A Brief Look into Water Resources Management and Ecosystem Health for Water and Food Security

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Abstract

Water and food security are worldwide objectives linked to healthy ecosystems that provide clean water and food. Human activities are progressively jeopardizing this equilibrium, affecting both resilience and sustainability. Ecosystem health and water resource management are linked, as ecosystems maintains water quantity and quality. However, urbanization, agriculture, industry and climate change are all inflicting considerable harm to ecosystems and altering hydrological processes. This review aims to explore the complex relationship between ecosystem health and water resource management and to highlight effective management practices and challenges. The review employs a comprehensive literature review, thematic analysis, and a thorough evaluation of case studies. Human activities such as urbanization, agriculture, industry, and climate change have a significant impact on ecosystems and hydrological processes. The review reveals how these activities endanger water quality and quantity, compromising resilience and sustainability. Case studies highlight the importance of protecting water resources and restoring degraded ecosystems to ensure water and food security. Effective strategies for mitigating the negative effects on ecosystems and water resources are identified, along with challenges in integrated water resource management. The paper emphasizes the importance of interdisciplinary collaboration, adaptive management, and ecosystem-based approaches to improving water and food security. It promotes climate-smart agriculture and fair access to resources as critical components of a resilient and safe future. Future prospects and existing efforts are highlighted to emphasize the importance of these techniques in dealing with ongoing and upcoming difficulties.

Keywords: Water resources management, ecosystems health, food security, climate change, water security.

1. Introduction

Water and food security are major concerns globally but we often neglect the fact that its ecosystems services that produce food and clean water for human needs.Water shapes our planet's landscapes and supports a diverse range of life forms, so we can no longer afford to neglect the effects of human activitiesas they are posing serious threats to the delicate balance of ecosystems and water resources making sustainability very difficult (Matthews, 2016).The intricate relationship between ecosystem health and water resource management is at the core of this problem (Sun & Vose, 2016).Water is required not just for human use, agriculture and industry but also for the proper functioning of natural ecosystems (Spring, 2020).Ecosystems are essential for controlling the amount and quality of water, removing impuritiesand recharging aquifers (Cheng et al., 2021; Ilic et al., 2021). Therefore, ecosystems and water resources are linked they each dependon the other to function (Pacetti, 2018). Human activity has a significant and wide-range of effect on ecosystems and water resources (Khan & Zaheer, 2018; Meter et al., 2016).Ecosystems have been degraded and hydrological processes have been altered by urbanization, climate change, agriculture and industrial activities (Kintu et al., 2019; McGrane, 2016).Urban growthcreates impermeable surfaces replacing permeable ones thus increasing runoff and decreasing infiltration worsening erosion and flooding (Lepeska, 2016) while deteriorating water quality (Ferreira et al., 2021).In an effort to feed a growing population, agricultural practices frequently employ excessive amounts of pesticides and fertilizers (Pericherla et al., 2020), which when soil erosion occurs leads to nutrient runoff and eutrophication of aquatic bodies (Pericherla& Vara, 2023). Industrial processes release pollutants into rivers, lakes and the ocean which endangers aquatic ecosystems and poisoning water supplies with heavy metals (Dehdashti et al., 2020).These problems are made worse by climate change which also raises sea levels, changes precipitation patterns and intensifies floods and droughts (Day &Rybczyk, 2019; Oloyede et al., 2021). With all these challenges, comprehensive strategies that acknowledge the inextricable connections between ecosystem health and water resource management are desperately needed, as emphasized byTabios III. (2018) and Grantham et al. (2019)who agrees that sustainable water management requires ecosystem-based strategies that include ecological principles, support natural processes and increase resilience to environmental change rather than relying solely on traditional technical solutions.This reviewhighlights the relationship between ecosystem health and the management of water resources through some case studies that features preservationof water resources and restoration of degraded ecosystems as an integral part of water and food security. It looked at the effects of human activities, solutions to those effects while emphasizing effective approaches.It seeks to draw our attention to plan a course for a more sustainable and resilient future for water and food security ensuring the possible minimal impact on the environmentat the same time.

2. Methodology

2.1 Database search and selection criteria

We conducted systematic searches on Google scholar, Web of science, Scopus, JSTOR, SpringerLink,andScienceDirect using the following keywords: water resources management, ecosystem health, water security, food security, climate change, environmental degradation, ecosystem restoration, industrial impacts, sustainability, natural resource protection, urbanization, agriculture, policy implications. Studies published during the last 20 years were evaluated, including peer-reviewed articles, government reports, and credible organizational publications, with a focus on water and food security. However, articles not available in English and studies not directly related towater resources and environmental health were excluded. Data was retrieved with an emphasis on findings related to the integration of water resources management and environmental health, as well as case studies with successful integration practices, challenges and proposed solutions.

2.2 Thematic analysis and synthesis

The retrieved data were classified to find reoccurring themes acrossstudies. This includes: the impact of human activities (urbanization, agriculture, industry, and climate change) on water and ecosystem health,case studies demonstrating effective water resources management and ecosystem restoration, challenges in integrated water resources management, and innovative approaches and solutions (nature-based solutions, water reuse and recycling, advanced technologies). The findings within each theme were synthesized to gain insights and highlight the interconnectedness of water resources management and ecosystem health.

2.3 Case study analysis

Three case studieswere selected based on their relevance and the availability of comprehensive data: the Everglades Restoration Project which focuses on wetland restoration; the Chesapeake Bay Watershed Management,which involves sustainable agriculture; and the Portland's Urban Green Infrastructure Program,which focuses on stormwater management. The project outcomes, challenges faced, and strategies implemented were analyzed, identifying common strategies and unique approaches, as well as evaluating the effectiveness of various management practices and their impact on ecosystem health and water security.

3. The impact of human activities

3.1 Urbanization

Cities expansion disrupts natural water cycles as natural surfaces are altered resulting to increase surface runoff and accelerates erosion (Kintu, 2019; Kaur, 2019; Bajracharya, 2016). This way, urban areas become pollution zones with runoff carrying pollutants and heavy metals into waterways, thus, harming aquatic ecosystems (Liu et al., 2018; Zanoletti & Bontempi, 2023). Urban sewer overflows during intense rainfall threaten both human health and aquatic organisms (Potera, 2015).

3.2 Agriculture

Agriculture is a major water user which contributes to water pollution and exerts pressure on ecosystem (Braden & Shortle, 2013; Kinzelbach, 2021). Intensive practices like irrigation, fertilizer and pesticide use degrade water quality (Shefali et al., 2020). Excessive irrigation drains aquifers and rivers resulting to waterlogging and soil salinization (Melgares, 2018; Singh, 2015). Agricultural inputs and waste cause eutrophication, oxygen depletion, and sediment runoff, harming aquatic environments (Rashmi et al., 2020; Kreutzweiser & Sibley, 2020; Kadiru et al., 2022).

3.3 Industry

Industrial pollutants are threats to ecosystems and water resources endangering aquatic life and human health (Grace, 2021; Sonone et al., 2020). Wastewater from industrial processes contains toxins, heavy metals and organic compounds that pollutes water sources (Sonone et al., 2020, Ibrahim et al., 2021). Industrial activities like mining and manufacturing disrupt landscapes, interfere with hydrology and fragment habitats, posing long-term risks to water supplies and ecosystems (Webster, 2015; Leppanen, 2017).

3.4 Climate change

Climate change is altering rainfall patterns and causing sea levels to rise which impacts agriculture, ecosystems and water supply (Ramírez & Kallarackal, 2018; Milner et al., 2017). This exacerbates other stresses like pollution and habitat degradation, while higher temperatures accelerate algae growth resulting to algal blooms and oxygen loss in water (Staudt et al., 2013; Green-Gavrielidis & Thornber, 2022).

4. Case studies

4.1 Restoration of wetlands for water quality improvement: the Everglades restoration project.

The Everglades isa diverse wetland ecosystemwhich has suffered from human activities like urbanization and agriculture disrupting its natural processes and threatening its health (Finkl & Makowski, 2017; Lodge, 2019; D'Acunto et al., 2021). In view of these challenges, the Comprehensive Everglades Restoration Plan (CERP) aims to protect and restore the ecosystem focusing on hydrological restoration, wetland restoration, water quality improvement, ecosystem monitoring and adaptive management (Finkl & Makowski, 2017). Despite challenges like regulatory hurdles, competing stakeholder interests and funding constraints (Schwartz, 2010; Engel, 2012), progress has been made in restoring the hydrology, reviving the wetland and improving the water quality(Zielinki, 2006; Brown et al., 2014), showcasing the potential for collaborative restoration efforts and adaptive management.

4.2 Integrated watershed management for sustainable agriculture: Chesapeake Bay watershed management.

The Chesapeake Bay faces pollution from various human related sources threatening its ecosystem. The Watershed Management initiative aims to reduce pollution, restore habitats and foster collaboration among stakeholders while challenges include securing funding and balancing agricultural productivity with environmental conservation (Ribaudo & Shortle, 2011). Despitethese constraints, progress has been made in habitat restoration and pollution reduction (Hassett, 2006). The possibility of attaining sustainable agriculture while preserving and rehabilitating aquatic habitats is demonstrated by the cooperative efforts and innovative methods to watershed management.

4.3 Urban green infrastructure for stormwater management: Portland's urban green infrastructure program.

Portland is known for its creative and sustainable approaches to environmental and urban development by employing green roofs and permeable pavement (Schweitzer, 2013). The success of Portland's urban green infrastructure initiative can be linked to robust leadership, active community involvement and tactical collaborations across governmental bodies, nonprofit institutions and private industry participants (Aylett, 2013). Portland prioritizes natural solutions and incorporates green infrastructure into urban design and construction whichhas proved that implementing sustainable stormwater management strategies can result in cities that are healthier and more resilient to climate change (Lemont, 2018). McPhillipsand Matsler (2018) highlights Portland's continuous monitoring, assessment and adaptive management as the driving force that keeps improving its urban green infrastructure strategy alongside bringing in best practices and learning from other cities.

5. Challenges in water resources and environmental management

5.1 Conflicting interests among stakeholders

In integrated watermanagement, balancing different stakeholder interests is challenging (Yusof & Saad, 2020). Competing uses like agriculture, industry and environmental preservation strain water resources (Siyal et al., 2023). Conflicts arise between different sectors and regions over water distribution. Building consensus among stakeholders is crucial for sustainable management (Rodrigo & Brown, 2005). Effective governance structures and clear decision-making processes are essential to resolve conflicts and ensure fair access to water resources (Fearon, 2003; Burleson, 2011; Langsdale, 2022).

5.2 Institutional fragmentation and governance Issues

Integrated water management involves multiple tiers of governance (Ross, 2017), but progress can be hampered by bureaucratic inefficiency, lack of political will and corruption (Kim et al., 2015). Power distribution across tiers contributes to declining condition of water resources and ecosystem, as seen in the Murray Darling Basin, Australia (Cornell, 2009). This often results in decisions favoring short-term political interests over long-term sustainability goals, particularly in developing countries where political elites dominate decision-making (Berg, 2021).

5.3 Limited data availability and uncertainty

Accurate and up to date data are importantin integrated water resource management, but differences in quality and availability of data pose challenges (Casado-Perez et al., 2015; Dantas et al., 2021; Colohan & Onda, 2022). Evaluation of water availability, identifying trends and forecasting future water demand are affected by incomplete data (Perrone et al., 2015). Additionally, uncertainties like variations in hydrological conditions and climate change further complicate water management (Tortajada & Biswas, 2013; Mujumdar, 2013; John et al., 2020).Many water managers may not be able to use advanced modeling techniques and scenario analysis to predict future water availability and demand especially in developing nations (Buytaert et al., 2012; Scheider & Dunnigan, 2018).Despite these obstacles, employing risk management and adaptive strategies fosters resilience in water management (Goldsmith & Samson, 2012).

6. Approaches and solutions

6.1 Nature-based solutions

Nature-based solutions offermultiple benefits for biodiversity conservation, climate adaptation and community resilience leveraging the power of ecosystems to address water-related problems (Heneghan et al., 2022; Pathak et al., 2022).Green infrastructure such as urban trees and wetlands reduces stormwater runoff thereby reducing urban flooding (Carlyle-Moses et al., 2020; Alyaseri et al., 2021). Ecosystem restoration initiatives improve water quality and biodiversity while acting as natural filtration barriers against pollutants (Steven & Lowrance, 2011; Hasselquist et al., 2021).Strategies like reforestation and soil conservation reduce flooding risks, protecting both ecosystems and communities (Tamas, 2019; Cunniff, 2019).

6.2 Water reuse and recycling

Water reuse and recycling are sustainable practices that alleviate water scarcity by reclaiming and treating wastewater making it suitable for non-potable uses, reducing freshwater demand and pollution (Tian et al., 2017; Toretta et al., 2020; Nazari et al., 2012; Kotak, 2019; Chand et al., 2022). Direct potable reuse is employed in order to produce drinking water of higher quality directly from wastewater sources utilizingadvanced wastewater treatment techniques such as reverse osmosis (Khan, 2013; Drewes&Horstmeyer, 2015; Tang et al., 2018).Similarly, localized options for water reuse at the home and community levels are provided by decentralized water recycling systems such as greywater recycling systems and on-site wastewater treatment facilities further easing pressure on freshwater resources (Ahmed & Arora, 2012; Qomariyah, 2016; Bertolazzi, 2018).

6.3 Integrated water resources management

Integrated water resources management (IWRM) emphasizes stakeholder involvement and risk assessment as crucial for successful water management (Angarwal et al., 2021; Lim et al., 2022). Engaging local communities, governmental entities, indigenous peoples and civil society organizations in decision-making is important for effective and sustainable water management (Langsdale & Cardwell, 2022). This participatory approach promotes ownership, consensus-building and cooperation in water projects (Basco-Carrera, 2018). Risk assessment and management within IWRM help prioritize and identify water-related risks, analyze potential consequences and develop adaptation and mitigation plans (Volker et al., 2012; Giupponi & Gain, 2017). Integrating risk-based approaches into IWRM ensures the sustainability of water resources and the communities dependent on them, enhancing resilience to threats like natural disasters and climate change (Rasul, 2012; Gain et al., 2013).

6.4 Advanceand emerging technologies

Advanced technologies such as remote sensing and data analytics are transforming water management. Remote sensing methods provide a wide range of data on water availability and quality, helping to monitor changes and identify problems(Parece & Campbell, 2015; Chakraborty, 2018; Sibanda et al., 2021).Water managers can use this data to monitor changes in land cover, identify contaminated water sources and evaluate how climate change is affecting water supplies (Wen& Yang, 2011; Huang& Klemas, 2012; Muck et al., 2015).Meanwhile, water managers are empowered by data analytics including AI and machine learning to evaluate large datasets, streamline processes and reach well-informed conclusions (Lowe et al., 2022; Drogkoula et al., 2023).Robust management plans that address uncertainties and improve sustainability can be developed by integrating these technologies with climate projections and stakeholder engagement (Wilby & Murphy, 2018).

7. Discussion

As cities grow, there are more impermeable surfaces, which result in more surface runoff and subsequent water pollution. This has a direct impact on water quality, which is important for human use and agricultural productivity. The overuse of fertilizers in agriculture causes nutrient runoff and water contamination. Water quality is further contaminated by industrial pollutants, putting both aquatic life and water resources at risk. Water and food security are seriously threatened by the combined effects of these activities, particularly in light of climate change.These findings are consistent amongstudies showing that urbanization, agriculture, and industrial activitiessignificantly impact water quality and availability. Studies have long noted the negative effects of nutrient runoff from fertilizers and pollutants from industrial activities, highlighting the importance of implementing sustainable agricultural and industrial practices to maintain water quality, includingcutting-edge wastewater treatment technologies and promoting water-efficient irrigation methods into practice. These activities need to be supported by policymakers through funding and regulation. Water and food security can be achieved through initiatives that combine sustainable farming techniques with watershed management.The theoretical understanding of the relationship between ecosystem health, water resources and human activity is enhanced by this review. It implies that for sustainable water and food security, comprehensive, integrated measures are required. Two essential elements of these strategies are ecosystem-based management and interdisciplinary collaboration.

8. Limitation

This review has some limitations. It only includes articles written in English, so important information from articles in other languages might be missing. The review only looked at some few specific databases. This means it might have missed relevant articles from other sources or those using different search terms. The review focuses on three specific projects: the Everglades Restoration Project, Chesapeake Bay Watershed Management, and Portland's Urban Green Infrastructure Program. These projects are very specific and might not be relevant to other areas with different environmental and social conditions.

9. Conclusion

Human activities like urbanization, farming, and industry put a lot of pressure on water resources and ecosystems, making sustainable food and water security difficult to achieve. To address these challenges, we need sustainable farming and industrial practices, advanced wastewater treatment, and climate adaptation strategies like soil conservation and water-efficient irrigation. Integrated policies that prioritize climate-smart agriculture, sustainable water management, and fair access to resources are essential. Nature-based solutions such as wetland restoration and green infrastructure, along with technologies like remote sensing and smart sensorsare crucial for better water management.Water management is a complicated field with bright future combining cutting-edge technologies, flexible administration and knowledge of the interactions between water, energy and the environment. However, infrastructure efficiency and quality control are being completely transformed by innovations like real-time monitoring, predictive modeling and the integration of smart sensors, IoT and data analytics, making adaptive management essential for handling uncertainty and system changes. As we transition to renewable energy sources, water and energy systems must be optimized simultaneously. In this regard, sustainable water management must be supported by ecosystem-based adaptation techniques including restoration and nature-based solutions which increase resistance to climate change.Recognizing this as well asimplementing these sustainable practices and technologies, we may assure a future where food production is sustainable, fair, and resilient to climate change, securing water and food for future generations.

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