



A Review of Watershed Management in Bangladesh: Options, Challenges and Legal Framework

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Abstract: Watershed management in Bangladesh is a critical area that demands attention due to the country's intricate socio-environmental dynamics. This review explores the options, challenges, and legal framework perspectives associated with watershed management, aiming to provide a comprehensive understanding of the current landscape. The paper explores into the diverse strategies employed for sustainable watershed management, considering ecological, social, and economic dimensions. Challenges such as population pressure, climate change impacts, and resource depletion are analyzed, highlighting the complexities faced by policymakers and practitioners. The study scrutinizes the existing legal frameworks governing watershed management in Bangladesh, evaluating their effectiveness and proposing potential improvements. This critical review examines the current state of watershed management in Bangladesh, exploring various options, challenges, and legal frameworks that alter due to anthropogenic activities. Through a comprehensive analysis, this review aims to contribute valuable insights for enhancing the efficacy of watershed management practices in the context of Bangladesh's unique socio-environmental changing features.

1. Introduction

Bangladesh positioned in the western portion of the India are located within the 'Bengal Basin' and has a lot of rivers, lakes, beels, jeels and impoundment water bodies in plain land (Abhijit *et al.*, 2009, Mahmood Alam *et al.*, 2002). Bengal basin contains the world's largest river delta, which is 140,000 square kilometers (the Ganges-Padma, Jumna-Brahmaputra-Tista and Meghna rivers and numerous tributary complexes) and the world's largest submarine fan complex (the Bengal Fan). In addition, the headwaters of both the Ganges-Padma and Brahmaputra-Jamuna-Tista river systems are situated in the Himalayas ranges. It drains one of the heaviest rainfall areas of the world that discharged in summer time huge precipitation occur. Consequently, of these extensive catchments, flooding is an annual occurrence in Bangladesh and occurs mainly during the rainy season between May to October when the rainfall in the catchments is at its maximum intensity (Nishat and Mukherjee, 2013). Bangladesh

has an average annual surface flow of approximately 1,073 million acre feet (MAF) of which approximately 870 MAF (93%) are received from India as inflow and the remaining 203 MAF (7%) as rainfall. This rainfall water is enough to cover the entire country to a depth of 9.14m. Approximately 132 MAF (65% of rainfall and 12% of total) is lost to evaporation each year (114.30 cm), the remainder flows out to the Bay of Bengal. The characteristic of groundwater storage reservoirs in have three divisions: upper clay and silt layer, a middle composite aquifer (fine to very fine sand) and a main deep aquifer consisting of medium to coarse sand. Near average annual rainfall in the country varies from greater than five meters in the northwest to less than 1.5 meters in the west (Nepal *et al.*, 2017). Groundwater is contaminated by elevated levels of heavy metals Ca, Mg, Fe, Cr, and Pb in some areas of Bangladesh (Islam and Mostafa, 2021). The mainstream of Bangladesh receives rainfall between 1.5 and 2.5 meters of precipitation annually and relatively high rainfall area in catchment of Bangladesh. Most rivers in Bangladesh lose water to groundwater aquifers during the wet season and gain water from February to April basically beginning from summer seasons. With its dense population, predominantly agricultural economy, and an intricate network of rivers and water bodies, the country's vulnerability and reliance on effective watershed management becomes apparent (Alimullah Miyan, 2015; Sullivan, 2011). The significance of watershed management, the introduction elucidates its role in sustaining water resources, supporting agriculture, and preserving ecosystems (Siegmund-Schultze *et al.*, 2018). The interconnectedness of these elements is underscored, emphasizing the need for an integrated approach that transcends traditional silos. The introduction sets the tone for a holistic examination that considers ecological, social, and economic dimensions. Bangladesh, with its densely populated and agrarian society, faces significant challenges in managing its watersheds effectively (Yadav *et al.*, 2020; Abdulla *et al.*, 2021). The review begins by outlining the importance of watershed management in ensuring sustainable water resources, agricultural productivity, and overall environmental health which are as follows: 1. the paper explores various options available for watershed management in Bangladesh. This includes the implementation of sustainable agricultural practices, afforestation initiatives, and the promotion of water conservation techniques. 2. Several challenges impede effective watershed management in Bangladesh. Population pressure, exacerbated by rapid urbanization, leads to increased demand for water resources and agricultural land. Climate change impacts, including unpredictable rainfall patterns and extreme weather events, further intensify these challenges. 3. An in-depth analysis of the existing legal frameworks governing watershed management in Bangladesh is crucial for understanding the regulatory environment (Md Monirul Islam *et al.*, 2020). The review assesses the current legislation, highlighting areas that require refinement. It also explores the enforcement mechanisms and the role of stakeholders in ensuring compliance with watershed management regulations. 4. Recognizing the interconnected nature of watershed management, the review advocates for an integrated approach that considers ecological, social, and economic factors. It emphasizes the importance of community involvement and stakeholder engagement in decision-making processes. 5. Community participation is identified as a key factor in successful watershed management. The review discusses the importance of empowering local communities, fostering awareness, and building capacity to actively engage in sustainable practices. It explores successful community-based watershed management models from other regions that could serve as inspiration for similar initiatives in Bangladesh. The outlines of the specific objectives the critical reviews are:

1. to scrutinize the diverse present management options of watershed management in Bangladesh.

2. to identify and analyze the major challenges of effective watershed management, including climate change impacts on watershed management
3. to evaluate legal frameworks governing watershed management in Bangladesh and enforcement mechanisms.
4. to initiate the practical recommendations aimed at enhancing the effectiveness of watershed management practices in Bangladesh.

2. Material and methods

The review collected information from a range of different scientific publications on watershed management strategy in present context of Bangladesh. Articles were collected without any time restrictions from different sources. Several relevant terms used such as ‘watershed management’, ‘watershed management options and challenges’ and ‘legal framework’ were searching research articles in freely available online journals subscribed by the online access. Collected research articles were sorted out and finally synthesis of literature focused on some specific filed of watershed management practices which are faced life-threatening situation in the local and international levels. Moreover, many conference proceedings and books chapters on relevant issues were also analyzed for common understanding of the lectured issue. Therefore, watershed management policies include different strategic direction and future implementations of law and policies that protect water resources for surface and ground water access safeguarding as a potable water supply have been highlighted.

3. Results and Discussions

Watershed management in Bangladesh presents a complex landscape shaped by a myriad of factors. This section delves into the key findings from the critical review, exploring the options, challenges, and legal framework perspectives to offer a nuanced understanding of the state of watershed management in the country. Therefore, watershed pollution causes serious threats for public health that indicate different diseases of human health and others aquatic organisms. Some studies reported that it need urgent action for take initiatives for present watershed management for achieves Sustainable Development Goals (SDGs) in future aspect. There are some watershed management options as follows:

3.1. Watershed Management Options

The analysis reveals a spectrum of options available for effective watershed management in Bangladesh. Traditional methods such as afforestation and soil conservation practices remain vital, but innovative approaches, including the integration of technology like GIS and remote sensing, showcase promise in enhancing monitoring and management efforts for watershed management. Successful case studies of watershed management from both local and international contexts highlight the diverse strategies that can be tailored to the unique socio-environmental dynamics of Bangladesh. Watershed management options are surface water, ground water and others watershed management options are as follows:

3.1.1. Surface water management options

Bangladesh, situated in the delta of major rivers like the Ganges and Brahmaputra, faces significant challenges in surface water management. In surface water management in rivers, lakes, ponds and others open water bodies are necessary for protection from any kind of water pollution that are

negatively impact on water. The country experiences both floods and droughts, making it crucial to adopt effective strategies for water resource management. One key approach is the construction of embankments and levees to control flooding. These structures help prevent water from inundating agricultural fields and human settlements during the monsoon season. However, there is a need for careful planning and maintenance to ensure their long-term effectiveness and minimize negative environmental impacts. Additionally, the creation of reservoirs and dams provides a means to regulate water flow, store excess water during the rainy season, and release it during dry periods. This helps in maintaining a more consistent water supply for agriculture, reducing the impact of both floods and droughts (Srivastav *et al.*, 2021). However, the construction of such structures must be done considering ecological and social consequences. Investing in modern irrigation systems is another vital aspect of surface water management in Bangladesh. Efficient irrigation practices can enhance agricultural productivity, especially during dry spells, and contribute to food security with use several techniques such as drip irrigation and water-efficient crop varieties can optimize water usage, ensuring sustainable agriculture (Mallareddy *et al.*, 2023). Furthermore, promoting community-based water management initiatives can empower local communities to take charge of their water resources. This involves educating local communities and related stakeholders on water conservation, providing training in sustainable farming practices, and encouraging the adoption of water-saving technologies. A comprehensive surface water management strategy for Bangladesh should include a combination of infrastructure development, sustainable agricultural practices, and community involvement. By addressing both floods and droughts through a holistic approach, Bangladesh can build resilience against the challenges implies by its unique hydrological conditions.

3.1.2. Groundwater management options

In Bangladesh, groundwater serves as a crucial source of drinking water and irrigation, especially in regions where surface water availability is very limited (Afrida *et al.*, 2020). Effective groundwater management is essential to ensure sustainable use and mitigate the challenges implies by over-extraction and contamination by anthropogenic activities and industrial effluent discharged. One key strategy is the implementation of aquifer recharge initiatives. This involves artificially replenishing groundwater by directing excess surface water into the ground during periods of abundance. Constructing recharge basins and encouraging the natural percolation of rainwater into the aquifers helps maintain groundwater levels and ensures a more sustainable extraction rate. To address over-extraction, regulations and policies should be enforced to monitor and control groundwater usage. Implementing metering systems, issuing permits, and setting extraction limits can help prevent the depletion of aquifers. Additionally, promoting water-saving technologies in agriculture, such as efficient irrigation practices and crop selection based on water availability, can contribute to sustainable groundwater management. Another aspect is the identification and protection of recharge zones and vulnerable areas. By mapping out areas where groundwater is recharged naturally, authorities can implement measures to safeguard these zones from pollution and over-exploitation. This involves controlling industrial discharges, waste disposal, and agricultural runoff to prevent contamination of groundwater sources. Severe anthropogenic activities have caused contamination to groundwater quality which accordingly disturbs human health and aquatic environment (Wu and Sun, 2016). Community engagement and awareness programs play a vital role in sustainable groundwater management. Educating local communities about the importance of water conservation, proper sanitation practices, and the consequences of over-extraction can foster a sense of responsibility. Community-driven initiatives, such as the establishment of water user associations, can empower locals

to actively participate in managing and preserving their groundwater resources. A comprehensive approach to groundwater management in Bangladesh should include aquifer recharge strategies, regulatory measures, protection of recharge zones, promotion of water-saving technologies, and community involvement. In recent aspects, Bangladesh can work towards ensuring the long-term sustainability of its vital groundwater resources. Therefore, due to continuous depletion of groundwater level is an accelerating rate from year to year. Rate of depletion in wet season is higher than the rate in dry season. Recharging of groundwater occur mainly in between four monsoon months June-September (about 80% of rainfall occur in monsoon period in Bangladesh) and replenishment of water level by annual rainfall is overruled by annual increasing amount of withdrawal. Ground water pollution can contaminate on other water bodies that degrades water quality in any watershed which are significantly changes watershed in long term effect.

3.1.3 Others water body management options

Managing others water bodies in Bangladesh is crucial for sustaining ecosystems, supporting livelihoods, and ensuring water quality (Md Shawkat Islam Sohel *et al.*, 2015; Bilal *et al.*, 2023). The country's diverse landscape, featuring rivers, lakes, and wetlands, requires a comprehensive approach to address various challenges. One significant option is the implementation of integrated water resource management (IWRM). This approach considers the interconnectedness of different water bodies and aims to balance the competing demands on water resources. Developing guidelines and implementing IWRM plans, Bangladesh can optimize water usage, minimize conflicts, and ensure the sustainable use of open water bodies. Wetland conservation and restoration are essential components of others water body management. Bangladesh's wetlands provide vital habitats for biodiversity, act as natural water purifiers, and offer flood control. Protecting these areas from encroachment, pollution, and unsustainable exploitation is crucial. Implementing conservation measures, such as establishing protected areas and regulating land-use practices, can help maintain the ecological balance of wetlands. Efforts to control water pollution play a pivotal role in open water body management. Industrial discharges, agricultural runoff, and untreated sewage can serious threats to water quality. Strict enforcement of pollution control regulations, establishment of wastewater treatment facilities, and promotion of eco-friendly agricultural practices are essential to prevent degradation of others open water bodies. Local peoples participations and community stakeholder's involvement is another key aspect to manage open water body. Engaging local communities in the sustainable management of open water bodies ensures that their needs are considered, and traditional knowledge is leveraged (Chief *et al.*, 2016). Community-based initiatives, such as participatory fisheries management and eco-tourism, can provide economic incentives for conservation while empowering local residents. Investing in infrastructure for sustainable navigation and transportation on rivers is also important. Moreover, balancing the needs of transportation with ecological preservation requires well-designed navigation channels and regulations to prevent excessive dredging and habitat destruction. Moreover, a holistic approach to others open water body management in Bangladesh involves integrated water resource management, wetland conservation, pollution control, community engagement and sustainable navigation infrastructure. Furthermore, in government initiatives these options, Bangladesh can safeguard its water bodies for current and future generations for sustainable use of long term purposes that can help for local and urban people for get better water sources. Different water sources should be carefully managed my proper initiatives which are encouraged to people sustainable use of water.



Fig. 1: Watershed pollution due to anthropogenic activities (picture sources from internet)

3.2. Challenges in Watershed Management

Bangladesh faces challenges in watershed management, including deforestation, soil erosion, and inadequate water retention (Narendra *et al.*, 2021). Rapid urbanization and agricultural expansion contribute to increased runoff and decreased groundwater recharge. Pollution from industrial and agricultural activities further degrades water quality (Alaqarbeh *et al.*, 2022; Bouknana *et al.*, 2014). Overcoming these challenges requires integrated approaches, afforestation initiatives, erosion control measures, and community engagement to ensure sustainable watershed management and address the complex interplay of ecological and human factors. There are some challenges of watershed management are as follows:

3.2.1. Fresh water and ground water stress

Bangladesh tackles with significant freshwater and groundwater stress, posing multifaceted challenges in watershed management. The country's has dense population, coupled with agricultural dependence on water resources, amplifies the demand for freshwater within watersheds. Groundwater stress arises from over-extraction due to extensive irrigation practices and inadequate recharge mechanisms. This depletes aquifers, leading to a decline in water tables and threatening the sustainability of groundwater-dependent agriculture. Bangladesh is increasingly suffering different challenges from scarce drinking water sources and health risks that indirectly attributed to climate change impact in the environmental stress (Amit Hasan Anik *et al.*, 2023). Freshwater stress is exacerbated by climate change-induced factors such as altered precipitation patterns, increased temperatures and extreme weather events. These factors impact the availability and distribution of freshwater resources within watersheds, further straining water supply for agriculture, industry and domestic use. Efficient water management strategies are imperative to address these challenges. Implementing sustainable agricultural practices, promoting water-saving technologies and enhancing irrigation efficiency contribute to alleviating

freshwater stress. Additionally, watershed management plans need to incorporate measures for groundwater recharge, afforestation and the protection of water sources to ensure long-term water security (Leah *et al.*, 2021). International technological collaboration and knowledge-sharing are essential, as the impacts of freshwater and groundwater stress extend beyond national borders. By adopting holistic and adaptive approaches, Bangladesh can navigate the complexities of managing freshwater and groundwater resources, ensuring resilience in the face of growing demands and changing climatic conditions for future watershed management.

3.2.2. Flood and flash flood impact on watersheds

Floods and flash flood impact on watersheds implies the significant challenges in watershed management in Bangladesh (Akhtar Alam *et al.*, 2021). The country's low-lying topography, coupled with heavy monsoon rains and upstream river flow, leads to recurrent and severe flooding in riverine areas. This inundation disrupts watershed ecosystems, erodes soil, and damages agricultural fields and infrastructure. Managing floods requires a multifaceted approach, including the construction of effective embankments, levees, and flood shelters. However, inadequate maintenance and the sheer scale of the challenge make sustainable flood management a continual struggle. Climate change exacerbates the situation with increased frequency and intensity of extreme weather events. Coordinated efforts in early warning systems, community-based flood preparedness, and adaptive land-use planning are essential. Integrating floodplain management with sustainable agriculture practices and afforestation can mitigate the impacts of flooding, preserving the balance between human needs and ecological resilience in Bangladesh's watershed areas.

3.2.3. Drought and desertification impacts

A drought and desertification impact indicates major significant challenges in watershed management in Bangladesh, impacting water availability for agriculture, drinking purposes and ecosystems services. Climate change exacerbates the frequency and severity of droughts impacts, affecting the already water-stressed regions. Inadequate water storage infrastructure, over-extraction of groundwater, and unsustainable irrigation practices contribute to the vulnerability of watersheds. In addition, addressing drought challenges requires the development of efficient water storage systems, promoting water-saving technologies in agriculture, and implementing sustainable groundwater management practices (Mojid and Mainuddin, 2021). Community involvement is crucial in raising awareness for mass peoples regarding water conservation and adapting agricultural practices to drought-resistant crops. Integrated watershed management plans should consider the unique challenges implies by drought, incorporating measures to enhance water resilience, such as rainwater harvesting and reforestation and manage desertification impact on forest areas. Developing early warning systems and contingency plans helps communities cope with water scarcity during prolonged dry periods, ensuring a balanced approach to watershed management that considers both human needs and environmental sustainability in the context of changing climatic conditions in Bangladesh.

3.2.4. Heavy metal pollution in water bodies

Heavy metal pollution in water bodies presents a significant challenge in watershed management in Bangladesh. Heavy metal pollution in the water bodies has been local and international ecological phenomenon that indicates water stress (Soumya Pandey and Neeta Kumari, 2023). Industrial discharges, agricultural runoff, and improper waste disposal contribute to the contamination of rivers and lakes with heavy metals like chromium, nickel, manganese, mercury, arsenic, lead, and cadmium and others metals that have potential ecological risk to the environment. This poses severe threats to

aquatic ecosystems, sediments pollution and public health as these metals accumulate in the food chain that causes major eco-toxicological issues since they are non-biodegradable, persistent and harmful to the aquatic environment (Mansor *et al.*, 2023). Managing heavy metal pollution requires stringent regulations on industrial and agricultural practices, effective wastewater treatment, and proper disposal of industrial waste and stop leachate discharged the open waste dumping site. The widespread use of agrochemicals further exacerbates the issue, necessitating sustainable agricultural practices to minimize runoff (Akartasse *et al.*, 2022). Furthermore, implementing monitoring systems and regular water quality assessments are essential to identify pollution sources and assess the effectiveness of mitigation measures. Public awareness campaigns can play a role in promoting responsible waste disposal and reducing the use of harmful chemicals. In addition, addressing heavy metal pollution is integral to holistic watershed management, ensuring the sustainability of water resources and safeguarding the health of ecosystems and communities in Bangladesh.

3.2.5. Plastic pollution due to the impacts on watershed

Plastic pollution is a pressing challenge in watershed management in Bangladesh and its severe impact on water and sediments pollution in the terrestrial and aquatic environment (Tariqul *et al.*, 2023). The improper disposal of plastic waste, coupled with inadequate waste management infrastructure, results in the contamination of rivers and water bodies. Micro-plastic debris poses serious threats to aquatic ecosystems, affecting marine life and disrupting the balance of the watershed (Srinidhi Sridharan *et al.*, 2021). Micro-plastics, in particular, have harmful effects on aquatic organisms and can enter the food chain, impacting human health. Tackling plastic pollution requires a comprehensive approach, including strict regulations on plastic use and disposal, improved waste collection and recycling systems, and public awareness campaigns. Community engagement is vital to instill responsible plastic management practices, emphasizing the reduction, reuse, and recycling of plastic materials. In addition, promoting alternative eco-friendly materials and encouraging the adoption of sustainable lifestyles contribute to mitigating the impact of plastic pollution on watershed ecosystems. By addressing plastic pollution, Bangladesh can safeguard its water resources, preserve biodiversity, and promote a healthier environment for both aquatic life and human communities.

3.2.6. Waterborne diseases due to water contamination

Waterborne diseases pose a significant challenge in watershed management in Bangladesh (Aashlesha *et al.*, 2021). Contaminated water sources, often a result of poor sanitation, agricultural runoff, and industrial discharges, contribute to the spread of diseases such as cholera, dysentery, and typhoid. Inadequate wastewater treatment and the lack of proper sanitation facilities exacerbate the problem. Watershed management strategies need to prioritize water quality improvement through the implementation of robust sanitation infrastructure, sewage treatment plants and the enforcement of pollution control measures. Community education on proper hygiene practices, access to clean water, and the importance of sanitation plays a crucial role in preventing waterborne diseases. Integrating health considerations into watershed management plans ensures a holistic approach to addressing the complex interplay of water quality and public health. Collaborative efforts between government agencies, local communities, and healthcare institutions are essential to effectively combat waterborne diseases and create a healthier living environment for the people of Bangladesh (Pieters *et al.*, 2023).

3.2.7. Sewage pollution and inadequate sanitation

Sewage pollution is a critical challenge in watershed management in Bangladesh that mixed with ground and open water body in different seasons and pollutes the environment (Deb *et al.*, 2021; Soheli,

2015). Rapid urbanization and inadequate sanitation infrastructure lead to the discharge of untreated sewage into water bodies, contaminating rivers and lakes. The high population density further strains existing sewage systems, contributing to the deterioration of water quality. Sewage pollution poses health risks, fostering the spread of waterborne diseases and affecting ecosystems. To address this challenge, comprehensive wastewater treatment facilities need to be established to treat urban and industrial effluents before their release into water bodies. Strict enforcement of pollution control regulations is crucial to prevent illegal discharges. Sustainable urban planning that integrates efficient sewage disposal systems and decentralized treatment options can contribute to mitigating sewage pollution. Public awareness campaigns are essential to educate communities about the impact of improper sewage disposal and promote responsible waste management practices. Furthermore, sewage pollution in watershed management plans, Bangladesh can improve water quality, protect ecosystems, and enhance the overall well-being of its population in rural and urban areas.

3.2.8. River erosion impacts on water bodies

River erosion stands as a formidable challenge in watershed management in Bangladesh. The country's intricate network of rivers, including the Ganges and Brahmaputra, experiences frequent erosion, displacing communities and causing the loss of arable land. Unplanned human activities, deforestation, and climate change contribute to the vulnerability of riverbanks. Managing river erosion necessitates strategic interventions such as afforestation along vulnerable areas to stabilize banks and reduce erosion (Saikumar *et al.*, 2023; Prasad *et al.*, 2016). Implementing riverbank protection measures, like the construction of embankments and revetments, helps shield communities and agricultural land from erosion impacts. Moreover, sustainable land-use planning and zoning regulations are crucial to prevent settlements in high-risk erosion zones. Community involvement and relocation strategies are essential components of addressing the human dimensions of river erosion. Integrated approaches that consider both engineering solutions and ecosystem-based measures contribute to a holistic response. Incorporating climate-resilient practices and early warning systems into watershed management plans aids in anticipating and mitigating the impact of river erosion. Collaborative efforts between government agencies, local communities, and environmental organizations are paramount to developing effective strategies that balance human needs with the preservation of river ecosystems in Bangladesh.

3.2.9. Saline water intrusion in coastal areas

Saline water intrusion indicates a significant challenge in watershed management in Bangladesh, particularly in coastal regions (Shammi *et al.*, 2019; Nazmul *et al.*, 2021). Rising sea levels, exacerbated by climate change, intensify the intrusion of saltwater into freshwater sources, impacting both surface water and groundwater. This phenomenon endangers the availability of drinking water and agricultural irrigation, leading to salinity-induced crop loss. Effective watershed management strategies to address saline water intrusion include the implementation of sustainable agricultural practices that are resilient to saltwater, such as cultivating salt-tolerant crops and adopting efficient irrigation methods. Constructing coastal embankments and protective structures can help shield vulnerable areas from saltwater incursion. In addition, promoting the use of alternative freshwater sources, such as rainwater harvesting and the development of community-based desalination facilities, can mitigate the impact of saline water intrusion. Integrated water resource management plans should consider the delicate balance between preserving ecosystems and meeting human needs. Community awareness and capacity-building programs are crucial to empower local residents to adapt to changing conditions and

implement sustainable practices. Collaboration between government agencies, research institutions, and communities is essential to develop and implement comprehensive strategies that address the multifaceted challenges of saline water intrusion in Bangladesh's watershed management.

3.2.10. Water pollution impacts on watersheds

Water pollution is a pressing challenge in watershed management in Bangladesh, impacting the country's surface water bodies, rivers and lakes. Industrial discharges, agricultural runoff, and inadequate sewage treatment contribute to the contamination of water sources with pollutants such as heavy metals, pesticides, and pathogens (Akhtar *et al.*, 2021; Ahmed *et al.*, 2021). This poses serious threats to aquatic ecosystems, public health, and the overall quality of water resources. To address water pollution, effective wastewater treatment facilities are crucial to treat industrial and domestic effluents before discharge into water bodies. Stringent enforcement of pollution control regulations and penalties for non-compliance are essential to deter illegal discharges. Sustainable agricultural practices, including organic farming and reduced chemical usage, contribute to minimizing agricultural runoff (Ashoka Gamage *et al.*, 2023). Community involvement and awareness programs play a key role in preventing water pollution. Educating the public on responsible waste disposal, promoting the use of eco-friendly products, and fostering a sense of environmental stewardship are vital components of a holistic approach to watershed management. Implementing monitoring systems for water quality and establishing early warning systems help identify pollution sources and take timely corrective actions. Collaborative efforts involving government agencies, industries, local communities, and environmental organizations are essential to develop and implement comprehensive strategies that effectively address water pollution in Bangladesh's watershed management.

3.2.11. Impact on climate changes on water resources and associated challenges

Climate change significantly impacts water resources in Bangladesh, posing multifaceted challenges like rising temperatures contribute to the melting of Himalayan glaciers, affecting the flow patterns of major rivers like the Ganges and Brahmaputra (Dimri *et al.*, 2016). This alteration in river dynamics intensifies the frequency and severity of floods and droughts, disrupting water availability and agricultural cycles. Sea-level rise, induced by climate change, exacerbates salinity intrusion into freshwater sources in coastal areas. The summarized model has been employed to build up a scenario the effects of the relative sea level rise on groundwater salinity by 2050 that allowed to identify more affected by the relative sea level rise and increase in salinization of groundwater and the alter volumes of freshwater in coastal areas (Colombani *et al.*, 2016). This intrusion negatively impacts drinking water quality and renders agricultural lands unsuitable for cultivation. Increased frequency of extreme weather events, including cyclones and storm surges, further compounds the vulnerability of water resources. Watershed management faces the challenge of adapting to these changing climatic conditions. Sustainable practices, such as rainwater harvesting, resilient crop choices, and efficient irrigation systems, become imperative. Strengthening coastal defenses, developing climate-resilient infrastructure, and implementing early warning systems are essential components of climate-adaptive watershed management. Community engagement and awareness play a crucial role in building resilience. Educating communities about climate change impacts, promoting sustainable practices, and fostering adaptive strategies empower local residents to cope with the evolving challenges. A coordinated effort involving government initiatives, scientific research and community participation is essential to navigate the complex landscape of climate change impacts on water resources in Bangladesh.

3.2.12. Agriculture activities and irrigation and use of pesticide and fertilizer

Agriculture activities within watershed management in Bangladesh face several challenges that impact both agricultural productivity and environmental sustainability (Sithara *et al.*, 2016). The intricate network of rivers and water bodies is essential for irrigation, but also prone to flooding, posing a continuous risk to crops and livestock. Soil erosion, a common consequence of water runoff in watersheds, negatively affects farmland productivity. Sedimentation in rivers and water bodies, caused by agricultural runoff, further exacerbates the degradation of aquatic ecosystems. Pesticide and fertilizer use in agriculture contribute to water pollution, impacting the quality of both surface and groundwater resources within the watershed. Balancing the need for agricultural inputs with environmental conservation becomes a delicate challenge. The increasing demand for water resources for irrigation conflicts with the needs of other sectors and ecosystems within the watershed. Managing water allocation efficiently and sustainably becomes imperative to prevent over-extraction and maintain ecological balance. Climate change-induced shifts in precipitation patterns and extreme weather events pose additional uncertainties for agricultural planning and production. Developing adaptive strategies, promoting water-efficient farming practices, and integrating climate-smart agriculture into watershed management plans are essential to address these challenges and ensure the long-term sustainability of agriculture in Bangladesh.

3.2.13. Globalization impacts on watershed management

The globalization of watershed management presents a set of challenges that transcend national boundaries and require collaborative solutions. Major watershed management challenge is the interconnectedness of water resources across borders, demanding coordinated efforts to address trans-boundary issues such as water pollution, water scarcity and water-ecosystem degradation. Differing governance structures and policies among countries pose a challenge to harmonizing approaches to watershed management. Coordinating strategies, sharing data, and fostering international cooperation become crucial for effective global watershed management. The increased demand for water resources due to population growth and economic activities intensifies competition and conflicts over trans-boundary water bodies. Balancing the needs of various stakeholders and ensuring equitable access to water resources become complex tasks on a global scale. Global climate change exacerbates the challenges, leading to shifts in precipitation patterns, extreme weather events, and alterations in water availability (Mohammed Dore, 2005). Collaborative efforts are essential to develop adaptive strategies that consider the global impact of climate change on watershed ecosystems. Addressing the globalization of watershed management challenges requires the establishment of international frameworks, agreements, and platforms for information exchange and joint decision-making for both developed and developing countries international level. Promoting sustainable practices, enforcing water quality standards, and fostering a shared sense of responsibility for global water resources are critical components of a successful global watershed management approach.

3.3. Legal Framework Perspectives

The assessment of existing legal frameworks governing watershed management reveals a mixed scenario. While regulations are in place, enforcement mechanisms and coordination among relevant authorities often fall short. The review suggests that a comprehensive and well-coordinated legal framework is essential for ensuring effective watershed management. Legal framework requires strengthening enforcement mechanisms, improving stakeholder collaboration and aligning regulations with contemporary environmental challenges. Strengthening legal frameworks are as follows: 1.

- Amend and update existing legislation to align with contemporary environmental challenges.
2. Strengthen enforcement mechanisms to ensure compliance with watershed management regulations.
3. Establish a unified and well-coordinated legal framework that involves all relevant stakeholders.

Table 1: Relevant Laws, Regulations, Rules and Ordinances

Act/Rule/Law/Ordinance	Key Features	Applicability
Environmental conservation Rules, 2023	National Environmental Quality Standards (NEQS) for ambient air, surface water, groundwater, drinking water, industrial effluents	Activity associated with such environmental issues which are followed to ECR 2023
The Environment Conservation Act, 1995 and amendment in 2010.	Promulgation of standards for quality of water and different purposes; formulation of environmental guidelines relating to control and mitigation of environmental pollution and improvement of the environmental standard	Activity associated with such environmental standard issues on water pollution management.
National Environment Management Action Plan, 1995	Features include the conservation of natural habitats, bio-diversity, energy, sustainable development and improvement of life of all living organisms	Deals mainly with the activities in environmental pollution management that improve the ecosystems
The ground Water Management Ordinance, 1985	The ordinance guide the management of ground water resources and control the ground water pollution	Improve the quality of ground water Management
National 3R (Reduce, Reuse, Recycle) Strategy for Waste Management, 2010	To ensure 3R goal for management waste is achieve elimination of waste disposal on open dumps, rivers, flood plains through control of waste at source and recycling of waste	Applicable as the large-scale organic waste will be produced due to the develop waste generation practices
The National Water Policy, 2000	To safeguard efficient management of water resources with proper development of surface and ground water, availability of water to all concerned and capacity building for water resource management	Applicable as water is being used during construction and operation phase
The National Water Policy, 1999	To ensure protection, restoration and enhancement of water resources that depends on surface and groundwater	Protection of water quality, including regulations concerning industrial effluent; sanitation and potable water, surface water
Bangladesh Delta Plan, 2100	Watershed management is an integrated approach to managing land, water, and other natural resources within a specific geographic area defined by the flow of water.	Comprehensive planning for water resources involves rivers, tributaries, and water bodies within the delta.

3.3.1. Wetland Protection Act, 2000

The Wetland Act, 2000; and Wetland Conservation Act 2000; play a crucial role in maintaining ecological balance by providing habitat for diverse flora and fauna, regulating water flow, and acting as a natural filter for pollutants. Recognizing the significance of wetlands, many countries have implemented laws and regulations to protect these valuable ecosystems. A Wetland Protection Act typically outlines measures for the conservation and sustainable use of wetlands. These measures may include: 1. the act may require the identification and mapping of wetlands to have a clear understanding of their location and extent. 2. It may specify activities that are prohibited in wetland areas, such as drainage, filling, or any other activities that could harm the ecological integrity of the wetlands. 3. The legislation might establish a permitting process for activities that are allowed in wetlands under certain conditions. This process often involves an environmental impact assessment to ensure that proposed activities will not harm the wetland ecosystem. 3. Some wetland protection acts include provisions for establishing buffer zones around wetland areas to minimize the impact of human activities on these ecosystems. 4. The legislation may outline specific conservation measures, such as restoration and rehabilitation programs, to enhance the health and resilience of wetlands. 5. There are usually provisions for regular monitoring of wetland areas to ensure compliance with the law. Enforcement mechanisms and penalties for violations may also be specified.

3.4. Integrated Approach and Community Participation

The review underscores the importance of adopting an integrated approach that considers ecological, social, and economic factors in tandem. Successful watershed management models globally exemplify the efficacy of holistic strategies. Community participation emerges as a linchpin for success, emphasizing the need to empower local communities, enhance awareness, and build capacity to actively engage in sustainable practices. The discussion investigates into the nuances of community participations based approaches, illustrating how they contribute to the overall resilience and success of watershed management initiatives.

3.5. Cross-Cutting Themes

Throughout the discussion, cross-cutting themes such as the importance of data-driven decision-making, the role of technology in enhancing monitoring and evaluation, and the need for adaptive management strategies resonate. The interplay between options, challenges, and legal frameworks is highlighted, emphasizing the interconnected nature of these elements in shaping the effectiveness of watershed management efforts.

3.6. Policy Implications and Future Directions

This section concludes by outlining policy implications derived from the critical review. Recommendations for policymakers include the formulation of comprehensive and adaptive policies, strengthened enforcement mechanisms, and increased investment in local community-based initiatives. Future directions for research are also proposed, underscoring the need for continuous monitoring, evaluation, and the exploration of emerging technologies to address evolving challenges in watershed management and proper sustainable use of water in all aspects in rural and urban areas and minimize the impact of water contamination. In essence, the section synthesizes the findings from the critical review, providing a comprehensive understanding of the current state of watershed management in Bangladesh. The nuanced exploration of options, challenges, and legal framework perspectives lays the groundwork for informed decision-making and future research endeavors in this critical domain (Chan *et al.*, 2016).

4. Recommendations and Conclusion

Develop adaptive management strategies to address dynamic challenges, invest in technology for real-time monitoring, and establish early warning systems. Invest in capacity-building programs for government officials and community leaders involved in watershed management, ensuring proficiency in technology use. Engage in international collaborations for expertise and resources, participating in regional forums to address trans-boundary watershed issues. Encourage an integrated watershed management approach, fostering collaboration among government agencies, NGOs, and local communities to implement holistic strategies. Implement community-based initiatives, educating and empowering local communities to actively participate in decision-making processes for watershed management. Implementing these recommendations will foster a more sustainable and resilient watershed management framework in Bangladesh, addressing environmental concerns while meeting socio-economic needs. In conclusion, this critical review provides a comprehensive overview of watershed management in Bangladesh. It emphasizes the urgency of addressing the challenges posed by population pressure, climate change, and resource depletion. The review advocates for a multi-faceted approach that integrates ecological, social, and economic considerations, with a particular emphasis on community participation. Furthermore, it calls for a reevaluation and enhancement of the legal frameworks governing watershed management to ensure effective regulation and enforcement. This review will contribute valuable insights for policymakers, practitioners and researchers working towards sustainable watershed management in Bangladesh.

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