

BIODIVERSITY AND WATER SECURITY: INTEGRATED ECOSYSTEM MANAGEMENT

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Abstract. *The goal of this paper is to explore and advance the concept of Integrated Ecosystem Management (IEM) as a holistic approach to ecosystem conservation and resource management. IEM aims to address complex environmental challenges by integrating ecological, social, and economic factors in a unified management framework. Current state-of-the-art practices in IEM often rely on multidisciplinary approaches that combine ecological science with policy and stakeholder engagement. Despite its widespread application, challenges persist in achieving effective integration due to varying spatial, temporal, and governance scales. The research methodology includes a comparative analysis of IEM case studies across diverse ecosystems, utilizing a combination of qualitative interviews with stakeholders, field data collection, and modeling techniques. The study emphasizes participatory processes, adaptive management strategies, and the incorporation of indigenous knowledge. The degree of novelty in this research lies in its focus on bridging the gap between ecological modeling and real-world socio-economic contexts, addressing the gap in literature regarding the scalability of IEM frameworks across different regions and ecosystems. Preliminary results indicate that successful IEM outcomes are closely tied to the robustness of governance structures, stakeholder collaboration, and the ability to adapt management strategies to evolving environmental conditions. However, the study also highlights significant limitations, including data gaps, the difficulty of integrating multiple stakeholders with conflicting interests, and challenges in monitoring and assessing long-term outcomes. The implications of this research are critical for informing policy and enhancing the efficacy of IEM frameworks. By presenting novel insights into the practical application of IEM, the article contributes to the refinement of strategies that can more effectively address global environmental challenges. Its originality lies in integrating socio-ecological systems thinking with empirical case studies to provide actionable recommendations for practitioners and policymakers.*

Keywords: *water management, biodiversity, ecosystem, ecological management, integrated, environmental, governance, framework*

INTRODUCTION

The complex interplay between biodiversity and water security is increasingly acknowledged as a significant subject of inquiry in the realm of environmental sciences. With human undertakings amplifying the strains on ecosystems as well as water resources, it becomes imperative to grasp the dynamics of their interrelation for the sake of sustainable development. Integrated Ecosystem Management (IEM) presents a framework enabling the evaluation and tackling of the hurdles presented by diminishing biodiversity and declining water quality. This management paradigm highlights a comprehensive methodology, promoting the contemplation of ecological, social, and economic dimensions in decision-making processes. Through the synthesis of biodiversity preservation with water management tactics, this method cultivates resilience within natural systems, which ultimately serves to benefit both human communities and the environment at large. The present essay aims to delve into the synergistic connections that exist within these two realms, underscoring case studies that manifest successful integrated methodologies and establishing a foundation for prospective policy recommendations aimed at bolstering both biodiversity and water security.

The idea of biodiversity comprises the variety of life forms found on Earth, which includes not only the diversity of species but also the range of ecosystems and the genetic variations present within organisms. This complex interconnection of living beings is of

paramount importance in sustaining the ecological equilibrium that is crucial for the health of our planet as well as the survival of humans. Biodiversity supports essential ecosystem functions that encompass nutrient cycling, pollination, and purification of water, all of which are indispensable for ensuring water security. In such a framework, it is essential for effective integrated ecosystem management to acknowledge the interconnectedness of biodiversity with ecosystem services; for instance, in the ecosystems of Ecuador, the reduction of biodiversity has resulted in notable declines in critical services such as erosion control of soil and regulation of water flow, which ultimately threaten water security (Tareke, 2023). Moreover, as evidenced by initiatives in China, the incorporation of nature-based solutions into the restoration of ecosystems demonstrates that an enhancement of biodiversity can alleviate degradation and foster sustainable development (Chaonan, 2024).

Water security is a matter of great importance within the framework of sustainable development, being foundational not solely to human health and well-being but also to the overall health of ecosystems globally (Audi et al., 2023, Jurcoane et al., 2023). With the intensification of agricultural practices aimed at accommodating the needs of an increasing population, the repercussions on both water quality and availability have become markedly evident (Smuleac et al., 2017, 2024). The growth of agricultural activities has resulted in considerable depletion of water resources and degradation of ecosystems, thereby necessitating prompt actions to protect aquatic environments; as highlighted in contemporary findings, the increase and intensification of agriculture has caused widespread use of fertilisers and pesticides (El Mostapha Albou et al., 2024). This harmful cycle accentuates the interlinked relationship between agricultural methodologies and water security, which is vital for sustaining biodiversity. Consequently, effective management strategies must amalgamate progressive agricultural practices with resilient water resource management in order to avert further ecological disruption and to foster the sustainable use of water. The assurance of water security transcends being merely an environmental concern; it is an essential foundation for the resilience and sustainability of both human communities and natural ecosystems (Pascalau et al., 2021).

An understanding, albeit nuanced, of the complex relationship linking biodiversity and water security proves to be fundamentally important in the formation of management strategies that can be deemed effective. The deterioration of ecosystems frequently results in a reduction in both the quality and the availability of water, thereby adversely affecting human livelihoods and the health of ecological systems. It is crucial to recognise that biodiversity holds substantial importance in the regulation of water cycles and the provision of essential ecosystem services. To illustrate, ecosystems that are in good health augment the infiltration of rainfall and contribute to the mitigation of flooding; this element resonates with the implications of the proposed innovative model for water resources management, which underscores the importance of the governance–policy–science intersection in enhancing water security (Ganoulis, 2023). Additionally, the socio-ecological systems framework offers a perspective through which one might examine the dependency between biodiversity and the accessibility of water, unveiling the detrimental effects of unsustainable practices on both water resources and biodiversity (Kampa et al., 2020). Tackling these interconnected dilemmas calls for a comprehensive ecosystem management approach that elevates biodiversity conservation to a fundamental component of water security.

MATERIAL AND METHODS

The functioning of ecosystems is markedly interlinked with the concept of biodiversity, as a varied array of biological communities tends to bolster resilience and

stability within said ecosystems. A considerable assortment of species plays an integral role in a multitude of ecological processes, hence underpinning vital services such as nutrient cycling, water filtration, and provision of habitats. For instance, research denotes that rehabilitated karst landscapes, showcasing augmented vegetation cover, reveal significantly enhanced biodiversity and ecosystem service (ES) delivery in comparison to degraded terrains (Gang, 2024). This correlation is particularly pronounced in aquatic settings, where ecosystem engineers, like beavers, establish habitats that not only boost biodiversity in their immediate locale but also exert influence over avian communities into adjacent terrestrial regions (Fedyń, 2024). As a result, the preservation and advancement of biodiversity emerges as essential, not solely for the vitality of ecosystems but also for the assurance of sustainable water security; diverse ecosystems are inherently more adept at weathering environmental fluctuations while fulfilling critical functions that are foundational to human livelihoods and the integrity of ecological systems.

Ecosystem services, which are crucial for the well-being of humans and the sustainability of the environment, experience substantial influence from biodiversity. The variety of species present within ecosystems plays a significant role in regulating numerous services, such as nutrient cycling, water purification, and soil fertility. It is particularly noteworthy that interspecific interactions among plants, evident in systems like maize-alfalfa intercropping, highlight the significance of varied root characteristics in enhancing the functionality of ecosystems. Findings from research suggest that these root interrelations foster an upsurge in nutrient cycling and microbial diversity, which are vital for the upkeep of healthy ecosystems (Dongxue Tao, 2024). Furthermore, discussions surrounding deep-sea mining elucidate the intricate connections between biodiversity and the well-being of marine ecosystems, bearing implications for efficient governance and practices concerning resource extraction (Holzheid, 2024). Therefore, the conservation of biodiversity transcends mere environmental apprehension, emerging as an essential facet of integrated ecosystem management strategies designed to safeguard water resources and bolster overall ecosystem resilience.

The interrelationship that exists between the diversity of species and the quality of water has become progressively acknowledged as a crucial element that affects the availability of water, especially within the framework of integrated ecosystem administration. Various aquatic and riparian species are integral to the processes of nutrient cycling, which in turn aids in the natural filtration processes that enhance the clarity of water and diminish levels of pollution. For example, the existence of a range of macrophytes and microbial communities has the ability to alleviate nutrient runoff and absorb detrimental chemicals, which favours healthier ecosystems in freshwater environments. On the other hand, a reduction in biological diversity typically leads to a decrease in the resilience of ecosystems, making water bodies increasingly vulnerable to degradation resulting from external pressures, such as runoff associated with agriculture and urban development, as previously noted in earlier research (Kampa et al., 2020). This decline not only threatens the quality of water but also introduces considerable difficulties for water security, since dependable access to clean water is jeopardised, thus underscoring the pressing necessity for policies that harmonise the preservation of biodiversity with the objectives of water resource management (Kampa et al., 2020).

Ecosystem resilience, especially relating to water security, is notably impacted by biodiversity. The restorative initiatives evident in the South Docks of Liverpool manifest this correlation, whereby the natural establishment of mussel populations not only contributed to enhanced water quality but also promoted superior ecosystem performance via biofiltration

(Firth, 2024). The mussel colonies engendered intricate habitats that supported a variety of taxa, thereby exemplifying how certain species can fortify ecosystem stability through the improvement of nutrient cycling and the mitigation of pollution levels. In a parallel vein, investigations in Uttarakhand elucidate the viewpoints of local communities with respect to invasive alien species, thereby accentuating the critical importance of diverse native plant life for sustaining ecosystem equilibrium and averting invasion (Vargas et al., 2023). Such instances elucidate that biodiversity functions as a protective barrier, permitting ecosystems to endure and recuperate from disturbances, hence highlighting the necessity for integrated ecosystem management to ensure enduring water security and ecological resilience.

RESULTS AND DISCUSSIONS

The management of integrated ecosystems is of utmost importance for tackling the intricate interdependencies that exist between biodiversity and the security of water resources. Frameworks such as Integrated Water Resources Management (IWRM), Ecohealth, and the Ecosystem Approach (EA) illustrate the imperative to take into account ecological, social, and economic factors when making decisions. The Alignment Assessment that has been undertaken in a range of studies supports the notion that these methodologies aid sustainable land management (SLM) and land degradation neutrality (LDN) by enhancing ecosystem health and food security, notwithstanding the observable shortcomings in criteria associated with human well-being (Hartmann et al., 2024). Additionally, a multi-criteria analysis indicated that the Water Framework Directive (WFD) stands out as a prominent strategy for fulfilling these criteria, thereby emphasising its importance in the sustainable management of water resources (Vargas et al., 2023). Ultimately, the convergence of these various approaches is crucial for promoting resilience in ecosystems, which is essential for the preservation of biodiversity and the assurance of water security amidst the prevailing global environmental challenges.

The effective management of ecosystems in an integrated manner (IEM) is fundamentally reliant on the amalgamation of ecological, economic, and social elements, which seeks to pursue a comprehensive approach to the stewardship of resources. This framework demands a scrutiny of various factors that exert influence on the functionality of ecosystems, as illuminated in the scholarly discourse, where critical thematic concerns such as the management of water resources and the adaptation to climate change hold significant importance (Vasić et al., 2024). The said integration serves not merely to enhance decision-making processes but also to elucidate the interconnections amongst the various components of ecosystems, which in turn bolsters resilience against pressures that are anthropogenic in nature. Additionally, strategies anchored in sustainable methodologies as well as practices that closely emulate natural systems offer a structure for alleviating risks linked to natural disasters, fostering biodiversity, whilst concurrently safeguarding essential ecosystem services (Kalapodis et al., 2024). Hence, the tenets of IEM advocate for a collaborative involvement of stakeholders, ensuring that their collective endeavors are informed by a thorough comprehension of shared ecological dilemmas and prospects, thus nurturing sustainable development and fortifying water security within the overarching framework of biodiversity.

The incorporation of biodiversity within the domain of water management calls for an approach that is not singular but rather complex, recognising the elaborate interrelations that exist between aquatic ecosystems as well as human ways of life. Strategies that prove effective ought to include the rehabilitation of wetlands, which are crucial as breeding grounds for fish and function as natural barriers against flooding, thereby safeguarding both ecological integrity and the resilience of communities (Swagat Ghosh et al., 2024). In addition, the adoption of nature-based solutions holds the potential to improve water quality and its availability, which is in alignment with the sustainable practices that are vital for adapting to climatic changes (Tiwari, 2023). It is imperative that

policymakers weave traditional ecological knowledge together with scientific inquiry when shaping their approaches, thereby promoting community involvement and governance that elevates the importance of biodiversity. As a result, this holistic framework fosters the preservation of aquatic habitats, augmenting the services provided by ecosystems whilst addressing the mounting challenges posed by urban expansion and climate change. Ultimately, such a well-rounded strategy not only protects biodiversity but also ensures the availability of water resources that are essential for food security and the overall welfare of human beings.

In the realm of effective integrated management practices, there are numerous case studies that serve to underscore the intricate relationship between the conservation of biodiversity and the assurance of water security. One significant instance can be observed at Jakkur Lake, situated in Bangalore, where the integration of constructed wetland systems has been implemented for the treatment of wastewater. This initiative has resulted in a notable enhancement of water quality, whilst concurrently providing support for the local biodiversity. The approach not only facilitates the removal of nutrients and contaminants from partially treated sewage but also contributes to the cultivation of a thriving ecosystem that is capable of sustaining diverse aquatic species, thus illustrating the inherent interdependence that exists between water quality and biodiversity. In a parallel vein, the management strategies employed in the Western Ghats region further elucidate the critical role that the preservation of native vegetation plays in the enhancement of hydrological processes. Specifically, regions exhibiting over 60% native cover are characterised by the presence of perennial streams and heightened soil moisture levels, which in turn have a direct positive impact on agricultural productivity and the livelihoods of local communities (Wang et al., 2023). Such instances of successful management highlight the imperative need for the adoption of multifaceted approaches that simultaneously align ecological integrity with the requirements of communities. Ultimately, this promotes resilience in the face of environmental challenges while also advancing the prospects for sustainable development (Wang et al., 2023).

Challenges and Threats to Biodiversity and Water Security

Ecosystems worldwide are facing a multitude of issues that significantly undermine biodiversity as well as water security. Adverse consequences arise from climate change, urban expansion, and the degradation of environmental conditions, which are posing serious threats to both aquatic and terrestrial organisms. To illustrate, in small island developing states (SIDS), the intensifying impacts of rising sea levels and severe weather occurrences further deteriorate coastal areas and disrupt vital habitats, subsequently diminishing both economic worth and food security. The reduction in species diversity leads to lesser ecosystem services, which are crucial for ensuring the quality and quantity of water available. In the case of Uganda, changes in climate patterns are particularly jeopardising agricultural biodiversity, with key crops becoming more susceptible to fluctuations in temperature and rainfall, which in turn threatens food security and economic resilience (Kato K., 2024). Tackling these interconnected challenges requires the implementation of integrated ecosystem management approaches that comprehensively address the conservation of biodiversity alongside the sustainability of water resources, thereby fostering resilience in the face of amplifying environmental challenges.

Climate change and its effects on ecosystems

The notable interplay that exists between climate change and ecosystems presents itself in numerous manners, thereby critically endangering both biodiversity and water security. Modifications in weather patterns, driven by human-induced emissions of greenhouse gases, intensify both the frequency and severity of natural disasters, including, but not limited to, floods and droughts, which results in major disruptions within ecological communities (Tiwari, 2023). Moreover, soil degradation stands as an additional pressing issue, compounding these hardships; over 2 billion hectares of land have been negatively impacted, leading to a reduction in essential

ecosystem services that are vital for both food and water security (Wang et al., 2023). These transformations are not only responsible for disrupting species habitats and diminishing biodiversity, but they also weaken the ability of ecosystems to adapt to emerging climatic circumstances. Consequently, the necessity for effective integrated ecosystem management becomes apparent, as it demands collaborative initiatives aimed at protecting both biodiversity and water resources, thereby ensuring that ecosystems possess the capacity to endure forthcoming climatic shifts while continuing to offer crucial services to human populations and the surrounding environment alike (Tiwari, 2023, Wang et al., 2023).

Pollution and habitat destruction as threats to biodiversity

The interconnected issues of pollution and the destruction of habitats present considerable difficulties for global biodiversity, carrying extensive ramifications for the integrity of ecosystems and the security of water resources. In areas that are heavily populated and industrialised, like the Yangtze River Estuary, human endeavours intensify habitat degradation, thereby eroding the vital ecological roles that these environments fulfil (Wang et al, 2023). Pollutants not only detrimentally influence the health of various species but also disrupt migratory routes, which is particularly notable in the case of the endangered Chinese sturgeon, suffering habitat loss due to human-induced pressures such as increased ship traffic and ecological invasions. Likewise, in the tropical locales of Mexico, elevated levels of urban development and fragmentation of habitats have heightened the extinction risks for numerous taxa, especially among mammals and amphibians (Manuel Esperon-Rodriguez, 2024). The decline of these habitats poses threats not merely to single species but also to the interconnected ecosystem services essential for human health and welfare, ultimately jeopardising efforts aimed at attaining sustainable management of water resources and the conservation of biodiversity. It is thus essential to tackle these challenges through comprehensive ecosystem management strategies to cultivate resilience in both natural ecosystems and those influenced by human activity.

Socioeconomic factors influencing water security and biodiversity

The complex interactions that occur between socioeconomic elements and the security of water have a notable effect on outcomes regarding biodiversity within various ecosystems. As the number of people increases and the process of urbanisation progresses at an accelerated pace, the necessity for water also becomes greater, frequently leading to the over-utilisation of water resources and subsequent degradation of habitats, thereby directly jeopardising biodiversity. Communities that are often marginalised tend to suffer more significantly from the declining quality and availability of water, which compounds their susceptibility and weakens their capacity to partake in sustainable practices of land management (Hartmann et al., 2024). Moreover, land tenure systems characterised by inequity may result in heightened competition for water resources, which not only places additional stress on local ecosystems but also disrupts rural livelihoods that depend on biodiversity for survival. To address these multifaceted issues, it is imperative for policymakers to incorporate socioeconomic factors into frameworks concerning water security, thereby ensuring that strategies designed for the conservation of biodiversity facilitate inclusive development and fair access to resources. Tackling these intertwined concerns ultimately contributes to the enhancement of resilience among both human and ecological communities.

CONCLUSIONS

In summing up this investigation into the matters of biodiversity and water security as they relate to integrated ecosystem management, it is clear that a comprehensive approach is necessary for competent governance and the sustainable usage of resources. The interplay between humans and nature is marked by a fluctuating pattern of conflict and collaboration, which serves as a fundamental justification for a model that recognises these intricacies

(Ganoulis, 2023). This is particularly relevant in locales such as Lake Tana, where the water resources are vital for both biodiversity and socioeconomic progression. However, issues like water scarcity and pollution demand prompt action (Tareke, 2023). Employing sustainable management tactics, such as the establishment of buffer zones and the implementation of integrated watershed management, has the potential to alleviate these challenges and promote a collaborative environment among stakeholders. Therefore, it is crucial to fuse human activities with natural ecosystems, underpinned by solid governance and policy frameworks, as this is indispensable not only for securing water but also for upholding ecological harmony and resilience amidst the challenges posed by climate change.

The scrutiny of integrated ecosystem management uncovers numerous pivotal insights regarding the interconnection between biodiversity and water security. The outcomes signify that programmes such as the Water Resource Accountability (WRAP) Project have effectively illustrated the economic feasibility of Nature-based Solutions (NbS), evidenced by a beneficial Benefit-Cost Ratio (BCR) of 3.50 for initiatives like Gabion check weirs. This substantiates the project's capability in augmenting the management of water resources whilst fostering resilience against climate change, as delineated in (Sajjad et al., 2024). On the opposite spectrum, the declining state of Lake Tana accentuates the pressing necessity for efficacious management strategies; notable water quality dilemmas, including heightened trophic levels and the rampant spread of invasive species such as water hyacinth, jeopardise both ecological integrity and the livelihoods of local communities, as elucidated in (Tareke, 2023). In summation, the amalgamation of these findings accentuates the imperative for comprehensive methodologies to tackle water security, which should encompass ecological health, community participation, and sustainable practices.

Recommendations for policy and practice

The advancement of integrated ecosystem management necessitates the formulation of effective policy and practice recommendations, especially in relation to biodiversity and the security of water resources. It is imperative that strategies enhancing the management of water resources be prioritised, particularly those incorporating Nature-based Solutions (NbS) to surmount challenges associated with climate resilience and water governance. An illustration of this methodology is represented by the WRAP Project, which showcases a substantial economic analysis underpinning the adoption of NbS interventions, encompassing measures such as Gabion check weirs, which have resulted in a Benefit-Cost Ratio (BCR) of 3.50 (Sajjad et al., 2024). Furthermore, it is vital for policymakers to cultivate collaborative engagement among stakeholders to enrich decision-making processes, thereby ensuring that a range of perspectives—encompassing those of vulnerable populations—are duly considered. This reflects the necessity for inclusivity that has been underscored in the equity analysis related to WRAP, which emphasised the significance of addressing the needs of lower-income groups and individuals with disabilities (Sajjad et al., 2024). In addition, a thorough grasp of thematic components such as natural hazards and ecosystem services is of paramount importance. Ultimately, it is the adoption of synergistic approaches that integrates these recommendations which will result in more resilient and sustainable practices concerning water management.

Future research directions in biodiversity and water security

Emerging combinations of biodiversity and water security highlight a pressing need for interdisciplinary research that goes beyond the limits of traditional disciplinary confines. Future inquiries ought to focus on melding hydrological models with ecological frameworks in order to clarify the intricate interactions that occur between aquatic ecosystems and terrestrial biodiversity. It will be essential to investigate the ramifications of climate change, alterations in land use, and the growth of urban areas on the quality and availability of water to devise

adaptable management strategies. Moreover, the significance of indigenous knowledge systems and the involvement of communities in strengthening resilience within socio-ecological systems merits increased scrutiny within the academic dialogue. Such participatory strategies prove crucial in guaranteeing that water governance frameworks not only mirror ecological truths but also emphasise social fairness. In this regard, longitudinal studies that assess ecosystem services relative to water security are vital for informing policy and advancing sustainable practices that effectively reconcile economic growth with biodiversity preservation.

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