

Fodder is a main source of nutrients for livestock, but its availability is limited in developing countries (Kumar et al., 2023). Eco-profile studies improve fodder production and suggest measures for efficient grassland management. It increases the carrying capacity of grazing land by regulating overgrazing and overexploitation practices (Koli and Bhardwaj, 2018). Singh et al. (2018) recommended the introduction of high-yielding grasses and pasture legumes using integrated silvi-pastural/horti-silvi pasture systems to improve the overall productivity in the watershed.

Additionally, infrastructure for straw management and storage has been neglected in many parts of the world. It can be revamped by eco-profile based approach that can contribute significantly to livestock feed. The study facilitates the design of stores and bunkers for straw, pellets, bales, blocks, and silage to have better payback (Singh et al., 2018). Hence, proper fodder management helps to conserve watersheds from overgrazing, degradation, and river siltation (Kumar et al., 2023).

3.2.3 Energy harvest

Energy harvesting involves capturing and converting natural energy into usable forms of energy. River basin management contributes immensely to energy harvesting from rivers and water bodies through large-scale hydropower plants that generate significant amounts of electricity. Challenges emanate when some energy harvesting techniques, such as the run-of-river, divert a portion of a river's flow regime, creating more negative impacts. It is advisable to promote alternative electricity-generating technologies, such as underwater turbines, tapping solar energy, and wind power, that have minimal environmental impacts compared to conventional hydropower projects.

Based on the case regarding the Gorges Dam in China, methods available for energy harvesting from river basins and watersheds may have environmental impacts, as indicated by site degradation, sedimentation, and community displacement (Cheng et al., 2018). Sustainable watershed conservation practices by communities contribute to the protection of water bodies from siltation and continue providing various energy forms. Hence, there is a need for eco-profile studies that continuously assess the conditions of the river basin, which facilitates sustainable methods to harvest energy from watersheds and river basins. The study also suggests alternative methods to store the sun energy in watershed regions and monitor the energy production impacts in long-term conditions.

3.2.4 Socio-economic wellbeing

River basins are a basic characteristic of the earth's land surface system (Li et al., 2021), involving social, economic, and environmental interactions (Latour and Groen, 1994; Tesfaye et al., 2018) to achieve long-term benefits for both people and ecosystems (Cheng et al., 2018). Most human settlements are found within river basins due to its benefits, including freshwater supply, food production (Best, 2019), fisheries, and transportation (Meybeck et al., 2023). Therefore, benefits derived from river basin functions contribute to improving the resilience of rural people (Wen et al., 2023). Engaging rural communities enhances their livelihood and wellbeing (Kar et al., 2022) while ensuring sustainable management of water resources (Brauman, 2015). With this background, eco-profile studies help assess the impact of integrating various stakeholders in watershed management. It allows and encourages interactive sustainable strategies that address human needs and enhance the protection of water resources.

River basins support a range of economic activities such as agriculture, industry, tourism, and transportation to maximize benefits for all stakeholders while minimizing negative impacts on the environment and local communities. For instance, agriculture is a significant economic activity in many river basins (Syahputra et al., 2023; Liu et al., 2015). River basins often attract outdoor enthusiasts seeking recreational opportunities such as fishing, boating, and wildlife viewing. Such economic opportunities enhance tourism and recreation management in a way that preserves the basin's natural beauty and cultural heritage while providing economic opportunities for local communities.

3.3 Eco-profile in water rights and conflicts

Disputes faced in river basin management require attention to quick and amicable solutions. Conflicts emanating from water rights need the involvement of local stakeholders, as most of these conflicts are local. Water use occurs at various scales within and across river basin boundaries of nations (Figure 4). In most cases, water sharing is meant to improve relationships and cultural values among different water users. However, conflicts start when peace fails to prevail and there is a lack of understanding of the complex social dynamics surrounding water usage. Water shortages due to damming (Schillinger et al., 2020; Talhami and Zeitoun, 2020) and transboundary water sharing (Doring et al., 2024; Nath et al., 2021) exacerbate water conflicts worldwide. According to the United Nations Economic Commission for Europe (UNECE, 2021), "nearly 60 percent of the world's freshwater is found in 310 international rivers and over 500 transboundary aquifers." This has a bearing on human security and international relations, prompting the need for effective solutions. The local and global increase in demand for water resources is under threat from increasing human population, urbanization, and climate change, further weakening community resilience. Uncertainty and fear that might lead to "water wars" and disagreements triggered by the sharing of river basins by riparian states lead to competition and conflict. Positively, such misunderstandings contribute to engagement and cooperation through signing agreements of shared water resources. However, it remains debatable whether agreements materialize or not, though it remains a fact that water scarcity leads to both conflict and cooperation (Doring et al., 2024).

Different priorities in water usage and pollution are the major drivers of most river basin conflicts (Uereyen and Kuenzer, 2019; Ohno et al., 2010) worldwide. Increased water demand for irrigation, domestic use, hydropower, industry, and plantations, among others, may result in conflicts among users. Additionally, pollution from agrochemicals and mining contributes to water contamination (Kanyagui and Viswanathan, 2022). Usually, conflicts emanate from how water is used either as an input or as a medium for waste disposal (Figure 5). Water users are directly affected because water pollution knows no boundaries (Kanyagui and Viswanathan, 2022). Arsenic contamination of water (Sultana,

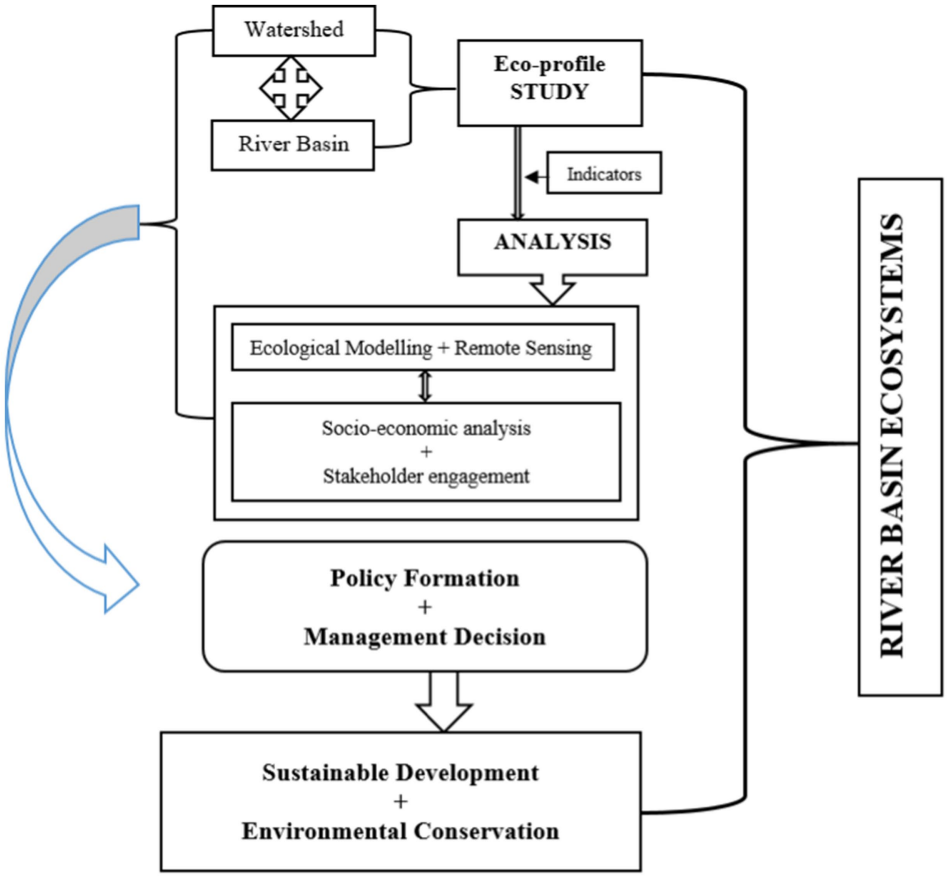

FIGURE 4
Ecological modeling of river basins ecosystems.

2011), increased water for irrigation after the Green revolution (Molle, 2007), large-scale farming (Wu et al., 2012), and hydropower production (Sneddon and Fox, 2012) have lead to water use conflicts in micro–macro scale.

Culturall, spiritual and religious practices have interfered with water rights in most sacred rivers, as in the case of the Ganges and Brahmaputra in India (Kandicuppa et al., 2016), which faced pollution and obstruction from dam building (Rodríguez-Labajos and Martínez-Alier, 2015). Additionally, dam construction within river basins lead to displacements of people locally, infringing on their water rights in both upstream and downstream (Figure 6). Therefore, conflicts emanate as displaced people lack adequate compensation, cropland, and biodiversity loss. Activities like plantations of *Eucalyptus* spp., *Jatropha* spp., and sugarcane greatly contribute to water depletion as they compete for water and land with other crops.

Disputes occurring in watersheds and river basins at the macro-level can be addressed by the use of policies (Table 1) designed through international organizations such as the UNECE, The United Nations Regional Centre for Preventive Diplomacy for Central Asia (UNRCCA), and the Intergovernmental Authority on Development (IGAD) (Doring et al., 2024). However, solutions to address conflicts at the micro-level remain limited. This is due to the unwillingness of some nations to provide legal rights to water due to financial and governance constraints (United Nations, 2023). It is, therefore, crucial to explore practical solutions to address various local water conflicts using such tools in the eco-profile assessment approach (Figure 5).

Eco-profile assessment helps in monitoring water rights and conflicts. With this background, the eco-profile studies identify the root cause of water conflicts and problems associated with water rights in the watershed and river basin environmental conditions (Chandrakar et al., 2016; Pandya and Sharma, 2022). This acts as a precursor to the decision-making process in solving challenges associated with water at the micro-scale.

3.4 Case study 1 focuses on addressing water rights and conflicts caused by human actions in the watershed and river basin regions in Africa

A study, "Integrated Watershed Management Framework and Groundwater Resources in Africa-A Review of West Africa Sub-Region" (Tang and Adesina, 2022), examined how human actions relate to the behavior of rainwater, groundwater, and river basin resources in

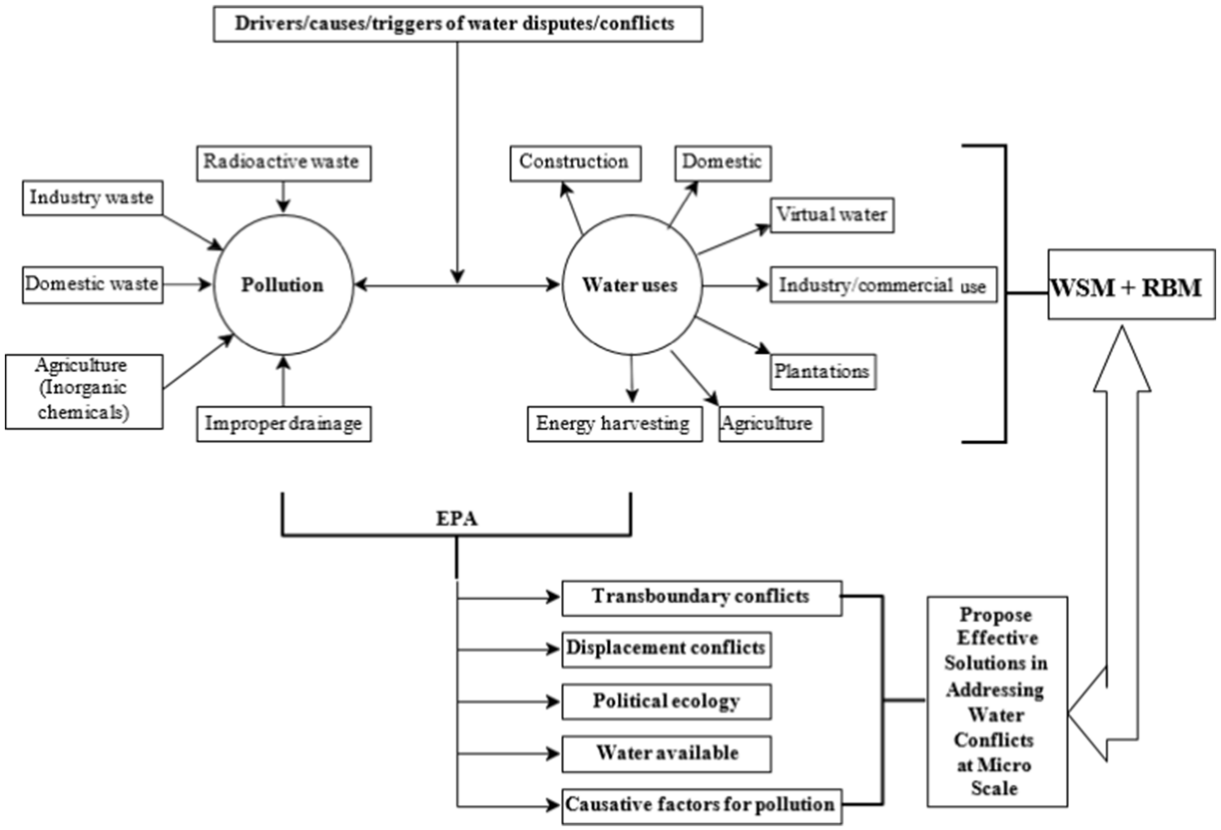

FIGURE 5
Including eco-profile approaches (EPA) in addressing water rights and conflicts.

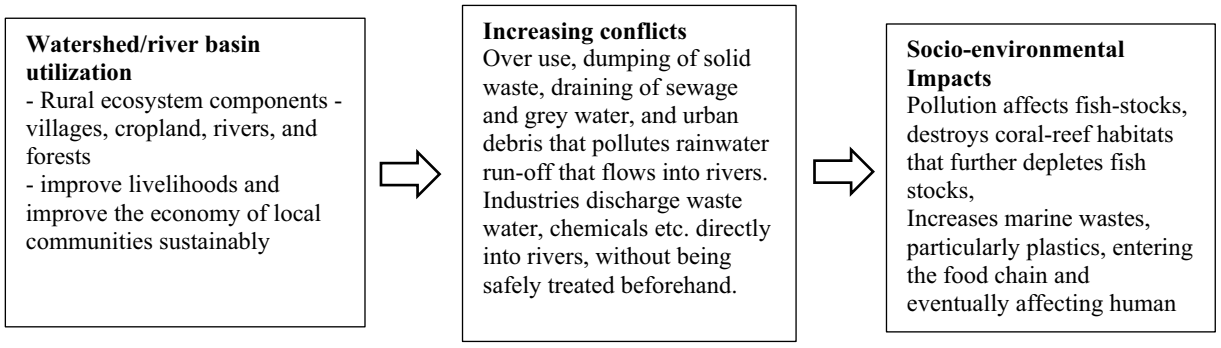

FIGURE 6
Cause of water conflicts and its impacts.

African watersheds. It emphasised that human actions greatly change river flows and water quality in high and low land. Integrated Watershed Management (IWM) uses an eco-profile approach to manage activities within watersheds, considering several social, economic, and ecological factors, along with human, institutional, natural, factors.

The paper stresses that watersheds, river basins, and groundwater resources provide important services to communities and preserve biodiversity. The authors stated that a number of sustainable management practices based on eco-profile studies could help protect groundwater resources throughout watersheds. The study encourages the various communities to work together, participating alongside water users, including cities, firms, people, groups, and property owners. They also recomended strategies and plans for stakeholder consultation to address local and transboundary problems.

The authors highlight that over 65% of Africa's population lives in rural areas and mainly does subsistence farming. Timely adequate rainfall is crucial because 95% of cropland in sub-Saharan Africa is rain-fed. However, rainfall in Africa varies a great deal annually and decadally. This variation also occurs across longer durations, creating challenges for obtaining adequate water resources to meet livelihood operations.

TABLE 1 Existing water rights policies/frameworks to address possible conflicts and problems addressed.

Existing policies/ frameworks	Proposed year	Conflicts focused	Problems addressed
Water framework drive (WFD)	2000	Centralistic authority	Limited/lack of awareness
International river basin management (IRBM)	1992	Administrative disparities/ overlap of roles	Pollution, Waste disposal
Integrated water resources management (IWRM)	1977	Riparian zone shrinkage	Land degradation (soil erosion, siltation)
Water policy	1987	Competition (limited resources)	Water shortage
Local authority waters program (LAWPRO)	2025	Transboundary	Habitat disruption
River basin management and plan (RBMP)	2020	Water usage	Biodiversity loss

The detailed eco-profile conceptual framework depicts multiple key drivers along with planned management measures at three levels: continental, sub-regional, and national. This framework capably guides the watershed management practices for proven benefits at regional in West African countries. Further, the study comparatively analyzes the best watershed, catchment, and river basin management practices, revealing that the best practices can be promoted in West African regions.

This study ultimately provides useful information about how to bring together watershed management with groundwater resources in West Africa. The suggested IWM framework follows the eco-profile approach to focus on socio-economic and ecological elements. This study provides strong base for policymakers and practitioners seeking to improve water resource sustainability and address issues related to water rights and conflicts in these regions.

The authors urgently call for a fully organized, completely coordinated structure involving each important stakeholder and an institutional framework. They strongly advise the creation of a framework to streamline and produce large synergies among national, regional, and intercontinental efforts that significantly improve Africa's waterways and resources.

3.5 Case study 2 focuses on the benefits of commoning water and addressing water rights and conflicts in India

The study by Kandicuppa et al. (2016) titled "Benefits of Commoning Water: Social Return on Investment (SROI) Assessment of the Water Commons Programme" presents a single in-depth case of community-based water resource management across India. This program was implemented in place across eight districts in Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, and Rajasthan. It targeted to set up water commons as a workable property system with state and individual ownership for preserving water rights.

The entire project starts with an eco-profile study before implementing watershed management practices. The study starts with a detailed mapping ecology of watershed regions, surface and groundwater flows, integrated water conservation into many land restoration efforts, and thereby improved local governance through village institutions. Community participation was undeniably important because farmers, women, marginalized groups, and Panchayati Raj Institutions (PRIs) were stakeholders.

The project used money from the Hindustan Unilever Foundation, National Bank for Agriculture and Rural Development (NABARD), as well as Mahatma Gandhi National Rural Employment Guarantee (MGNREGA) scheme for physical interventions. Building water collection sites, improving soil and water conditions, and promoting farming methods that use water efficiently. Seed treatment, water-use planning, and setting up irrigation frequencies, were important strategies to reduce water conflict. Implementing such measures increased water availability for crops and livestock, reduced soil loss, improved crop production, and improved living conditions. Farmers choose crops that need less water. These farmers consequently conserved a meaningful amount of water and produced more.

The SROI assessment highlighted notable benefits such as 919 TCM (Kandicuppa et al., 2016) of water savings, increased biomass production worth INR 39.35 million, and 33,844 saved pumping hours, translating into INR 7.05 million in energy cost reductions. Institutional strengthening enabled better governance, conflict resolution, and sustainable management of common resources. This case study underscores the potential of community-led water. The FES initiative demonstrates that with collective action, proper planning, and institutional support, sustainable water management practices address the conflicts at the regional level.

3.6 Community role in eco-profile and managing water rights and conflicts

Communities often provide valuable information about natural resources in their local environment (Table 2). Such information is essential as an inventory baseline data for eco-profile assessment studies (Grin et al., 2010) that help to address local challenges (Li et al., 2018). The community contributes to the improvement of eco-profile indicators such as resource use efficiency, waste management, and pollution reduction in watersheds and river basins (Norton, 2020).

Therefore, river basin management without collective people participation at both local and basin-scale levels faces challenges (Mostert, 2018; Withanachchi et al., 2018), because they contribute to solving water conflicts that are normally associated with water uses (Syahputra et al., 2023). Interventions in river basins aim to address functional issues such as water pollution, habitat destruction, and fragmentation (Schaffer-Smith et al., 2022; Park and Chon, 2015), erosion and sedimentation, and social and economic issues (Islam et al., 2020). Eco-profile studies contribute positive nature-based solutions through forestry interventions that can mimic natural processes to regulate water quantity and quality in rivers (Singh et al., 2022; Swanson et al., 2017). Table 2 records the watershed/river basin

TABLE 2 Interventions made from eco-profile assessment and community role in addressing water rights and conflicts.

Watershed/River basin interventions based on eco-profile assessment	Community role in addressing water rights and conflicts	Author records
Forestry intervention for rejuvenating Ganga river basin.	Community engagement helps conserve forests by stopping wildfires, indiscriminately cutting down trees, and controlling river or stream bank cultivation. That improves the soil structure, increasing percolation, reducing soil erosion, and reducing river siltation. Later, there was a record of increased water availability in river basin regions to reduce the conflicts.	Singh et al. (2022)
Interventions to reduce the soil loss, sediment loads, and sediment delivery ratio in the Abbay Basin in Ethiopia.	Imparting traditional knowledge gained by the community to reduce soil loss, sediment loads, and sediment delivery. Such interventions reduce land degradation, deforestation, soil erosion, and nutrient depletion and augment the water resources.	Khairy (2022)
Interventions to improve the water quality across extremes in Cape Fear River Basin.	Smart farming by the community is key to reducing soil erosion, agricultural pesticides, and chemicals, reducing greenhouse gases from industries to combat temperature increases, and reducing global warming.	Schaffer-Smith et al. (2022)
Increase water availability for the surrounding population, as well as agricultural use and freshwater fisheries.	Improving soil structure and controlling land degradation processes were implemented, and the community was encouraged to participate in conservation activities that prevent runoff and flooding.	Syahputra et al. (2023)
Sustainably improving the economy and stakeholder livelihoods of local communities.	Community involvement through indigenous knowledge approaches as a precursor to policy implementation in conservation and sustainable river basin management.	Debnath (2016)
Limit the over-extraction of resources, i.e., overfishing ends up depleting aquatic resources, causing water quality deterioration, and sedimentation.	Community awareness to realize the dangers of settling along the riverbanks.	Angriani et al. (2018)

interventions based on eco-profile assessment and community role in addressing water rights and conflicts.

3.7 Eco-profile framework

The institutional and integrated framework for water resources management in river basins consists of established rules, norms, practices, and organizations that provide a structure for human activities related to water management (Sulistyaningsih et al., 2021). The integrated framework highlights (Figure 4) the importance of collaboration among different sectors and stakeholders to address specific watershed and river basin problems (Bouckaert et al., 2018; Xiao et al., 2014). Its successful adaptation beyond the study region requires careful consideration of cultural, socio-economic, ecological, and institutional aspects, which differ between regions. Framework development in eco-profile studies should encourage multi-stakeholder partnerships among various organization (Figure 4) that give technical and financial support to promote policy implementation and river basin management (Fenta et al., 2023). However, land degradation in watershed and river basin management remains a challenge worldwide despite research and policy development efforts to address the ecological and socio-economic problems (Schwilch et al., 2012; Verburg et al., 2022).

3.7.1 Inclusion of eco-profile policies in watershed and river basin management

The eco-profile evaluation in watershed and river basin policy varies between countries and regions due to differences in institutional structures, policies, and laws. There is a need to modify and align the existing policies at the local level and implementation across the regional level (Fenta et al., 2023). In cases where local communities have limited knowledge of the potential benefits of policies, awareness is necessary (Hasan et al., 2023). Policies act as important legal frameworks in watershed and river basin management to address water conflict issues with an emphasis on supporting human livelihoods (Cavus et al., 2023; Zhao et al., 2021). Integrated river basin and water resource management identifies critical factors for genuine stakeholder involvement in decision-making at the basin level to make more relevant and useful policies.

Countries like Tanzania and South Africa have initiated water sector reform programs that stress comprehensive river basin management with an eco-profile study (Yi et al., 2018), involving community users, government stakeholders, cost-benefits, and sustainable ecosystem resource use in river basin regions (Sulistyaningsih et al., 2021). However, multi-stakeholder involvement in river basin management in Indonesia leads to the abuse of centralistic authority and sometimes-overlapping roles, leading to sectoral conflicts in policy implementation in the Brantas watershed (Sulistyaningsih et al., 2021). The regulations were not designed for institutional arrangements that support the efficient functioning and management of the Brantas watershed (Rahmawati et al., 2014). Therefore, such policies should be improved to help understand the changing land use in watersheds (Sonu and Bhagyanathan, 2022). Previous studies on watershed governance focused on environmental conservation based on ecological perspectives (Kagaya and Wada, 2021), community participation (Kandicuppa et al., 2016), and sustainable development (Upadani, 2017). However, research focussing on eco-profile assessment in policy-making and watershed governance is limited.

Problems in watershed and river basin management (Curtis et al., 2005) continuously change every time due to natural and anthropogenic causes; for example, changes in the riverbank landscape may lead to increased erosion and floods, causing riparian zone shrinkage. Alternatively, intermittent monsoon rains in rainfed regions sometimes lead to increased runoff due to reduced infiltration, causing siltation, low water tables, and inadequate water resources (Hasan et al., 2023). Additionally, habitat disruption leading to

biodiversity decline and diminishing biomass production negatively impacts water-based livelihood activities such as fisheries, gardening, and irrigation, leading to low economic status in rural areas. These challenges contribute to water conflicts in poorly managed ecosystems that require eco-profile based watershed and river basin management policies to help address the problems. Funding, institutional gaps, and economic and population growth problems contribute to conflicts within states and interstates. Conflict of interest leads to overlapping duties, naturally unbalanced distribution, and administrative disparities under multiple jurisdictions within river basins, which remains challenging (Cai and Zhang, 2018).

In most cases, effective solutions to conflicts in watershed and river basin management are rather complex and difficult. This is due to the limited institutional capacity to cope with most of the problems. A collaborative approach is necessary to bring success is an uphill task that depends on the design of the institutional arrangements and the ability of participants to reach a consensus through effective negotiation. However, it is in the interest of this paper to link the principles of the eco-profile assessment approach in addressing watershed and river basin conflict-associated challenges by identifying indicators of problems leading to such conflicts. Therefore, if problem-linked polices or frameworks are put in place, water rights and conflict challenges can be addressed starting at the local level with contributions from local people rather than a top-down approach. Such an approach directly contributes to community wellbeing and the protection of ecosystem values within the river basin.

4 Conclusion

Watershed and river basin management is a multidimensional approach, it evaluates regional, physical, biological, socio-economic, and institutional components. The evaluation identifies problems and valuable resources potentially at risk to achieve a sustainable use of water resources. Some of the problems in river basins result in conflicts that are often difficult to address due to limitations of institutional capacity to cope with them. Stakeholder involvement, brings long-term stability, especially in the effort to address water rights and conflict issues. There is a need for local and broader policy development since water resources management involves cross-regional governments and many institutions.

Increased droughts, water abstraction, pollution, and river modifications significantly deteriorate rivers' ecological health. Therefore, there is a need to collaborate among institutions with interests in water management to solve problems associated with eco-profile evaluation. The availability of financial, human, and technical resources may vary between regions, making it difficult to implement watershed and river basin policies. It might also require investments and resources that are not readily available. However, partnerships with government agencies, academic and research institutions, and international organizations can help to mobilize resources and support the successful adaptation and implementation of policies. The barrier related to the inclusion of an eco-profile approach and finance facility for eco-profile can be overcome by partnership with multiple stakeholders. The inclusion should not be limited to watershed and river basin policies that can be promoted widely to all integrated water resource management practices worldwide.

However, an institutional gap may develop in trying to have these institutions (formal and informal) work together, since they have complex relationships. Creating channels for informed dialogue among the stakeholders can overcome such institutional gaps. Additionally, policy framework initiations at the micro-scale feed into macro-scale cross-boundary frameworks. Unfortunately, solutions to address water conflicts remain limited due to the unwillingness of some nations to provide legal rights to water due to financial and governance constraints. Similarly, research focusing on the inclusion of eco-profiles in policy-making and river basin governance remains limited. However, it is in the interest of this paper to sort for solutions using the eco-profile approach in addressing water rights and conflict-associated challenges; additionally, other benefits that can extracted from the eco-profile are discussed. Identifying indicators problems by systematic eco-profile studies will reduce conflicts and improve livelihoods and wellbeing, especially of rural communities at the micro–macro scale.

Author contributions

MD: Conceptualization, Writing – original draft, Writing – review & editing, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization. RS: Conceptualization, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Investigation, Project administration. TN: Conceptualization, Supervision, Visualization, Writing – original draft, Writing – review & editing, Methodology, Resources, Validation. SS: Methodology, Conceptualization, Writing – review & editing. DR: Writing – original draft, Writing – review & editing. RT: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Acknowledgments

This project has been funded by the E4LIFE International Ph.D. Fellowship Program offered by Amrita Vishwa Vidyapeetham. We extended our gratitude to the Amrita Live-in-Labs® academic program for providing all the support. The author(s) of this paper wish to thank the Asian Development Bank Institute (ADBI), Japan, for their support.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

References

Angriani, P., Sumarmi, Ruja, I. N., and Bachri, S. (2018). River management: the importance of the roles of the public sector and community in river preservation in Banjarmasin (a case study of the Kuin River, Banjarmasin, South Kalimantan–Indonesia). *Sustain. Cities Soc.* 43, 11–20. doi: 10.1016/j.scs.2018.08.004

Baloch, M. A., and Tanık, A. (2008). Development of an integrated watershed management strategy for resource conservation in Balochistan Province of Pakistan. *Desalination* 226, 38–46. doi: 10.1016/j.desal.2007.02.098

Best, J. (2019). Anthropogenic stresses on the world's big rivers. *Nat. Geosci.* 12, 7–21. doi: 10.1038/s41561-018-0262-x

Bouckaert, F., Wei, Y., Hussey, K., Pittock, J., and Ison, R. (2018). Improving the role of river basin organisations in sustainable river basin governance by linking social institutional capacity and basin biophysical capacity. *Curr. Opin. Environ. Sustain.* 33, 70–79. doi: 10.1016/j.cosust.2018.04.015

Brauman, K. A. (2015). Hydrologic ecosystem services: linking ecohydrologic processes to human well-being in water research and watershed management. *Wiley Interdiscip. Rev. Water* 2, 345–358. doi: 10.1002/wat2.1081

Cai, Y., and Zhang, L. (2018). Multi-scale ecological indicators for supporting sustainable watershed management. *Ecol. Indic.* 92, 1–10. doi: 10.1016/j.ecolind.2018.05.079

Cavus, Y., Aksoy, H., and Stahl, K. (2023). Human intervention against drought in Seyhan River basin, Turkey: Copernicus Publications (No. EGU23-484). Copernicus Meetings.

Chandrakar, B., Dewangan, N. P., Verma, S., and Mishra, A. (2016). "Empowering community for river basin management" in Urban Hydrology, watershed management and socio-economic aspects, Springer, Cham. 323–329.

Cheng, X., Chen, L., Sun, R., and Kong, P. (2018). Land use changes and socio-economic development strongly deteriorate river ecosystem health in one of the largest basins in China. *Sci. Total Environ.* 616, 376–385. doi: 10.1016/j.scitotenv.2017.10.316

Curtis, A., Byron, I., and MacKay, J. (2005). Integrating socio-economic and biophysical data to underpin collaborative watershed management 1. *JAWRA J Am Water Resourc Assoc* 41, 549–563. doi: 10.1111/j.1752-1688.2005.tb03754.x

Dale, V. H., and Beyeler, S. C. (2001). Challenges in the development and use of ecological indicators. *Ecol. Indic.* 1, 3–10. doi: 10.1016/S1470-160X(01)00003-6

Dandadzi, P., and Kothurkar, N. K. (2023). Assessing the sustainability of biosand filters: unveiling interlinkages and leveraging factors for effective implementation. Environ. Sustain. Indicat. 20:100311. doi: 10.1016/j.indic.2023.100311

Darghouth, S., Ward, C., Gambarelli, G., Styger, E., and Roux, J. (2008). Watershed management approaches, policies, and operations: lessons for scaling up. Washington, D.C.: The World Bank.

Debnath, R. (2016). A review of the sustainability of recent watershed management programmes in Bangladesh. *Lakes Reserv. Res. Manag.* 21, 152–161. doi: 10.1111/lre.12129

den Haan, R. J., Fliervoet, J. M., van der Voort, M. C., Cortes Arevalo, V. J., and Hulscher, S. J. (2019). Understanding actor perspectives regarding challenges for integrated river basin management. *Int. J. River Basin Manag.* 17, 229–242. doi: 10.1080/15715124.2018.1503186

Diop, M., Chirinda, N., Beniaich, A., El Gharous, M., and El Mejahed, K. (2022). Soil and water conservation in Africa: state of play and potential role in tackling soil degradation and building soil health in agricultural lands. *Sustain. For.* 14:13425. doi: 10.3390/su142013425

Doring, S., Kim, K., and Swain, A. (2024). Integrating socio-hydrology and peace and conflict research. *J. Hydrol.* 633:131000. doi: 10.1016/j.jhydrol.2024.131000

Dwivedi, S., Mishra, S., and Tripathi, R. D. (2018). Ganga water pollution: a potential health threat to inhabitants of ganga basin. *Environ. Int.* 117, 327–338. doi: 10.1016/j.envint.2018.05.015

European Environment Agency (2020). The European Environment—State and Outlook 2020. European Environment Agency.

Fargnoli, M., Costantino, F., Tronci, M., and Bisillo, S. (2013). Ecological profile of industrial products over the environmental compliance. *Int. J. Sustain. Eng.* 6, 117–130. doi: 10.1080/19397038.2012.680519

Farid Ahmed, M., Mokhtar, M. B., Lim, C. K., Suza, I. A. B. C., Ayob, K. A. K., Khirotdin, R. P. K., et al. (2023). Integrated river basin management for sustainable development: time for stronger action. *Water* 15:2497. doi: 10.3390/w15132497

Fenta, A. A., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Yasuda, H., Kawai, T., et al. (2023). An integrated framework for improving watershed management planning. *Environ. Res.* 236:116872:116872. doi: 10.1016/j.envres.2023.116872

Finotto, F. (2011). Landscape assessment: the ecological profile. *Landsc Indicat*, Springer, Dordrecht. 47–75. doi: 10.1007/978-94-007-0366-7_4

Foundation for Ecological Security. (2009). Available online at: https://fes.org.in/ (Accessed March 2025).

Gai, L., Nunes, J. P., Baartman, J. E., Zhang, H., Wang, F., de Roo, A., et al. (2019). Assessing the impact of human interventions on floods and low flows in the Wei River basin in China using the LISFLOOD model. *Sci. Total Environ.* 653, 116872, 116872–111094. doi: 10.1016/j.scitotenv.2018.10.379

Gain, A. K., Giupponi, C., Renaud, F. G., and Vafeidis, A. T. (2020). Sustainability of complex social-ecological systems: methods, tools, and approaches. *Reg. Environ. Chang.* 20, 1–4. doi: 10.1007/s10113-020-01692-9

Geetha, P., and Soman, K. P. (2019). "Assessment of watershed areas of western and eastern ghats using geospatial techniques" in 2019 International Conference on Communication and Signal Processing (ICCSP) (New Jersey, USA: IEEE), 0127–0130. doi: 10.1109/ICCSP.2019.8697998

Ghorbani Nejad, S., Falah, F., Daneshfar, M., Haghizadeh, A., and Rahmati, O. (2017). Delineation of groundwater potential zones using remote sensing and GIS-based data-driven models. *Geocarto Int.* 32, 167–187. doi: 10.1080/10106049.2015.1132481

Grin, J., Rotmans, J., and Schot, J. (2010). *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change* (1st ed.). Routledge. doi: 10.4324/9780203856598

Hafizan, C., Nur, Z. Z., and Hussein, N. (2023). A framework for criteria weighting in a sustainable river basin. Malaysian. *J. Civ. Eng.* 35, 43–46. doi: 10.11113/mjce.v35.19928

Hasan, N., Pushpalatha, R., Manivasagam, V. S., Arlikatti, S., and Cibin, R. (2023). Global sustainable water management: a systematic qualitative review. *Water Resour. Manag.* 37, 5255–5272. doi: 10.1007/s11269-023-03604-y

Islam, A., Barman, S. D., Islam, M., and Ghosh, S. (2020). Role of human interventions in the evolution of forms and processes in the Mayurakshi River basin. In: *Anthropogeomorphology of Bhagirathi-Hooghly River System in India*. (England, Taylor and Francis: CRC Press)135–187. doi: 10.1201/97810030323735-5

Jezequel, C., Oberdorff, T., Tedesco, P. A., and Schmitt, L. (2022). Geomorphological diversity of rivers in the Amazon Basin. *Geomorphology* 400:108078:108078. doi: 10.1016/j.geomorph.2021.108078

Kagaya, S., and Wada, T. (2021). The application of environmental governance for sustainable watershed-based management. *Asia Pac. J. Reg. Sci.* 5, 643–671. doi: 10.1007/s41685-020-00185-1

Kandicuppa, S., Priyadarshini, P., Rao, K., Mudliar, R., and Singh, S. (2016). Benefits of Commoning water: social return on investment (SROI) assessment of the water commons Programme. *Found. Ecol. Secur.* 35:108078.

Kanyagui, M. K., Rajendrakumar, S., and Viswanathan, P. K. (2024). Institutional arrangements for improving water and sanitation services in the rural villages of India: a systems thinking approach: World Water Policy.

Kanyagui, M. K., and Viswanathan, P. K. (2022). Water and sanitation services in India and Ghana: an assessment of implications for rural health and related SDGs. *Water Policy* 24, 1073–1094. doi: 10.2166/wp.2022.079

Kar, S. K., Kumar, S., Sankar, M., Patra, S., Singh, R. M., Shrimali, S. S., et al. (2022). Process-based modelling of soil erosion: scope and limitation in the Indian context. *Curr. Sci.* 122, 533–541. doi: 10.18520/cs/v122/i5/533-541

Khairy, W. M. (2022). Distributive analysis of soil loss in the Abbay River basin in Ethiopia after watershed management interventions. *Model. Earth Syst. Environ.* 8, 3231–3246. doi: 10.1007/s40808-021-01278-2

Khoiri, A., Sunarno, W., Sajidan, S., and Sukarmin, S. (2021). Analysing students' environmental awareness profile usin g strategic environmental assessment. *F1000Res* 10:305. doi: 10.12688/f1000research.51523.2

Koli, P., and Bhardwaj, N. R. (2018). Status and use of pesticides in forage crops in India. *J. Pestic. Sci.* 43, 225–232. doi: 10.1584/jpestics.D18-004

Kuenzer, C., Heimhuber, V., Day, J., Varis, O., Bucx, T., Renaud, F., et al. (2020). Profiling resilience and adaptation in mega deltas: a comparative assessment of the Mekong, yellow, Yangtze, and Rhine deltas. *Ocean Coast Manag* 198:105362:105362. doi: 10.1016/j.ocecoaman.2020.105362

Kumar, S., Singh, P., Devi, U., Yathish, K. R., Saujanya, P. L., Kumar, R., et al. (2023). An overview of the current fodder scenario and the potential for improving fodder productivity through genetic interventions in India. *Anim. Nutr. Feed. Technol.* 23, 631–644. doi: 10.5958/0974-181X.2023.00054.9

Latour, J., and Groen, C. (1994). Ecological assessment of natural resources in agroecosystems of Dutch lowland peat area. *Environ. Manag.* 18, 105362, 105362–105464. doi: 10.1007/BF02393873

Lebel, L., Nikitina, E., Pahl-Wostl, C., and Knieper, C. (2013). Institutional fit and river basin governance: a new approach using multiple composite measures. *Ecol. Soc.* 18. Available at: https://www.jstor.org/stable/26269250

Lessmann, J., Troya, M. J., Flecker, A. S., Funk, W. C., Guayasamin, J. M., Ochoa-Herrera, V., et al. (2019). Validating anthropogenic threat maps as a tool for assessing river ecological integrity in Andean–Amazon basins. *PeerJ* 7:e8060. doi: 10.7717/peerj.8060

Li, X., Cheng, G., Lin, H., Cai, X., Fang, M., Ge, Y., et al. (2018). Watershed system model: the essentials to model complex human-nature system at the river basin scale. *J. Geophys. Res. Atmos.* 123, 3019–3034. doi: 10.1002/2017JD028154

Li, N., and Wang, J. (2022). Comprehensive eco-environment quality index model with spatiotemporal characteristics. *Sensors* 22:e8060. doi: 10.3390/s22249635

Li, X., Zhang, L., Zheng, Y., Yang, D., Wu, F., Tian, Y., et al. (2021). Novel hybrid coupling of ecohydrology and socioeconomy at river basin scale: a watershed system model for the Heihe River basin. *Environ. Model Softw.* 141:105058. doi: 10.1016/j.envsoft.2021.105058

Liu, H., Zhao, W., He, Z., and Liu, J. (2015). Soil moisture dynamics across landscape types in an arid inland river basin of Northwest China. *Hydrol. Process.* 29, 105058–103341. doi: 10.1002/hyp.10444

Ma, D., Qian, B., Gu, H., Sun, Z., and Xu, Y. P. (2021). Assessing climate change impacts on streamflow and sediment load in the upstream of the Mekong River basin. *Int. J. Climatol.* 41, 3391–3410. doi: 10.1002/joc.7025

Marowa, D., Pokkiyarath, M., and Viswanathan, P. K. (2023, 2023). The nexus between sustainable agriculture practices, food security and climate change in India: a review. *Migrat. Lett.* 20, 181–202. doi: 10.59670/ml.v20iS1.3571

Maximillian, J., Brusseau, M. L., Glenn, E. P., and Matthias, A. D. (2019). Pollution and environmental perturbations in the global system. *Environ. Pollut. Sci.* 2019, 457–476. doi: 10.1016/b978-0-12-814719-1.00025-2

McManamay, R. A., George, R., Morrison, R. R., and Ruddell, B. L. (2022). Mapping hydrologic alteration and ecological consequences in stream reaches of the conterminous United States. *Scientific Data*, 9,:450, doi: 10.1038/s41597-022-01566-1, PMCID: PMC9334386.

Metlen, K. L., Fairbanks, T., Bennett, M., Volpe, J., Kuhn, B., Thompson, M. P., et al. (2021). Integrating forest restoration, adaptation, and proactive fire management: Rogue River basin case study. *Can. J. For. Res.* 51, 1292–1306. doi: 10.1139/cjfr-2020-0480

Meybeck, M., Bouleau, G., Carré, C., Garnier, J., and Lestel, L. (2023). Rivers help us to quantify the socio-ecological functioning of their basin at the Anthropocene: the seine example (1850–2020). *Compt. Rend. Géosci.* 355, 1–19. doi: 10.5802/crgeos.140

Molle, F. (2007). Scales and power in river basin management: the Chao Phraya River in Thailand 1. *Geogr. J.* 173, 358–373. doi: 10.1111/j.1475-4959.2007.00255.x

Molle, F., Gaafar, I., El-Agha, D. E., and Rap, E. (2018). The Nile delta's water and salt balances and implications for management. *Agric. Water Manag.* 197, 110–121.

Molle, F., Wester, P., and Hirsch, P. (2010). River basin closure: processes, implications, and responses. *Agric. Water Manag.* 97, 569–577. doi: 10.1016/j.agwat.2009.01.004

Mostert, E. (2018). River basin management and community: the great Ouse Basin, 1850–present. *Int. J. River Basin Manag.* 16, 51–59. doi: 10.1080/15715124.2017.1339355

Nath, B., Ni-Meister, W., and Choudhury, R. (2021). Impact of urbanization on land use and land cover change in Guwahati city, India and its implication on declining groundwater level. *Groundw. Sustain. Dev.* 12:100500. doi: 10.1016/j.gsd.2020.100500

Neeraja, U. V., Rajendrakumar, S., Saneesh, C. S., Dyda, V., and Knight, T. M. (2021). Fire alters diversity, composition, and structure of dry tropical forests in the eastern Ghats. *Ecol. Evol.* 11, 6593–6603. doi: 10.1002/ece3.7514

Norton, B. G. (2020). Sustainable values, sustainable change: a guide to environmental decision making. llinois, USA: University of Chicago Press.

Ohno, T., Tanaka, T., and Sakagami, M. (2010). Does social capital encourage participatory watershed management? An analysis using survey data from the Yodo River watershed. *Soc. Nat. Resour.* 23, 303–321. doi: 10.1080/08941920802078224

Pandya, A. B., and Sharma, P. (2022). River basin management in the context of integrated water resources management. *Irrig. Drain.* 71, 1122–1126. doi: 10.1002/ird.2762

Park, Y. S., and Chon, T. S. (2015). Editorial: ecosystem assessment and management. *Eco. Inform.* 29, 93–95. doi: 10.1016/j.ecoinf.2015.05.003

Peng, L., Wu, H., and Li, Z. (2023). Spatial–temporal evolutions of ecological environment quality and ecological resilience pattern in the middle and lower reaches of the Yangtze River Economic Belt. *Remote Sens.* 15:430. doi: 10.3390/rs15020430

Pomara, L. Y., and Lee, D. C. (2021). The role of regional ecological assessment in quantifying ecosystem services for forest management. *Land* 10:725. doi: 10.3390/land10070725

Pradhan, C., Chembolu, V., Bharti, R., and Dutta, S. (2023). Regulated rivers in India: research progress and future directions. *ISH J. Hydraul. Eng.* 29, 58–70. doi: 10.1080/09715010.2021.1975319

Rahmawati, F., Erani, A., Ashar, K., and Santoso, D. B. (2014). The institutional coordination of Brantas watershed management. *J. Econ. Sustain. Dev* 5, 207–216.

Ramachandra, T. V., Chandran, M. S., Joshi, N. V., Sreekantha, R. K., Rajinikanth, R., Desai, S. R., et al. (2012). Ecological profile of Sharavathi River basin. *Sahyadri Conservafion Series* 22, 1–161. Available at: https://shorturl.at/RLXV

Ramakrishnan, R., Rajendrakumar, S., and Kothurkar, N. K. (2024). Regional sustainability of the Kattunayakan tribe in Kerala, India through the enhancement of agricultural, livestock, and livelihood options. *Agric. Syst.* 217:103929. doi: 10.1016/j.agsy.2024.103929

Ricci, G. F., D'Ambrosio, E., De Girolamo, A. M., and Gentile, F. (2022). Efficiency and feasibility of Best management practices to reduce nutrient loads in an agricultural river basin. *Agric. Water Manag.* 259:107241. doi: 10.1016/j.agwat.2021.107241

Rodríguez-Labajos, B., and Martínez-Alier, J. (2015). Political ecology of water conflicts. *Wiley Interdiscip. Rev. Water* 2, 537–558. doi: 10.1002/wat2.1092

Rowland, J. A., Bland, L. M., Keith, D. A., Juffe-Bignoli, D., Burgman, M. A., Etter, A., et al. (2020). Ecosystem indices to support global biodiversity conservation. *Conserv. Lett.* 13:e12680. doi: 10.1111/conl.12680

Savita, K. M., and Kushwaha, S. P. S. (2018). Forest resource dependence & ecological assessment of forest fringes in rainfed districts of India. *Indian Forester* 144, 211–220.

Schaffer-Smith, D., DeMeester, J. E., Tong, D., Myint, S. W., Libera, D. A., and Muenich, R. L. (2022). Landscape pollution source dynamics highlight priority locations for basin-scale interventions to protect water quality under extreme events. Hoboken, USA: Authorea Preprints.

Schillinger, J., Ozerol, G., Güven-Griemert, S., and Heldeweg, M. (2020). Water in war: understanding the impacts of armed conflict on water resources and their management. *Wiley Interdiscip. Rev. Water* 7:e1480. doi: 10.1002/wat2.1480

Scholes, R., Montanarella, L., Brainich, A., Barger, N., Brink, B., Cantele, M., et al. (2018). Summary for policymakers of the thematic assessment report on land degradation and restoration of the intergovernmental science-policy platform on biodiversity and ecosystem services. Bonn: IPBES Secretariat.

Schwilch, G., Bachmann, F., and de Graaff, J. (2012). Decision support for selecting SLM technologies with stakeholders. *Appl. Geogr.* 34, 86–98. doi: 10.1016/j.apgeog.2011.11.002

Shaffril, H. A. M., Krauss, S. E., and Samsuddin, S. F. (2018). A systematic review on Asian's farmers' adaptation practices towards climate change. *Sci. Total Environ.* 644, 683–695. doi: 10.1016/j.scitotenv.2018.06.349

Siddig, A. A., Ellison, A. M., Ochs, A., Villar-Leeman, C., and Lau, M. K. (2016). How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in ecological indicators. *Ecol. Indic.* 60, 223–230. doi: 10.1016/j.ecolind.2015.06.036

Singh, O., Kar, S. K., and Reddy, N. M. (2022). Impact of forestry interventions on groundwater recharge and sediment control in the Ganga River basin. *Open J. Forestry* 13, 13–31. doi: 10.4236/ojf.2023.131002

Singh, T., Ramakrishnan, S., Mahanta, S. K., Tyagi, V. C., and Roy, A. K. (2018). Tropical forage legumes in India: status and scope for sustaining livestock production. United Kingdom: Forage groups.

Sneddon, C., and Fox, C. (2012). Inland capture fisheries and large river systems: a political economy of Mekong fisheries. *J. Agrar. Chang.* 12, 279–299. doi: 10.1111/j.1471-0366.2011.00350.x

Sonu, T. S., and Bhagyanathan, A. (2022). The impact of upstream land use land cover change on downstream flooding: a case of Kuttanad and Meenachil River basin, Kerala, India. *Urban Climate* 41:101089. doi: 10.1016/j.uclim.2022.101089

Staentzel, C., Combroux, I., Barillier, A., Grac, C., Chanez, E., and Beisel, J. N. (2019). Effects of a river restoration project along the old Rhine River (France-Germany): response of macroinvertebrate communities. *Ecol. Eng.* 127, 114–124. doi: 10.1016/j.ecoleng.2018.10.024

Sulistyaningsih, T., Nurmandi, A., Salahudin, S., Roziqin, A., Kamil, M., Sihidi, I. T., et al. (2021). Public policy analysis on watershed governance in Indonesia. *Sustain. For.* 13:6615. doi: 10.3390/su13126615

Sultana, F. (2011). Suffering for water, suffering from water: emotional geographies of resource access, control and conflict. *Geoforum* 42, 163–172. doi: 10.1016/j.geoforum.2010.12.002

Swanson, S., Kozlowski, D., Hall, R., Heggem, D., and Lin, J. (2017). Riparian proper functioning condition assessment to improve watershed management for water quality. *J. Soil Water Conserv.* 72, 168–182. doi: 10.2489/jswc.72.2.168

Syahputra, B., Fajar, B., and Sudarno, S. (2023). Community participation in river basin management. *River Basin Manag.* doi: 10.5772/intechopen.105954

Talhami, M., and Zeitoun, M. (2020). The impact of attacks on urban services II: reverberating effects of damage to water and wastewater systems on infectious disease. *Int. Rev. Red Cross* 102, 1293–1325. doi: 10.1017/S1816383121000667

Tang, X., and Adesina, J. A. (2022). Integrated watershed management framework and groundwater resources in Africa—a review of West Africa sub-region. *Water* 14, 1–18. doi: 10.3390/w14030288

Tesfaye, G., Debebe, Y., and Yakob, T. (2018). Impact of participatory integrated watershed management on hydrological, environment of watershed and socio-economic, case study at Somodo watershed, South Western Ethiopia. *Int. J. Earth Environ. Sci.* 3, 1–7.

Uereyen, S., and Kuenzer, C. (2019). A review of earth observation-based analyses for major river basins. *Remote Sens.* 11:2951. doi: 10.3390/rs11242951

UNECE (2021). Handbook on water allocation in a transboundary context. United Nations publication (ECE/MP.WAT/64). Geneva: United Nations.

United Nations (2023). The sustainable development goals report 2023. UN, New York, NY. Available online at: https://unstats.un.org/sdgs/report/2023/.

Upadani, I. G. A. W. (2017). Model Pemanfaatan Modal Sosial Dalam Pemberdayaan Masyarakat Pedesaan Mengelola Daerah Aliran Sungai (Das) Di Bali. *WICAKSANA* 1, 11–22.

Verburg, P. H., Metternicht, G., Aynekulu, E., Deng, X., Schulze, K., Herrmann, S., et al. (2022). The contribution of integrated land use planning and integrated landscape management to implementing land degradation neutrality: entry points and support tools. A report of the science- policy Interface. Bonn: United Nations Convention to Combat Desertification (UNCCD).

Wen, G., Wu, B., Wang, L., Wang, X., and Xie, H. (2023). Analysis of eco-environmental geological problems and their driving forces in the Henan section of the Yellow River Basin, China. *Sustain. For.* 15:6818. doi: 10.3390/su15086818

Withanachchi, S. S., Kunchulia, I., Ghambashidze, G., Al Sidawi, R., Urushadze, T., and Ploeger, A. (2018). Farmers' perception of water quality and risks in the Mashavera River basin, Georgia: analyzing the vulnerability of the social-ecological system through community perceptions. *Sustain. For.* 10:3062. doi: 10.3390/su10093062

Woldearegay, K., Grum, B., Hessel, R., van Steenbergen, F., Fleskens, L., Yazew, E., et al. (2023). Watershed management, groundwater recharge and drought resilience: an integrated approach to adapt to rainfall variability in northern Ethiopia Beijing, China: International Soil and Water Conservation Research.

Wu, J., Wu, J., Wang, X., and Zhong, M. (2012). Securing water for wetland conservation: a comparative analysis of policy options to protect a national nature reserve in China. *J. Environ. Manag.* 94, 102–111. doi: 10.1016/j.jenvman.2011.06.033

Xiao, H., Liu, Y., Yu, Z., Zhang, Q., and Zhang, X. (2014). Combination of ecoprofile and least-cost model for eco-network planning. *Chin. Geogr. Sci.* 24, 113–125. doi: 10.1007/s11769-014-0660-y

Yi, H., Güneralp, B., Kreuter, U. P., Güneralp, İ., and Filippi, A. M. (2018). Spatial and temporal changes in biodiversity and ecosystem services in the San Antonio River basin, Texas, from 1984 to 2010. *Sci. Total Environ.* 619, 1259–1271. doi: 10.1016/j.scitotenv.2017.10.302

Yu, Z., Qin, T., Yan, D., Yang, M., Yu, H., and Shi, W. (2018). The impact on the ecosystem services rvalue of the ecological shelter zone reconstruction in the upper reaches basin of the Yangtze River in China. *Int. J. Environ. Res. Public Health* 15:2273. doi: 10.3390/ijerph15102273

Zelenakova, M. (2009). Preliminary flood risk assessment in the Hornád watershed. *River Basin Manag.* 5, 15–24. doi: 10.2495/RM090021

Zhao, L., Wang, X., Ma, Y., Li, S., and Wang, L. (2021). Investigation and assessment of ecological water resources in the salt marsh area of a salt Lake: a case study of west Taijinar lake in the Qaidam Basin, China. *PLoS One* 16:e0245993. doi: 10.1371/journal.pone.0245993