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Research Article

A Review on Water Security in Dhaka City, Bangladesh: Calling for Ensuring Sustainability

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Abstract

Dhaka is currently facing a number of significant challenges, and one of them is the protection of water resources. The city is experiencing rapid depletion of groundwater as well as substantial pollution of its surface water. This article aims to highlight a review of the literature on the challenges of water security in Dhaka. The sustainability issues of water resources were elaborated in terms of management, quantity, and quality aspects. Having reviewed, it has been found that groundwater is depleting drastically over the years, which may have environmental, economic, and social consequences in the near future. Due to the rapid depletion of groundwater, land subsidence, increased cost of groundwater abstraction, shortage of drinking water, and social unrest were categorized as high-risk factors. In addition, the water quality of the surrounding rivers has been mostly categorized as 'poor' and 'very poor' according to the Weighted Arithmetic Index (WAI) and the Canadian Council of Ministers of the Environment (CCME) techniques. Therefore, ensuring the sustainability of water resources is an urgent call.

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Introduction

Globally, the Sustainable Development Goal (SDG) 6 seeks to guarantee universal access to clean water and proper sanitation while also promoting the sustainable use and conservation of these resources [1]. This goal not only gives priority to the supply of drinking water, sanitation, and hygiene services but also highlights the sustainable management of water resources on a worldwide scale. The goal encompasses crucial progress in the areas of water accessibility, reduction of pollution, cross-boundary water management, improvement of water use efficiency, and reduction of unsustainable water withdrawals [2].

Bangladesh is one of the developing nations that suffers from major water resource issues as a result of improper water resource management [3]. Urban water management is facing growing challenges due to significant transformations, such as climate change, population expansion, environmental degradation, and the processes of globalization and development. These issues are particularly severe in megacities like Dhaka, Bangladesh. The combination of urbanization, migration from rural to urban areas, and escalating pollution exerts significant pressure on the adjacent water bodies [4]. Dhaka, the capital of Bangladesh, is one of the world's fastest-growing cities and a hub for economic growth and urbanization [5]. As the city gains recognition as a hub for several industries, it is gradually losing its natural resources [6]. Rapid urbanization leads to water pollution and has the potential to impede sustainable development [7]. The demand for water in Dhaka is surprisingly rising because of the rapidly growing population [8]. Striking a balance between the city's water supplies and the needs of its rapidly increasing population of over 20 million citizens is a challenging task [9]. Urban areas' waste and pollution flow into nearby rivers and water bodies, polluting the water and groundwater aquifers, which negatively impacts the water ecosystem [10].

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To be more precise, Dhaka relies heavily on groundwater [9] and there has been extensive groundwater extraction to meet the growing demand for drinking water among its inhabitants [11]. The situation of groundwater extraction is strongly linked to the urbanization, and city expansion [12]. The overall groundwater quality in the aquifers is satisfactory [13], but the overuse of Dhaka's groundwater presents significant threats to both its quantity and quality because of the resource's rapid depletion [14]. On the other hand, Dhaka is geographically surrounded by four significant rivers, namely the Buriganga, Dhaleshwari, Shitalakhya, and Turag. These water bodies are extremely contaminated due to the outflow of untreated home sewage and a significant amount of industrial effluent from over 7,000 factories. As a consequence, the urban rivers are plagued by the presence of black and filthy water, with untreated sewage contributing 98% of the total pollution [15]. The Buriganga, Turag, and Balu Rivers are highly contaminated. Subsequently, the observed water quality index (WQI) values indicated a significant decline in the water quality of the rivers, rendering them unsuitable for drinking purposes [16]. The phenomenon of increased population and migration is anticipated to exert a notable impact on urban water consumption [14]. Overall, this paper aims to highlight the challenges of water security in Dhaka, Bangladesh, based on a review of relevant topics. The sustainability issues of water resources in Dhaka were further elaborated in terms of management, quantity, and quality aspects.

Case city: Dhaka, Bangladesh

Dhaka is experiencing a rapid depletion of groundwater resources and widespread surface water pollution, which has become a concern for ensuring sustainable water supply. The practice of over-extraction of groundwater has presented significant challenges to the resource's overall sustainability, as the rate of groundwater extraction in Dhaka is 25% greater than the rate of natural recharge [11, 17]. On the other hand, over the past three decades, as shown in Figure 1, the water quality of the surrounding rivers in Dhaka (i.e., Dhaleshwari, Shitalakhya, Turag, and Buriganga Rivers) has deteriorated significantly due to anthropogenic activities [18]. With regard to water quantity, surface water source availability in Dhaka is decreasing significantly [19].

Sustainability assessment

To assess the pertinent sustainability issues of water resources in Dhaka city, the study applied the following sustainability assessment by considering water quality and quantity, and water resources management aspects (Figure 2). All dimensions of potential social, economic, and environmental impacts due to water insecurity and the WQI of surface water in and around Dhaka City were critically discussed.

1) Water demand and supply management

Dhaka Water Supply and Sewerage Authority (DWASA) is the responsible authority for water supply. Approximately 91% of the water supplied by DWASA is utilized for the residential sector, while the remaining 9% is allocated for commercial and industrial consumption [20]. Evidently, each individual residing in a residential area consumes an average of 310 liters of water per day (L d^{-1}), which is twice the recommended amount by DWASA (150 L d^{-1}) [19].

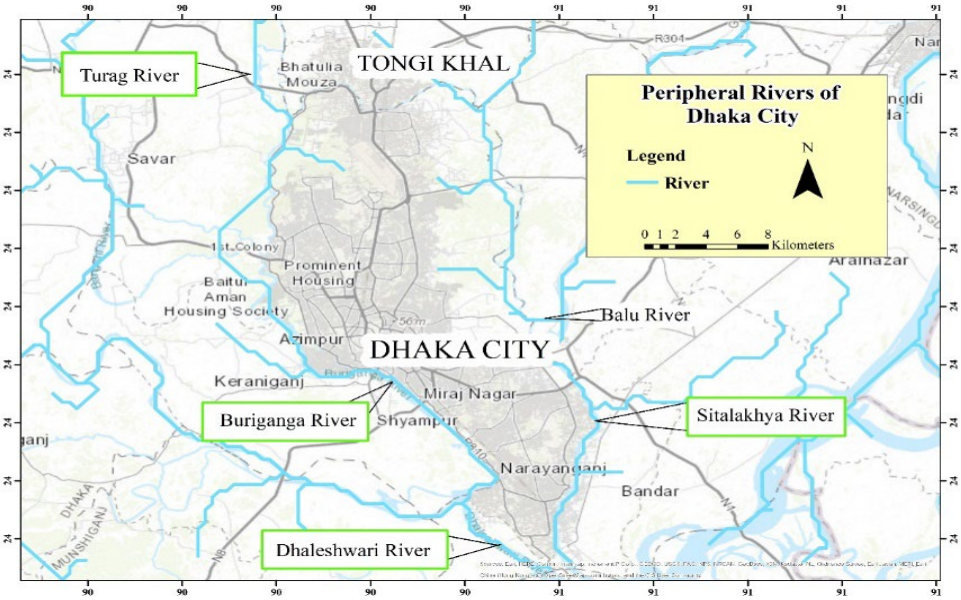

Figure 1 Location of rivers in and around Dhaka.

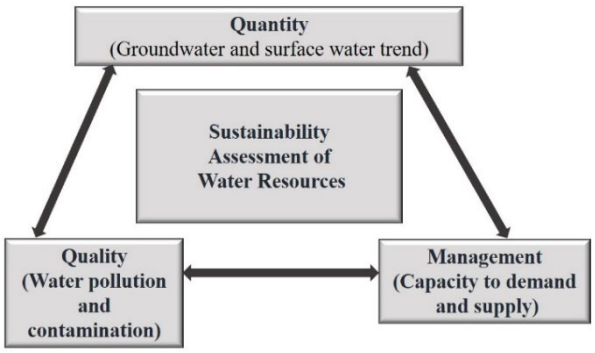

Figure 2 Sustainability assessment of water resources in Dhaka in terms of management, quantity and quality aspects.

According to the 2020-2021 annual report of DWASA, it currently produces water at a rate above 2,600 million liters per day (MLD) by utilizing 906 deep tube wells (DTWs) [21]. This study also reviewed the 2018-2019 annual report of DWASA and found evidence indicating inadequate water supply from 1963 to 2011 [22]. Though DWASA has overcome the water shortage, the increasing number of DTWs being installed annually to satisfy the city's demand in proportion to the growing population has the potential to have devastating effects on groundwater due to over-extraction. A study by Hossain and Bahauddin [23] noted that the vulnerable conditions of the aquifer may result in the drying of existing wells, land subsidence, and the intrusion of contaminated water from adjacent polluted rivers [23].

To alleviate the pressure on the city's groundwater sources and to meet water demand immediately, several adaptation actions are being practiced by DWASA [24]. For instance, presently, DWASA provides water to more than 20 million residents in Dhaka, intending to increase the proportion of surface water distribution. Unfortunately, the extant surface water sources within Dhaka city are making it increasingly difficult to produce acceptable quality water due to pollution. Aiming to ensure water security, DWASA also plans to expand its service coverage to about 29 million consumers by 2035. This requires significant capital investments to increase supply while ensuring long-term water security [9]. Although DWASA has the capacity to provide sufficient water to its people, there has been a growing scarcity of quality water at the household level, primarily due to inefficient management. In a scenario where things continue as they currently are, the situation indicates a concerning future where 12.37 million individuals may lack access to basic water needs by the year 2050 [25].

2) Groundwater depletion trend and rate

In Dhaka, most of the water supply (70%) comes from groundwater [26]. However, the city is experiencing rapid groundwater depletion, and its groundwater-based water supply is at risk of collapsing. With both public and private DTWs, this has resulted in an ever-increasing extraction of groundwater from both shallow and deep aquifers [24]. This excessive exploitation led to the declination of the groundwater table and deteriorated the water quality [27]. Parvin et al. [11] observed that the depth of the groundwater table in Dhaka showed a declining trend (Figure 3), especially after 1999. Unsustainable use of groundwater in Dhaka is a potential risk factor that gradually affects different uses of water, such as domestic water supply, agriculture, and socio-economic wellbeing [11].

Through analysis of Haque [28], it has been found that the groundwater levels in Lalbagh, Motijheel, Dhanmondi, Mirpur, Tejgaon, and Gulshan Regions have experienced significant levels of depletion, with average annual decreases of 3.32, 3.15, 2.97, 3.17, 2.97, and 2.72 m, respectively [28]. A study conducted by Islam and Islam [29] observed significant reductions in groundwater levels in Dhanmondi, Motijheel, Hazaribagh, and Ramna regions of Dhaka over a period of 30 years. The majority of the southern region experiences groundwater depletion due to the rapid urbanization and population growth observed in these localities [29]. A recent study by Moshfika et al. [24] noted that groundwater levels in urban areas were alarmingly declining with no noticeable recovery even during the monsoon season [24].

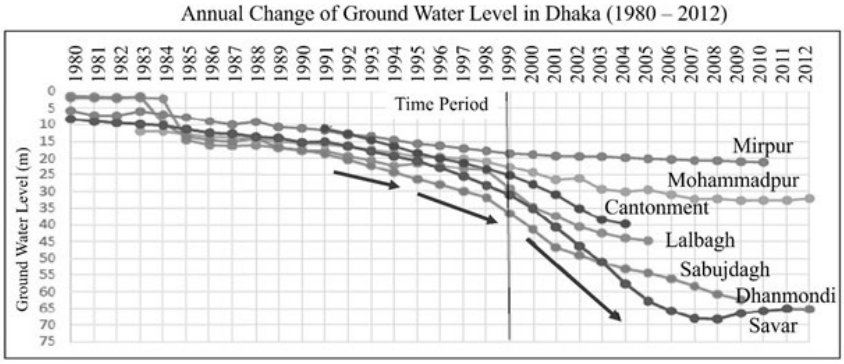

Figure 3 Variation of groundwater level in Dhaka City (1980 - 2012)(modified from Parvin et al. [11]).

Hossain and Bahauddin [23] found that the aquifer of this municipality is predominantly refilled via direct infiltration via precipitation, river water, and flooding. Nonetheless, as time passes, the recharge area of the city diminishes considerably due to unplanned urbanization. Depending on the location, the water level is currently declining at a rate of approximately 2 to 3 meters per year [23]. In order to compare the results within a global context, Syafiuddin [30] observed that China's population is consistently increasing. Almost 90% of their water supply, which is used for drinking, industrial, and agricultural reasons, comes from groundwater. The study also indicated that the overexploitation of groundwater is causing a range of issues, including ecological damage and land subsidence, which endanger human health [30].

3) Potential impact of groundwater depletion: Three perspectives on sustainability

The Institute of Water Modeling reports that groundwater levels in the vicinity of the city center are alarmingly dropping by 2–3 m annually. The evaluation area's natural environment and sociopolitical climate are probably going to suffer as a result of the declining groundwater table. Moreover, manufacturers can suffer financial consequences as a result of declining water levels. Some possible impacts and risks of groundwater that need to be handled are listed in Table 1. Three perspectives on sustainability assessment are given as follows:

3.1) Environmental perspective

A study undertaken by the Earth Observatory Centre at Dhaka University reveals that Dhaka is experiencing an annual average land subsidence rate of approximately half an inch as a consequence of excessive groundwater extraction. The rapid decline in groundwater levels may have a significant influence on several forms of infrastructure and the flow of surface water bodies in Dhaka. Therefore, "land subsidence" was categorized as a high-risk factor (Table 1). A reduction in the volume of groundwater may result in even drier surface waters and wetland areas in the vicinity of the Turag and Balu Rivers and also potentially exert adverse effects on plant ecosystems [17].

3.2) Economic perspective

From the perspective of economics, the linkage between groundwater depletion and irrigation is very important. A study conducted by Zahid et al. [31] emphasized that lowering the groundwater level directly leads to increased land subsidence, abandonment of wells, and also the pumping cost. The results of the benefit-cost analysis of pump technologies for groundwater irrigation in Dhaka city found that tube well pumping costs increase rapidly as a result of groundwater levels declining. DTW irrigation showed the highest capital costs compared to other technologies [31]. Further to this, Global Water Partnership noted that drying up of wells and increased abstraction costs were defined as "high" level of risk related to groundwater depletion in Dhaka City (Table 1) [17].

3.3) Social perspective

As depicted in Table 1, both shortfall in drinking water supply and social unrest were defined as "high" levels of risk related to groundwater depletion. Groundwater depletion would significantly increase water scarcity in the drinking water supply for Dhaka City's residents due to the possible threat of the upper aquifer drying up. Moreover, Islam [32] evaluated the relationship between violent conflict and water scarcity according to intra-state conflict in Bangladesh. The study highlighted the following three kinds of violent conflict over water scarcity: group versus group, society versus state, and individual versus group conflict. Firstly, in terms of group-versus-group conflict, the main conflict is people engaged in violent conflict to take control of the river bank, especially in the dry season. Secondly, due to society-state conflict, Bangladesh failed to meet the accelerating demand for water resources for drinking and using in daily life. Thirdly, in terms of individual versus group conflict, for instance, there was less rainfall in 2006 in the Rajshahi District. Individuals started conflicting with the pond owner as they were not getting enough irrigation water [32].

Table 1 Potential risks assessment of groundwater depletion in Dhaka [17]

Vulnerability	Threat	Level of risk
Environmental impacts	Land subsidence	High
	Reduction of water in nearby rivers, lakes and wetlands	Medium
	Degradation of plant health	Low
	Earthquake	Low
Economic impacts	Drying up of wells	High
	Higher water treatment cost	Medium
	Increased abstraction cost	High
Social impacts	Shortfall in drinking water supply	High
	Social unrest	High

4) Assessment of urban surface water trend

Figure 4 (a) illustrates a comparative assessment of the percentages of urban land and water surface in the dry season in Dhaka from 1990 to 2021. By the year 2000, the proportion of land surface had risen to 89.23%, while the proportion of water surface had decreased to 10.77%. In 2010, the land surface accounted for 90.64%, while the water surface decreased to 9.36%. In 2021, the proportion of land surface increased significantly to 94.84%, with only 5.16% remaining for water surface. Figure 4 (b) exhibits a line graph illustrating the changing trends in urban surface water coverage in Dhaka city from 1990 to 2021. In 1990, water surfaces accounted for approximately 12% of the overall covering area. During the subsequent decade, this ratio had a minor decline, reaching 10%. Later, in the subsequent decade, it continued to decrease to 9%. Nevertheless, the most notable transformation had taken place in the past ten years, as urban surface water coverage underwent a swift and substantial decline, reducing to 5% by 2021 [33].

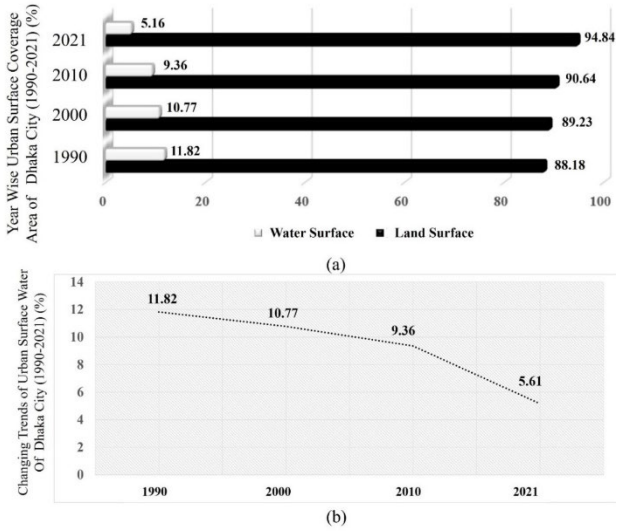

Figure 4 (a) Year wise urban surface coverage area of Dhaka City (1990–2021) and (b) changing trends of urban surface water of Dhaka City (1990–2021) [33].

Hossain et al. [33] also observed that the disappearance of these water bodies has extensive consequences for both the environment and the inhabitants of the city. Reduced water availability poses challenges for the local population, while the risk of flooding increases due to the diminishing capacity of natural water reservoirs to absorb excess rainfall. In recent years, Dhaka's dwellers have experienced extreme heat, which environmentalists attribute to the shrinking water bodies. The declining water bodies exacerbate the urban heat island effect, leading to uncomfortable living conditions and potential health hazards for the city's inhabitants [33]. The future projection of climate shows a continuous rise in temperature in the Dhaka City and related extreme events such as frequent outbreaks of tropical diseases and scarcity of water will have the most immediate effects of climate change in Dhaka [34].

5) Assessment of water quality

The excessive extraction of water from the Dupi Tila aquifer, which is the primary source of water supply in Dhaka city has resulted in the replenishment of water from rivers and increased leakage from areas with polluted land. Consequently, contaminated water has infiltrated the aquifer from an area of the river that is polluted. On the other hand, the peripheral rivers surrounding Dhaka City and the canals within it are severely contaminated [26].

5.1) Groundwater quality

One previous study performed by Bodrud-Doza et al. [35] in Dhaka reported that over one-fourth (26%) of groundwater samples exceeded the WHO standard for iron (Fe) (should not exceed 0.3 mg L^{-1}). Bodrud-Doza et al. [35] also found that there is a slight deterioration in the quality of groundwater with high concentrations of Fe and manganese (Mn) above the permissible levels (0.3–1.00 mg L^{-1} for Fe and 0.1 mg L^{-1} for Mn). On the one hand, a recent study by Ahsan et al. [36] noted that the groundwater quality in the Dhaka area is very good based on the analysis of ten ground-water samples and six ground-water quality parameters (including pH, dissolved oxygen (DO), chemical oxygen demand (COD), total solids (TS), total dissolved solid (TDS) and arsenic) [36].

5.2) Surface water quality

Numerous factors have contributed to the pollution of urban rivers in Bangladesh. The most significant driving forces are urbanization, increased population, and untreated wastewater discharge. Figure 5 shows a driving force-impact-challenge-response (DICR) frame-work to explore the situation of urban river pollution [15]. A previous study by Hoque et al. [18] noted that in 2009, the Department of Environment (DoE) declared the Buriganaga, Shitalakhya, Balu, and Turag Rivers as ecologically critical areas, with the Planning Commission calling them 'unsuitable for any human use' [18].

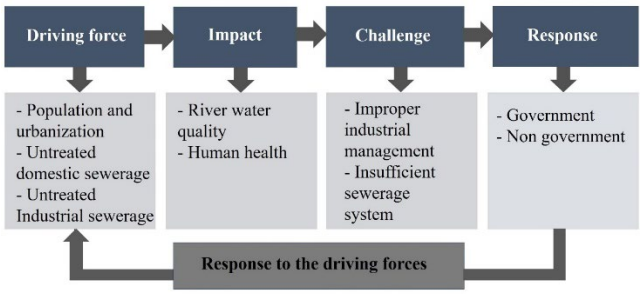

Figure 5 Schematic representation of the driving force-impact-challenges-response (DICR) framework (modified from Yin et al. [15]).

The sources and contamination of water in Buriganga present a significant risk to both public health and the long-term sustainability of the megacity's water supply [37]. Long-term consumption could also give rise to health issues such as reduced immunity, anemia, and cardiac fibrosis as well as numerous tissue inflammations in humans [38]. Table 2 depicts the water quality categorization based on both the WAI and the CCME techniques. To observe the WQI of the Buriganga River, the weighted arithmetic water quality index (WAWQI) value is '70.98' in the wet season (poor quality) and higher than 100 in the dry season (unsuitable for human consumption and fish culture) (Table 3) [16]. In terms of the water condition of Dhaleshwari River, Islam et al. [39] noted that the Dhaleshwari River has a substantial role in fostering socio-economic progress in central Dhaka [39]. However, the rivers surrounding Dhaka have been significantly polluted due to the rapid industrialization and urbanization of the city [40]. The physicochemical condition of the river has experienced a significant decline, with the majority of water quality indicators failing to fulfill the standard criteria for ensuring the safety of drinking water. If appropriate measures are not adopted soon enough, this will impact both ecological and public health around the river [39]. More interestingly, to observe the WQI of the Dhaleshwari River (Table 3), a study by Islam [16] noted that the WAIWQI value ranges from 76–100 (very poor) in the wet season and in the dry season, the WQI value is >100 (unsuitable for human consumption and fish culture) (data have been collected from numerous individual studies) [16].

Table 2 Water quality categorization based on WAWQI and CCME-WQI techniques [16, 45]

WAWQI	Rank	Potential uses	CCME-WQI	Rank	Interpretation
0-25	Excellent	Human consumption, agriculture and industrial	95-100	Excellent	Absence of threat to the water quality
26-50	Good	Human consumption, agriculture and industrial	80-94	Good	Small degree of threat to the water quality
51-75	Poor	Agriculture and industrial	65-79	Fair	Water quality occasionally endangered
76-100	Very Poor	Agriculture	45-64	Marginal	Frequent threat to the water quality
>100	Unsuitable for human consumption and fish culture	Needs to be treated properly before use	0-44	Poor	Water quality approximately always in danger

Table 3 WQI values and water quality rating of surface water in and around Dhaka

River	WQI method	WQI value	Water quality rating	Sources
Buriganga	WAI	70.98 (wet season)	Poor	[16]
		>100 (dry season)	Unsuitable for human consumption and fish culture	
Turag	WAI	76-100 (wet season)	Very poor	[16]
		>100 (dry season)	Unsuitable for human consumption and fish culture	
Shitalakhya	WAI	>100 (pre-monsoon)	Unsuitable for human consumption and fish culture	[43]
		26-50 (monsoon)	Good	
		76-100 (post-monsoon)	Very poor	
	CCME	10 (post-monsoon)	Poor	[43]
		13 (monsoon)	Poor	
		13 (pre-monsoon)	Poor	
Dhaleshwari	WAI	76-100 (wet season)	Very poor	[16]
		>100 (dry season)	Unsuitable for human consumption and fish culture	

On the contrary, the Shitalakhya, a significant urban river flowing through the industrialized districts of Gazipur, Dhaka, and Narayanganj in Bangladesh, is subject to substantial daily discharges of pollutants and heavy metals from numerous industries situated along its banks. Untreated effluents from these in-

dustries frequently generate substantial volumes of contaminated water, which are illegally discharged directly into the river [41]. A study by Alam et al. [42] noted that the water quality of the Shitalakhya River is suitable for aquaculture, irrigation, and for sustaining aquatic ecosystems, but not for drinking or domestic purposes without conventional treatments [42]. Further, Uddin and Jeong [3] indicated that the current water intake point as the raw water source for the drinking water treatment plant in Saidabad point is not safe due to the presence of hazardous pollutants and microbiological loads [3]. Chowdhury et al. [43] adopted thirteen water parameters (pH, DO, color, conductivity, TDS, TSS, hardness, chloride, turbidity, alkalinity, Fe, temperature and BOD) to rate the overall water quality of the Shitalakhya River and found that the water quality is also poor (samples were taken from Haripur in Narayanganj District in 2018). The CCME-WQI values of the Shitalakhya River are '10' in post-monsoon, '13' in monsoon, and '13' in pre-monsoon, signifying that the water quality is poor. On the contrary, WAWQI values range '26–50' in monsoon (good) and '76–100' in post-monsoon (very poor), whereas in the pre-monsoon, the WQI value is above '100' (unsuitable for drinking) (Table 3) [43].

Besides this, one of the world's most polluted rivers, the Turag, flows around the edge of the Dhaka megacity. The majority of the places had poor water quality as a result of intense urbanization and industrialization [44]. According to the WAI technique, the result of WQI in the dry season (December- March) is above '100' which means that water is 'not suitable for human consumption and fish culture' and during the wet season (July-October), the WQI value ranges from '76–100' which means water quality is 'very poor' (Table 3) [16].

A recent study by Shultana et al. [46] showed the water quality of five points of the Meghna, Buriganga, Turag, Shitalakhya and Dhaleshwari Rivers in 2021 in terms of TDS, Salinity, Electrical Conductivity (EC) and Turbidity and indicated that the water quality of the Meghna River is better than that of the other four rivers. Further, Maraz et al. [47] also noted that the water quality of the Meghna River is much better than that of the Buriganga, Dhaleshwari, and Shitalakhya Rivers [47]. However, scenarios imply that due to tributary canals that are overflowing with both domestic and industrial effluent, the water of the Meghna River may become too filthy for drinking within the next five years [48]. A study by Begum et al. [49] found that approximately 46.25% of the surveyed respondents living nearby the Meghna River indicated that contaminated water posed a problem for fisheries, 21.25% for agriculture, and 32.5% for livelihoods [49]. Economically, ADB [50] pointed out the economic valuation of the fisheries of the Meghna River and found that the total annual value of fish production in the area is $15,625,000. The river's fisheries are providing a livelihood for several thousand fishers. Table 4 shows the estimated economic value of the Meghna River in terms of water supply, fisheries, carbon storage, and biodiversity [50].

Table 4 Estimated economic valuation of Meghna River in terms of water supply, fisheries, carbon storage and biodiversity [50]

Value type	Description	$/year
Direct use value	Water supply to DWASA	45,510,000
	Fisheries	15,625,000
Indirect use value	Carbon storage	3,195,000
Existence value	Biodiversity	223,650

Having reviewed, it has been found that Dhaka City is experiencing a rapid depletion of its groundwater reserves year after year in several regions. To justify the statement, throughout the past 30 years, Dhanmondi, Motijheel, Mirpur, Hazaribagh, and Ramna areas of Dhaka showed drastic declines in groundwater tables [29]. The rise in urbanization has resulted in densely populated areas, which has raised concerns about groundwater depletion [51]. This issue has become more pressing with the rapid urbanization that has taken place. Changes in the quantity and quality of groundwater systems can be attributed to a combination of factors, including urbanization, climate change, and human activities [51]. Another study by Jerin and Ishtiaque [52] noted that the main causes of groundwater depletion are population density and overexploitation [52]. Therefore, to address the issue of excessive reliance on groundwater, it is crucial to promote the use of surface water. DWASA has developed a comprehensive master plan and assessed the future water production requirements. It should be noted that groundwater alone will not be able to meet this substantial demand. The marginal extraction cost would increase over time as the water table drops. For common property resources such as groundwater, pumping costs would rise too rapidly. Future users would also be hard hit in comparison to current users. On the contrary, it has been found that the water quality of the rivers in and around Dhaka is poor, underscoring the need for strong policies to restore and preserve the polluted river ecosystem and provide clean water to the city's residents. Due to the indiscriminate dumping of waste into the rivers, the water quality is getting worse year by year. Therefore, proper

waste disposal and management are extremely crucial for maintaining and developing water quality in the nearby rivers of Dhaka. By considering all of the above, the study found that Dhaka's current water supply system is not sustainable, and hence, there is a dire need for implementing integrated water resource management (IRWM) strategies. It will be very challenging to manage the water resources in the coming decades unless we address the current challenges of water security, demand and management, conservation, efficiency, and sustainable consumption.

Conclusion

Water is widely recognized as the most valuable natural resource, and there is currently a strong emphasis on improving water quality as an essential prerequisite for enhancing well-being and promoting sustainable development. Achieving SDG 6 (clean water and sanitation) will spontaneously bring about the achievement of SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), and SDG 11 (sustainable cities and communities). The study found that the groundwater quality in Dhaka is good till now, but several areas have been experiencing rapid depletion of groundwater over the last two decades, and the density of the wells is increasing with time. Surface water quality is in a vulnerable state. Therefore, taking the lessons learned from the degradation of the Buriganga, Turag, Shitalakhya, and Dhaleshwari Rivers, the protection of the Meghna River should be a top priority at the highest management levels. Therefore, the Meghna River must be protected from being polluted and collapsed, and other water bodies in Dhaka must be protected and restored. In light of these observations, it is recommended to build Dhaka as a sustainable urban city because, in the present context of population boom and rapid urbanization, water is becoming the most stressed natural resource in the greater Dhaka City.

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