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Water Resources Management in Bangladesh and Lessons Learned over the Last Century

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Abstract

Bangladesh, one of the world's largest river deltas, is shaped by the confluence of the Ganges, Brahmaputra, and Meghna rivers. Its geographical location downstream of the Himalayan basins forces it to manage approximately 1,211 billion cubic meters (bcm) of water annually through a network of 800 rivers (BWDB, 2024). This presents significant challenges in water management (WM), including flood control, drainage, and combating tidal floods, cyclones, and salinity intrusion, particularly in the coastal zone where 40 million people frequently face disasters. Water management in Bangladesh has a long history, beginning with indigenous practices and evolving over time into state-controlled systems. In the post-1947 period, the Government of Bangladesh implemented a range of water resource management (WRM) initiatives, including large-scale projects, minor irrigation in winter, and small-scale flood control. These efforts were complemented by structural and non-structural measures, such as flood forecasting and warning systems. In the 21st century, the adoption of the National Water Policy (NWPo) and Guidelines for Participatory Water Management (GPWM) integrated stakeholder participation, with SIA, EIA, and EMP becoming mandatory in planning. Bangladesh's recent WRM strategies emphasize participation, resilience, and capacity building, particularly in response to climate change. The Bangladesh Delta Plan 2100 (BDP2100), adopted in 2018, envisions a safe, climate-resilient, and prosperous delta by the end of the century, focusing on sustainable water resource use with minimal environmental impact. This article reviews the evolution of WRM approaches from ancient times through the colonial and modern periods, highlighting key lessons learned and adaptations that contribute to the formulation of the long-term BDP2100. This paper also presents water engineering education in Bangladesh.

Keywords: Water resources, Management, Governance, Climate Change, Environment, Adaptation, BDP2100, Water Education.

1. INTRODUCTION

Bangladesh, one of the world's largest river deltas, is formed by sediments carried by 57 transboundary rivers, primarily the world's three largest rivers—the Ganges, Brahmaputra, and Meghna (GBM)—which transport 1.5 billion tons of sediment annually. The delta is shaped by the confluence of these rivers. Due to its geographical location downstream of the Himalayan basins, Bangladesh is obligated to manage the drainage of approximately 1,211 billion cubic meters (bcm) of water, 87% of which originates from upper riparian sources, as well as the highest volume of sediment. This vast water and sediment flow moves through a 30,000 km river network comprising more than 800 rivers (Bangladesh Water Development Board (BWDB), 2024). Furthermore, the funnel-shaped estuary in the Bay of Bengal contributes to tidal floods, cyclones, and salinity intrusion, particularly affecting the coastal zone (CZ), where approximately 40 million people frequently face environmental disasters. However, 150 protected polders significantly contribute to food security in the region. The delta can be divided into two distinct regions: the Active Delta in the eastern zone, characterized by numerous islands and rich fishery resources, including the iconic Hilsha, and the Moribund Delta in the western region, which is shielded from natural disasters by the Sundarbans. This vast mangrove forest, recognized as a UNESCO World Heritage Site, is home to diverse ecosystems, biodiversity, and the endangered Royal Bengal Tiger. The intricate network of rivers, marshes, and wetlands that shape the delta underscores the critical importance of effective water management (WM). This low-lying nation, situated in the world's largest delta, is endowed with abundant water resources that have both sustained and challenged its population for centuries (Dr. Shamsul Alam, 2018e).

Bangladesh is home to a vast network of rivers, with some estimates suggesting the number exceeds 1,200 (Bangladesh Water Development Board (BWDB), 2024). These rivers, along with their tributaries and distributaries, cover approximately 7% of the nation's total area. While the extensive river system serves as a critical lifeline, it also contributes to frequent flooding. Wetlands and marshes, which cover between 30% to 50% of Bangladesh's land area during the monsoon season, play essential roles in food security, flood regulation, groundwater recharge, and supporting environmental and ecological diversity. Of particular importance is the haor basin in the northeast, a unique ecosystem of bowl-shaped depressions that remain submerged for half the year and perform vital functions in flood control and biodiversity conservation. In addition, the southeastern hilly region, though smaller, provides topographical variation and is home to the country's only hydroelectric project—the Kaptai Dam and reservoir.

Of the 57 transboundary rivers flowing through Bangladesh, 54 originate in India and 3 in Myanmar. This geographical reality has led to complex water-sharing challenges, particularly with India. The dispute over the Ganges waters, marked by the 30-year Ganges Water Treaty (1996), which expires in 2026, and the ongoing negotiations over the Teesta River, highlight the difficulties in managing shared water resources. Several other rivers remain without formal agreements, awaiting negotiation (Government of the People's Republic of Bangladesh, 1996).

Water management (WM) is fundamental to Bangladesh's development and impacts nearly every aspect of the nation's life and economy. It is essential for: (a) Ensuring drinking water supply and sanitation, (b) Controlling floods, drainage, salinity intrusion, pollution, and disaster management, (c) Enhancing agricultural productivity and ensuring food security through dry-season irrigation, (d) Supporting navigation, transportation, and fisheries, (e) Driving industrial development, (f) Preserving the environment, ecosystems, and biodiversity, and (g) Adapting to climate change (CC) and managing natural and anthropogenic changes (NAC), while building resilient infrastructural and non-structural disaster management systems (DMS). Bangladesh is fortunate to have an effective DMS, guided by the Standing Orders on Disaster (SOD), which clearly outlines responsibilities from the head of the government to the lowest administrative units, and has been successfully implemented for many years.

This paper presents few important aspects of water resources management in Bangladesh. It is expected that this would help to formulate or update national water resources management strategies of Bangladesh.

2. WATER RESOURCES MANAGEMENT IN BANGLADESH

2.1 Background

Historically, human settlements have been closely tied to water and natural food sources, which were essential for survival. As populations grew, these natural resources became insufficient, prompting communities to explore new methods for securing water and food. Over time, practices like cultivation and irrigation emerged, necessitating the efficient management of water resources. These early efforts laid the foundation for what is now known as water resources management (Kausher, 2017).

India, including the Bengal Province, has a history of water management spanning over 3,000 years due to its distinctive climate, characterized by intense monsoons followed by prolonged droughts. Rainfall is concentrated in just a few months, and is often uncertain and uneven, making agriculture in Bengal highly dependent on irrigation (Ali, 2002). Over the centuries, this dependence led to the development of various water control and distribution technologies, which evolved through different eras—from pre-colonial to colonial and post-colonial regimes (Naz & Subramanian, 2010).

Water management in India, including Bengal, has historically been shaped by socio-economic, political, and ecological factors, influencing water policies across diverse social groups (Naz & Subramanian, 2010). The Arthashastra, an ancient text written by Kautilya in the 3rd century B.C., provides detailed insights into water management during the Mauryan Empire. It highlights that local communities had a thorough understanding of rainfall patterns, soil types, and irrigation techniques tailored to their specific ecological contexts. The Arthashastra also mentions the state's role in supporting and promoting small-scale water harvesting structures (Agarwal & Narain, 1997).

2.2 Water Resources in Bangladesh

Bangladesh's water resources consist of internally generated surface water (rainfall and runoff), groundwater, and transboundary inflows. According to the Food and Agriculture Organization of the United Nations (FAO) (2013), the total annual renewable water resources are approximately 1,211 bcm, with surface water (SW) contributing 1,190 bcm and groundwater (GW) 21 bcm. Internal renewable resources are estimated at 105 bcm (SW: 84 bcm, GW: 21 bcm), while externally renewable resources total 1,106 bcm, the vast majority from transboundary river flows, and 0.03 bcm from groundwater. Water resources are essential for Bangladesh's sustainable development. The National Sustainable Development Strategy (NSDS) (Bangladesh Planning Commission, 2013) identifies five priority sectors: agriculture, industry, energy, transport, and human resource development. Human resource development, in particular, is strongly influenced by the availability and quality of water resources, as well as access to safe sanitation, with implications for poverty, gender, and health (Dr. Shamsul Alam, 2018e).

Bangladesh's SW resources include major rivers, regional rivers, transboundary inflows, and an extensive network of wetlands. However, water quality is a growing concern, as 32 rivers and many wetlands face serious environmental risks from pollution, encroachment, and the disconnection between wetlands and the river system. GW, the primary source for irrigation, drinking water, and industrial use, is threatened by arsenic contamination of shallow aquifers, saltwater intrusion, industrial pollution, and declining groundwater tables due to overexploitation (Kausher, 2017).

2.3 Water Vulnerability and Challenges

Water-related vulnerabilities and challenges in Bangladesh are both natural and human-induced. These include alternating floods and droughts, cyclones, increasing water demand from a growing population, large-scale sedimentation and riverbank erosion, rapid urbanization, industrialization, global warming, and deforestation. An emerging challenge is the degradation of surface and groundwater quality, the decline of natural wetlands, and the difficulty in maintaining healthy aquatic ecosystems. Climate change, upstream water development and abstraction, and the lack of sustainable financing for water infrastructure operation and maintenance further aggravate these issues (Local Government Engineering Department (LGED), 2015). With its extensive river systems, low-lying deltaic landforms, receiving maximum runoff from the Hindu Kush Himalayan (HKH) region and proximity to the Bay of Bengal, Bangladesh is particularly vulnerable to climate-related disasters. The country is already experiencing rising temperatures, shifts in rainfall patterns, accelerated sea level rise, salinity intrusion, and increased disaster intensity—all of which are expected to worsen in the future (Gain, 2017).

3. WATER RESOURCES DEVELOPMENT IN BANGLADESH

3.1 Water Resources Development in the Late Colonial Era (1920-1947)

Irrigation practices in Bengal were historically advanced compared to other regions. Approximately 3,000 years ago, Bengal's rulers implemented a method known as "overflow irrigation" (Ali, 2002). This traditional system involved constructing embankments along flood-prone rivers to serve both irrigation and flood protection purposes. When water was needed for irrigation, peasants would breach the embankments, diverting water, a practice described by Willcocks (1984). This system continued until around 1200 AD, which Willcocks referred to as the Ancient Era (Willcocks, 1930).

According to Ali (2002) key features of the overflow irrigation system included:

- Broad and shallow canals that carried floodwaters rich in clay and free of coarse sand.
- Long, parallel canals spaced appropriately to maximize irrigation coverage.
- Irrigation was managed through cuts in the canal banks, which were sealed once the floodwaters subsided.

Once the canals were breached, local boards, representing the rulers, took responsibility for distributing water. These boards, in collaboration with local peasants, ensured that every field received water systematically and efficiently. The management of overflow irrigation was highly organized and well-planned, reflecting the advanced water resource practices of the time.

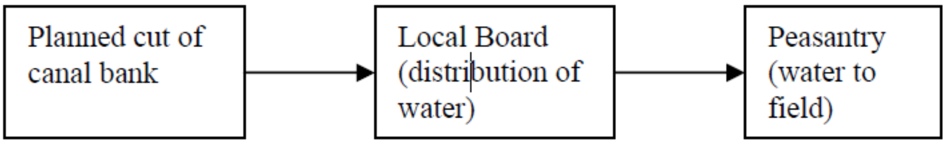

Figure 1: Ancient Period Overflow Irrigation Management System.

Figure 1 illustrates the traditional overflow irrigation system practiced in Bengal during the ancient period. The system efficiently distributed floodwaters for agricultural purposes, ensuring both irrigation and flood control.

With the introduction of the Zamindari Settlement in Bengal under Lord Cornwallis in 1793, a Permanent Settlement was established. This policy made zamindars the proprietors of their land in exchange for a fixed annual rent, leaving them autonomous in managing their estates. Colonial rule fundamentally redefined property relationships, assuming ownership over resources like land, water, forests, and minerals without fully understanding local irrigation systems. Additionally, the imposition of various taxes—such as land, water, well, and canal taxes—placed a heavy financial burden on local communities.

Under the zamindari system, intermediaries (zamindars) collected land revenue from farmers, with the government retaining 10/11ths of the total revenue, leaving only a fraction for the zamindars. The Permanent Settlement introduced a new zamindari system that commodified water resources, driven by the colonial state's focus on maximizing revenue from rivers (Worster, 1992). Colonial engineers, unfamiliar with local practices, failed to grasp the benefits of overflow irrigation and the dual role of zamindari embankments in irrigation and flood mitigation. In 1855, the colonial administration prohibited the breaching of embankments and brought them under direct control. However, new embankments constructed by the British for railways, roads, and flood control led to unintended consequences, such as waterlogging, drainage issues, and loss of irrigation benefits (Naz & Subramanian, 2010).

When agricultural production in Bengal began declining rapidly, the British Government enlisted William Willcocks, a British irrigation expert, to provide advice. In a series of lectures in the 1920s, Willcocks proposed reviving the ancient flood irrigation system of Bengal (Willcocks, 1930). Despite these efforts, food production in Bengal continued to decline. Scholars attribute this to an unbalanced focus on irrigation development in regions like Punjab and Madras, neglecting Bengal, which contributed to the Bengal Famine of 1942-43, resulting in the deaths of four million people (Naz & Subramanian, 2010).

During the early 20th century, the British introduced more systematic water management strategies, including:

- **Permanent Embankments**: Constructed along major rivers in the 1920s and 1930s to protect agricultural lands and settlements (Naz & Subramanian, 2010).
- **Irrigation Schemes**: Small-scale canal irrigation projects were initiated in northern Bengal to improve agricultural productivity.
- **River Surveys**: Comprehensive surveys of major rivers were conducted to gather hydrological data for planning interventions, including surveys from 1930 at Bheramara Ganges and Bahadurabad Jamuna.

These approaches had a positive impact on WRD, protecting agriculture from floods and boosting productivity, though the benefits were unevenly distributed. Improved flood protection came at a cost, as the disruption of natural flood cycles affected soil fertility and ecosystems in some areas. River transport remained vital for communication, with some improvements in navigation.

Lessons Learned:

Indigenous overflow irrigation, practiced since 300 BC, remained the principal WRD system until the 19th century. In the early 20th century, modern approaches such as permanent embankments, dredging, canal construction, and irrigation schemes marked the beginning of modern WRD in Bengal, now Bangladesh.

3.2 Water Resources Development in the Post-Colonial Era - The Pakistan Era (1947-1971)

With the formation of East Pakistan in 1947, the modern period of water resource management began. Due to prolonged neglect by British rulers, the region's water management systems had severely deteriorated, leading to frequent floods and crop damage. Before 1947, no government-led national water development policies or programs existed.

In response to the devastating floods of 1954 and 1955, the government formed a flood commission in December 1955 to address the issue. A UN Technical Assistance Mission, known as the Krug Mission, was commissioned in 1956 to explore water resource development in East Pakistan. The Krug Mission submitted its report in 1957, highlighting the severe flooding challenges (United Nations, 1957). Based on the UN's recommendations, the East Pakistan Water and Power Development Authority (EPWAPDA) was established in 1959 to coordinate the development of water and power resources in the region. In 1964, EPWAPDA, with the assistance of International Engineering Company Inc. (IECO), created a 20-year Master Plan for water resource development, focusing on large-scale flood control, drainage, and irrigation (FCDI) projects, including the Coastal Embankment Project (CEP), the Ganges-Kobadak Project (GK), and the Karnaphuli Irrigation Project (KIP) (EPWAPDA, 1964). These efforts aimed to enhance agricultural productivity and marked the beginning of an integrated flood control and water resource management approach in the country (Ali, 2002).

At the time, water sector development was almost entirely geared toward increasing agricultural production, aiming for national self-sufficiency, with a strong focus on FCDI projects (DFID, Water Resources Management in Bangladesh). While irrigation was considered within flood-protected areas, flood control through dykes and polders was seen as the primary means to boost agricultural yields (Ali, 2002).

The initial projects under the 1964 Master Plan delivered immediate results, significantly improving food security. However, after two decades, evaluations showed a decline in the performance of large-scale projects, particularly in terms of operations and maintenance (O&M) (Kausher, 2014).

The Coastal Embankment Project (CEP), initiated by EPWAPDA in the early 1960s, aimed to construct 92 polders covering 1.01 million hectares under the Grow More Food Program, which was completed by 1971. These projects were entirely state-led, with Embankment Kashia and Gate Kalashi appointed for O&M under state ownership (Kausher, 2018).

3.3 The Modern Era an Era of Community-Based Management and Along With Groundwater Revolution 1972 Onward

(i) Land and Water Resources Sector Study (World Bank), 1972

Following Bangladesh’s independence in December 1971, the Government of Bangladesh (GoB) restructured the East Pakistan Water and Power Development Authority (EPWAPDA), creating two distinct bodies: the Bangladesh Water Development Board (BWDB) and the Bangladesh Power Development Board (BPDB) (P.O. 59 of 1972). This separation aimed to accelerate water and power development projects. To address transboundary water sharing issues, the Joint Rivers Commission (JRC) was established on March 19, 1972, in Dhaka, as per the joint declaration of the Prime Ministers of Bangladesh and India, Sheikh Mujibur Rahman and Indira Gandhi. The JRC became operational in June 1972, with a counterpart commission in India based in New Delhi.

In its early years, the newly independent nation prioritized water resource development (WRD) and food security. The International Bank for Reconstruction and Development (IBRD) conducted a review of the water sector and presented its findings in the 1972 Land and Water Sector Study. The report recommended both structural and non-structural interventions for WRD, emphasizing flood forecasting and warning (FFW) services and flood-proofing through the construction of safe shelters such as Mujib Killas and multipurpose flood shelters near vulnerable areas. Additionally, the BWDB, established in 1972, adopted strategies for minor irrigation during the winter using low-lift pumps (LLP) and tube wells, alongside small-scale flood control projects in shallow-flooded areas. This marked a significant shift from the previous strategy, implemented in 1964. Projects like EIP, LRP, DDP, and SRP aimed to boost agricultural production, generate employment for unskilled labour during off-seasons, and involve beneficiaries in project planning, operation, and maintenance through Landless Contracting Societies (LCS). This participatory approach, incorporated into the Guidelines for Participatory Water Management (GPWM), had a positive impact on both productivity and governance.

(ii) Creation of New Planning and Research Organizations for Water Resource Development (WRD)

In the 1980s, the focus shifted from a mono-sectoral (agricultural) approach to a multi-sectoral strategy. The Master Planning Organization (MPO) was established in 1980, followed by the Water Resources Planning Organization (WARPO) in 1991. These organizations were responsible for national water planning, producing key documents such as NWP-I (1986), the Flood Action Plan (FAP, 1989), NWP-II (1991), and the Bangladesh Water and Flood Management Strategy (WFMS, 1995). The Flood Plan Coordination Organization (FPCO), created in 1990, conducted numerous studies before merging with WARPO in 1999. These plans provided extensive data, utilized various planning models, and informed public sector strategies, many of which were adopted by the government and supported by international donors (FPCO, BWFMS, 1995).

(iii) Attention to Policy, Plans, Guidelines, and Acts for Improved Water Resource Development (WRD)

Key milestones in Bangladesh's water resource management include the National Water Policy (NWPo), adopted in 1999, and the National Water Management Plan (NWMP), formulated in 2004. The Coastal Zone Policy (CZP) followed in 2005, alongside the GPWM in 2001. Prime Minister Sheikh Hasina recognized the National Water Policy as a bold step toward good governance in Bangladesh (MoWR, 1999). The NWPo emphasizes comprehensive, integrated, and equitable water management, with stakeholder participation at every stage of the project cycle.

The Participatory Water Management Rules (PWMR), established in 2014, provided a framework for implementing the national policies effectively. Mandatory Socio-economic Impact Assessments (SIA), Environmental Impact Assessments (EIA), and Environmental Management Plans (EMP) have been integrated into planning practices. The NWMP (2004) outlined 84 programs under 8 clusters for sustainable WRM across the country. The Haor Master Plan (2013) addressed WRM in the northeastern region, while the National Water Act (2013) further strengthened the application of policies, plans, and guidelines for water governance.

4. CHALLENGES, OPPORTUNITIES, AND FUTURE DIRECTION

Challenges:
As one of the world's most prominent deltas, formed at the convergence of the GBM rivers, Bangladesh faces numerous complex challenges. Its downstream position within the basins of these sediment-heavy rivers places immense pressure on its already limited land and water resources. The country must navigate critical issues such as water security, food production, and land degradation, while also being highly susceptible to natural disasters, including floods, riverbank erosion, cyclones, and droughts. These challenges stem from both natural factors and human activities. Nevertheless, Bangladesh has consistently demonstrated resilience, effectively adapting to shifting climatic conditions and leveraging the rich natural resources that its deltaic landscape provides (Dr. Shamsul Alam, 2018d).

Opportunities:
Bangladesh's fertile soil, combined with abundant water resources, offers significant opportunities for agriculture. By leveraging high-yield variety (HYV) seed-fertilizer irrigation technologies, Bangladesh has intensified land cultivation and expanded food production, particularly rice. Rice production has risen from 12 million tons in 1973 to 35.2 million tons in 2017, achieving food self-sufficiency and prospects for rice exports. This achievement is notable given the multiple risks posed by deltaic challenges and climate change (Alam, 2018d, 2018e). Additionally, Bangladesh's extensive river network presents a comparative advantage in inland water transport, providing an eco-friendly and cost-effective option for passenger and cargo transport. Inland waterways also support fisheries, a crucial source of income and protein, particularly for the rural poor. Inland water transport is a key source of rural employment, and freshwater fisheries remain vital for national food security (Alam, 2018b; General Economics Division (GED), 2018).

Achievements:
Bangladesh has made substantial progress in WRD through various initiatives, including flood and irrigation management via FCD and FCDI projects, coastal zone management through impoldering, and land reclamation. Other notable achievements include flood-proofing with multipurpose flood shelters, Haor management via submersible embankments to protect against flash floods, small-scale water resource development, and river management through dredging and erosion control. Urban flood protection and pollution control have also been key areas of progress. The introduction of Participatory Water Management has added a new dimension to improved water governance.

Table 1: Summary of Physical Achievements in WRD as of June 30, 2023 (Bangladesh Water Development Board (BWDB), 2023)

Item	Achievement
Completed Projects	970 nos.
Land reclamation, development & settlement	1086.62 sq km (49,578 acres land distributed to 39528 landless HH, benefiting 12,57,487 poor people)
IFCD ensured Area	71.61 lac ha (WDB 66.36 lac ha +LGED=5.25 lac ha)
Irrigated Area	70.27 lac ha, 61.19% of CA (BADC=5.55, BMDA=5.24, BWDB=16.49, Others=42.98)
Embankment	16631 km (Coastal-5816km, Submergible=2828km, others=7967km
Flood wall	21514km.
Irrigation/Drainage canal	9857km (Irrig. 5355km, Drang. 4502km)
Hydraulic Structure	15966 nos.
River maintenance	5050km (Re-ex=589km, dredging=1461km)
Cyclone Center	3500 nos.

Table 1 summarizes the key physical achievements in WRD in Bangladesh as of June 30, 2023. These accomplishments span a variety of sectors, including land reclamation, irrigation, embankment construction, flood management, and infrastructure development. The table reflects the extensive efforts undertaken to enhance water management, agriculture, and disaster resilience, benefiting millions across the country.

Transboundary Water Sharing

A significant milestone in Indo-Bangladesh relations was the signing of the Ganges Water Sharing Treaty on December 12, 1996, by the Prime Ministers of India and Bangladesh. This treaty governs the distribution of Ganges waters and remains in force for a period of thirty years, renewable by mutual agreement. A Joint Committee has been established to monitor the implementation of the treaty. Ongoing discussions between India and Bangladesh focus on sharing the waters of the Teesta and Feni rivers, alongside six other common rivers: Manu, Muhuri, Khowai, Gumti, Jaldhaka, and Torsa. The Government of India is working towards a water-sharing agreement that is acceptable to all parties and protects the interests of all stakeholders. During the monsoon season, a flood forecasting data transmission system is in place for major rivers, including the Ganges, Teesta, Brahmaputra, and Barak. This transmission from India to Bangladesh enables Bangladesh to relocate populations affected by floods to safer areas (Bangladesh Water Development Board (BWDB), 2024).

Flood Forecasting and Warning Services (Ffws)

FFWS, initiated by the Bangladesh Water Development Board (BWDB) in 1972, began with only eight stations under the Flood Forecasting and Warning Center (FFWC) (ffwc.gov.bd). Since then, the system has evolved significantly, incorporating more rivers and stations, adopting advanced technologies for data collection, processing, and forecasting, and extending the forecast time scale. Data is collected through various means, including mobile telephone communication, voice data via HF wireless networks, satellite imagery from sources such as GMS, NOAA, and IMD, as well as online data from the Bangladesh Meteorological Department (BMD) and regional agencies like RIMES. Additionally, upper catchment water level data from 11 stations across 8 rivers in India is provided by the Central Water Commission (CWC), India.

Currently, flood forecasts are generated using advanced technology for 61 locations across 35 rivers and 4 specific project sites, with predictions extending up to five days. The FFWS covers 82,000 sq. km of area, encompassing 216 catchments and 7,270 km of river length. Services include:

(i) Daily monsoon bulletins and river situation reports,

(ii) Deterministic river water level forecasts for 24, 48, 72, 96, and 120 hours at 54 locations,

(iii) Probabilistic 10-day water level forecasts (for select locations and on an experimental basis) at 38 sites,

(iv) Structure-based forecasts at 4 locations,

(v) Warning messages, special flood situation reports, flood forecast maps, and Interactive Voice Response (IVR) services through mobile (via the number 10941) (Bangladesh Water Development Board (BWDB), 2024).

Flood Proofing

One of the major interventions in flood management is the construction of 3,500 multipurpose cyclone centers (MPCS), which can shelter 70% to 80% of coastal cyclone-affected populations and their livestock. In addition, hundreds of Mujib Killas, built in the early 1970s, continue to provide shelter for livestock during disasters. The construction of MPCS is ongoing under various projects. The Department of Disaster Management (DDM) delivers early warnings through the Cyclone Preparedness Program (CPP) of the Red Crescent Society. This program facilitates pre-disaster preparations, post-disaster recovery services, and effective evacuation of people, livestock, and assets in accordance with the Standing Orders on Disaster (SOD). The maintenance of these critical infrastructures remains a priority (Bangladesh Water Development Board (BWDB), 2024; Hossain, 2003).

5. LESSONS LEARNED

Lessons from the Late Colonial Period

The indigenous practice of "overflow irrigation," introduced by peasants, served as the principal method of water resource development (WRD) from 300 BC until the late 19th century. However, in the early 20th century, the introduction of permanent embankments, dredging, canal digging, and formal irrigation schemes marked the beginning of modern WRD in Bengal, now Bangladesh.

The colonial officials' misunderstanding and disregard for the benefits of overflow irrigation, as well as the prohibition of breaching embankments in 1855, were significant missteps. These actions caused a rapid decline in agricultural productivity, eventually leading to the Bengal Famine of 1942, during which four million people perished from starvation (Agarwal & Narain, 1997; Naz & Subramanian, 2010).

Systematic Approaches in the 1920s

Based on the recommendations of Wilcox in the 1920s, the British colonial administration adopted more systematic WM practices. This included permanent embankments, small-scale irrigation schemes, and comprehensive river surveys. These initiatives protected agricultural lands, enhanced productivity, and enabled better long-term planning (Naz & Subramanian, 2010).

Post-Liberation Water Management

After Bangladesh’s liberation, the 1972 Land and Water Resources Sector Study (World Bank) led to the creation of new organizations and the introduction of policies, plans, and guidelines for further WRD improvements. These efforts, combined with non-structural interventions, food-for-work (FFW) services, and flood-proofing measures such as earthen killas and multipurpose flood shelters, revolutionized disaster safety strategies. This comprehensive approach drastically reduced the death toll from floods, cyclones, tidal surges, and even tsunamis to near zero.

Lessons for the Future

In the Upper Sweet Water Zones:

Globally, the opportunities for new land and water development projects are diminishing due to financial constraints and environmental concerns, and Bangladesh faces similar challenges. Significant investments have already been made in this sector over time, but the returns from these schemes have been unsatisfactory. The government is making considerable efforts to improve the performance of existing projects; however, it continues to fall short in identifying effective approaches that address the complexities of water management.

In the Coastal Zone (CZ) and Estuary:

It is important to recognize that the hydro-topographical conditions—such as freshwater availability and tidal flushing—are dynamic and subject to changes driven by both natural processes (e.g., sea level rise and land subsidence) and human interventions (e.g., drainage obstructions). Land suitability zoning indicates the potential for future development under both current and projected conditions. This zoning analysis could be extended to other flood control and drainage (FCD) areas to help resolve water management conflicts among different land users and professional groups. However, future conditions may require new and innovative interventions to adapt to these evolving challenges.

Future Direction:

Bangladesh faces significant challenges as a deltaic nation, particularly in managing its limited land and water resources. Key issues include water safety, food security, and land degradation, alongside vulnerability to natural disasters such as floods, cyclones, and droughts. These challenges, both natural and man-made, are compounded by the country's downstream location. However, Bangladesh's resilience and ability to adapt to changing climatic and economic conditions, along with its rich natural resources, offer opportunities for sustainable development (Dr. Shamsul Alam, 2018e; General Economics Division (GED), 2018).

6. THE BANGLADESH DELTA PLAN 2100 (BDP 2100)

The BDP 2100 is a comprehensive, long-term, and water-centric strategy, drawing from past experiences and lessons learned in WRM. It follows an interactive planning process consisting of three key steps: i) conducting baseline studies, ii) developing a delta vision, goals, and management framework, and iii) formulating an adaptive strategy. These steps were supported by extensive nationwide consultations, resulting in a robust investment plan.

The BDP 2100 incorporates global experiences while tailoring its approach to Bangladesh's unique challenges, particularly its tradition of resilience in water management. In essence, the plan seeks to address "How to foster socio-economic development under uncertain, changing conditions, especially concerning climate change and transboundary water resources?" It integrates strategies across various sectors and themes into a single, unified vision for the country's water management.

The long-term vision of BDP 2100 is to achieve a safe, climate-resilient, and prosperous delta by the end of the 21st century. The plan outlines short- and medium-term goals, including achieving upper-middle-income status and eradicating extreme poverty by 2030, with a longer-term aim of becoming a prosperous nation by 2041. The overarching challenge remains the sustainable management of water, ecology, and land resources in the context of natural disasters and climate change (Dr. Shamsul Alam, 2018a, 2018b, 2018c, 2018f).

Moving forward, WRM planning must incorporate climate change considerations, emphasizing adaptation and resilience. The Sustainable Development Goals (SDGs), Bangladesh Vision 2021, and Bangladesh Vision 2041 will serve as key frameworks guiding future WRM strategies. The ongoing BDP 2100 aims to address gaps in integration, enhance stakeholder and community participation, improve coordination between agencies and communities, and build the capacity of implementing bodies. It also focuses on optimizing the use of scarce water resources while minimizing environmental impacts.

7. WATER EDUCATION IN BANGLADESH

Water problems in Bangladesh is complex and has been well researched (e.g., Rahman et al., 2022). Water resources development and management in any country need skilled manpower. In Bangladesh, this sector is mainly managed by engineers and scientists; however, generalists from civil services often lead the ministry of water resources. Civil engineers and water resources engineers generally play the major role in water resources development sector, while mechanical engineers also have a significant role in maintaining equipment used in water sector. Geologists generally help in groundwater exploration and development. General science graduates also serve as technical officers who assist engineers. These engineers are educated in engineering colleges and universities in Bangladesh. The engineering technologists (known as diploma engineers) are educated in Polytechnique institutes who also work in water development sector.

The establishment of Ahsanullah Engineering College in 1948 played a bigger role in training engineers who played a major role in Water and Power Development Authority (WAPDA) to lead the water development projects in Bangladesh during 1950s. East Pakistan University of Engineering and Technology was established in 1962, which became Bangladesh University of Engineering and Technology (BUET) in 1971. BUET established water resources engineering department, which trains water engineers in Bangladesh. Rajshahi Engineering College was established in 1964 (in 2003 it was upgraded to Rajshahi University of Engineering & Technology (RUET)). Chittagong Engineering College was established in 1968, which was upgraded to Chittagong University of Engineering & Technology (CUET) in 2003. Khulna University of Engineering and Technology (KUET) was established in in 1967 as Khulna Engineering College. Agricultural engineering course at Bangladesh Agricultural University produces engineers who also work in water development sector. More recently, private and new public technological universities are producing engineers who are also working in water development sectors. Water engineers in Bangladesh often get in-service training and many of them receive diploma, Masters and PhD degrees from local and international universities such as Asian University of Technology (AIT) and Delft University of Technology. Currently, Bangladesh has a skilled manpower in water sectors who contribute to Bangladesh and international water management.

8. CONCLUSION

Bangladesh has a rich history of water management, transitioning from traditional methods to incorporating modern knowledge, technologies, and policies. While extensive water management infrastructure has been established, the country continues to face significant challenges, such as inadequate funding for O&M, salinization, waterlogging, flooding, and declining water quality. Greater emphasis on community participation through Water Management Organizations (WMOs) and collaboration with the private sector via Public-Private Partnerships (PPP) is essential for ensuring the sustainability of water resource management.

To support economic growth, environmental sustainability, and resilient ecosystems, integrated water management practices, land zoning, and environmentally conscious agriculture must be prioritized. The current early warning systems and cyclone shelters, though widely available, are often inaccessible to many during times of need due to poor evacuation routes. Expanding shelter infrastructure and improving access is critical for disaster preparedness. Additionally, challenges such as groundwater depletion, surface water pollution, increased salinity in coastal areas, and ineffective O&M in water supply systems must be addressed comprehensively.

The BDP2100 provides a strategic blueprint for addressing these issues. It recommends:

- Following the Integrated Water Resources Management (IWRM) framework for optimal water allocation.
- Encourage research and development in designing appropriate adaptive activities to manage climate change impacts on and through the water sector.
- Encouraging research to develop climate-resilient crops and improve water-use efficiency.
- Focusing on surface water irrigation while reducing groundwater dependency.
- Enhancing irrigation efficiency by minimizing water loss through better technologies and management.
- Promoting rainwater harvesting and local storage for use in dry seasons.
- Providing farmers with better knowledge of water management technologies.
- Continuing to monitor water resources, climate change, and ecosystems, particularly in sensitive areas, to inform adaptive and resilient planning.

By implementing these strategies, Bangladesh can ensure a sustainable and resilient future in water resources management, safeguarding both its people and environment. Bangladesh has a strong water education system, which needs to be strengthened by more international collaborations. Bangladesh also needs to standardise its water design practice by developing a guideline like Australian Rainfall and Runoff to meet challenges posed by climate change.

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