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Vulnerability of drinking water supply and respondent's perception on the quality of water supply in Dhaka City, Bangladesh

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Abstract

Dhaka, the capital of Bangladesh, has been consistently ranked as one of the most populated and polluted cities in the world. The city has been experiencing severe groundwater declination and widespread surface water pollution, which are its main drinking water sources. The sustainability of water resources is one of the largest issues facing by this megacity. The research aimed to evaluate the groundwater and surface water quality in Dhaka with respect to the drinking water standard of the Environment Conservation Rules (ECR)-1997, assess the vulnerability of drinking water supply, and explore the respondents' perception regarding the quality of supplied water. The study revealed that Iron (Fe) and Manganese (Mn) concentrations in groundwater were found to be in alarming condition in different areas of Dhaka during the years 2015–2019. Groundwater is drastically depleting over the years which requires ensuring sustainability. By using the Canadian Council of Ministers of the Environment (CCME) method, the Shitalakhya, Dhaleshwari, and Turag Rivers have a Drinking Water Quality Index (DWQI) value of less than '44', signifying that the water quality is poor and unsuitable for drinking and domestic purposes. The research also found a strong positive relationship between increasing population and groundwater depletion, a moderate positive relationship between rising temperature and groundwater depletion, and an inverse relationship between decreasing precipitation and groundwater depletion over the last 25 years (1990–2014). Regarding the vulnerability of drinking water supply, population density, groundwater depletion trend, and surface water quality were categorized as 'high' vulnerability factors. About 36% of the respondents living in Dhaka South City Corporation and Dhaka North City Corporation areas claimed that supplied water quality is poor. Nearly all surveyed households (98%) used water purifying techniques before drinking supplied water. More interestingly, over two-thirds (77%) of the total respondents showed interest in paying more for improved drinking water service over the current water bill. Some economic models were suggested as policies for sustainable water resource management in the greater Dhaka city.

Keywords Dhaka · Pollution · Drinking water · Groundwater · Surface water · Sustainability

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1 Introduction

Access to safe drinking water, along with hygiene and sanitation, is crucial to global health (Gizaw et al., 2022). Sustainable Development Goal (SDG) 6.1 aims to provide universal and equitable access to safe and affordable drinking water by 2030 (Hossain et al., 2021a). The sustainability of the environment is negatively impacted by water contamination (Sehreen et al., 2019). In Bangladesh, approximately 103 million people lack access to properly managed sanitary facilities, while 68.3 million lack access to properly managed drinking water (Asia-Pacific, 2021). Dhaka, the capital of Bangladesh, is a hub of economic development and rapid urbanization. As the city becomes known as the center of all industries, it is gradually losing its natural resources (Duti et al., 2012). The city is also experiencing a rapid increase in population due to a combination of factors, including urbanization and industrialization, that may hinder sustainable development (Yin et al., 2021; Sehreen et al., 2019; Kirby & Mainuddin, 2022).

It is challenging to strike a balance between the city's water sources and the needs of its more than 20 million residents and growing population (ADB, 2021). The city heavily relies on groundwater as a source of quality water. Unfortunately, the rapid and unplanned expansion of the city, coupled with uncontrolled well drilling, has placed an enormous strain on this essential water source (Moshfika et al., 2022). Large populations generate substantial quantities of raw effluent output, resulting in intense pressure for urban river pollution control (Yin et al., 2021). Consequently, due to contaminated surface water, Dhaka heavily depends on groundwater (ADB, 2022). For years, the extraction of groundwater in Dhaka has been carried out extensively to meet the growing need for drinking water among its residents, causing water resource management and sustainability issues (Parvin et al., 2019). The groundwater abstraction rate is about 25% higher than the natural recharge (Global Water Partnership, 2019). Despite the city is surrounded by four significant rivers, namely the Buriganga, Dhaleshwari, Shitalakhya, and Turag (Yin et al., 2021), the city faces significant challenges in ensuring an adequate supply of drinking water for its residents (Global Water Partnership, 2019). In the past three decades, the water quality in the rivers surrounding Dhaka has been severely degraded (Hoque et al., 2021) due to the discharge of untreated domestic sewage and a substantial amount of industrial wastewater. The urban rivers are plagued by the presence of black and foul water, with untreated sewage contributing to 98% of the overall pollution (Yin et al., 2021). The pollution load increases with annual increases in the population (Islam et al., 2015). A study of Yeazdani (2016) mentioned that, the city dwellers do not accept the water from Dhaka Water Supply and Sewerage Authority (DWASA) as drinking water. Alom and Habib (2016) noted that about 64% of city dwellers are not using the Dhaka WASA's supplied water for drinking purposes due to the bad smell. Approximately 40% of Dhaka residents boil water before drinking (Hossain et al., 2021b).

Meanwhile, climate change has an impact on local rainfall and temperature, putting the already vulnerable water sector at risk in Dhaka (Duti et al., 2012). Uddin et al. (2018) reported that rainfall is the primary natural source of water for the nearest rivers to Dhaka. The Buriganga River, for example, is being diluted as rainfall is decreasing due to climate change and wastewater production is rising due to industrialization. This situation will become increasingly problematic in the future as the impacts of global climate change on rainfall in Dhaka grow. Based on the importance of the topic, the objectives of this research were to (i) determine the groundwater quality of Dhaka and the Water Quality Index (WQI) of rivers in and around Dhaka with respect to the drinking water standard of the ECR-1997, (ii) assess the vulnerability of drinking water supply and its vulnerability classification, and (iii) explore the perception of the respondents regarding the quality of supplied water. Some policies and recommendations to ensure sustainable water management in Dhaka were also provided in this research.

2 Methods and materials

Dhaka city has been chosen as a case study due mainly to the groundwater in Dhaka is declining rapidly and the water of peripheral rivers in and around Dhaka (i.e., Shitalakhya, Dhaleshwari, and Turag) (Fig. 1) is getting polluted indiscriminately, which has become a matter of concern for providing a sustainable water supply in the city. To evaluate the water quality, data on the groundwater quality in Dhaka city during 2015–2019 has been collected from the Office of the Deputy Chief Microbiologist, Microbiology and Chemical Division (Dhaka WASA Central Laboratory) and data on surface water quality has been gathered from some published articles (i.e., Alam et al., 2020; Hasan et al., 2020; Rahman et al., 2021). Apart from the supply-side perspective, this study explored the demand side perspective on the respondent's perception of the quality of supplied water by Dhaka WASA. One hundred households ($n=100$) in Dhaka were randomly surveyed in 2022 (July and August) at Jatrabari, Dania (Ward No. 60 and 61), Dhaka South City Corporation (DSCC) area ($n=60$), and Shyamoli (Ward No. 28), Dhaka North City Corporation (DNCC) area ($n=40$) because these areas have one of the larger portions of population, which can represent the perception of the supplied water quality.

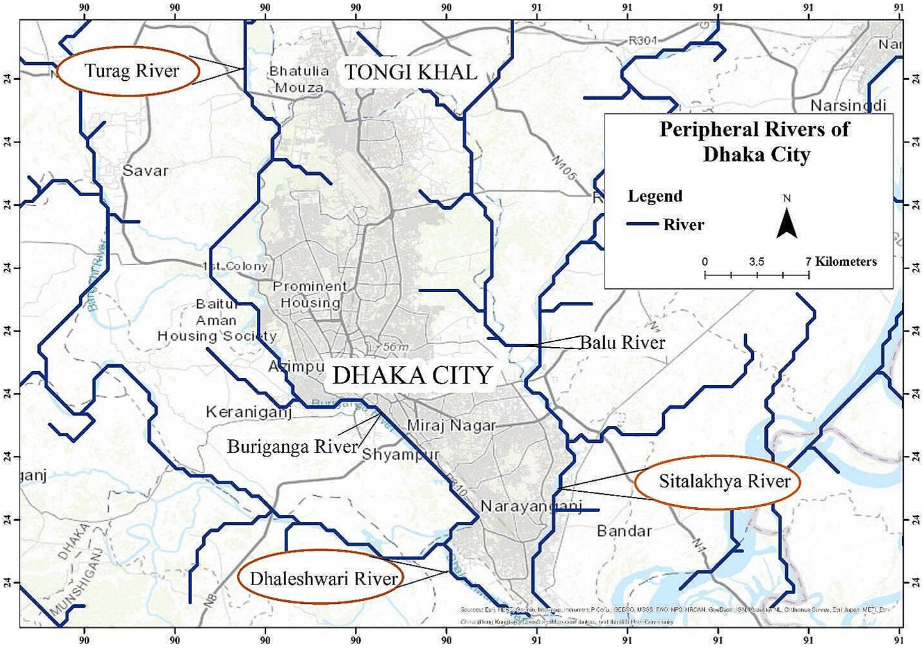


Fig. 1 Location of rivers in and around Dhaka

2.1 CCME water quality index (WQI) estimation

The Canadian Council of Ministers of the Environment (CCME) method was adopted to estimate the Water Quality Index (WQI) of the Rivers (Shitalakhya, Dhaleshwari, and Turag) in and around Dhaka city (Fig. 1) from 2018 to 2019 with respect to drinking water standards of ECR-1997. The water quality of the Shitalakhya (samples were gathered from Palash near the Ghorashal Power Station in Narsingdi by Alam et al., 2020), Dhaleshwari (samples were taken from the Dhaleshwari river in the vicinity of the Savar Tannery Industrial Park by Hasan et al., 2020), and Turag Rivers (samples were collected at four sites, which are near the Gabtoli Bridge, beside the Birulia Bridge, at Ashulia Station, and opposite the Tongi River port by Rahman et al., 2021) have been analyzed for the WQI. As described by Eqs. 1–2, 'Scope (F1) displays the level of water quality guidelines over the time period. 'Frequency (F2)' is about the percentage of individual tests that do not meet the objectives, and Amplitude (F3)' represents the amount by which failed tests do not meet their objectives (Eqs. 3–7). The combination of three variances creates a value ranging from 0 to 100 which shows the overall water quality index.

$$F1 = \frac{NumberofFailedVariables}{TotalNumberofVariables} \times 100 \tag{1}$$

$$F2 = \frac{NumberofFailedTests}{TotalNumberofTests} \times 100 \tag{2}$$

Where: F1 is the degree of guideline of water quality over the time period.

F2 is the percentage of individual tests which do not meet the objectives ('failed tests').

The following three steps (Eqs. 3–6) were used to estimate the amount by which failed test values which does not meet the objectives (F3).

Step 1- Calculation of excursion.

$$Excursion_i = \frac{FailedTestValue}{Objective} - 1 \tag{3}$$

Where: Excursion is the number of times by which an individual concentration is greater than the objective. Beside this, when the test value must not fall below the objective, Eq. 4 can be applied.

$$Excursion_i = \frac{Objective}{FailedTestValue} - 1 \tag{4}$$

Step 2- Calculation of normalized sum of excursions.

$$nse = \frac{\sum Excursion}{NumberofTests} \tag{5}$$

Where: nse is the combined amount by which individual tests are out of fulfillment.

Step 3-Calculation of F3.

$$F3 = \frac{nse}{0.01nse} + 0.01 \tag{6}$$

Where: F3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.

Finally, WQI was then calculated by using Eq. 7.

$$WQI = 100 - \frac{\sqrt{F1^2 + F2^2 + F3^2}}{\sqrt{3}} \tag{7}$$

The final estimated WQI score is categorized into the following five classes (Table 1).

2.2 Linkages of variables to the vulnerability of drinking water supply

To explore the vulnerability of groundwater supply for drinking water purposes, this research investigated the relationship between population and groundwater depletion, temperature and groundwater depletion, and precipitation and groundwater depletion over the last 25 years (1990–2014) (Mamoon et al., 2021). To determine the vulnerability classification for drinking water supply, the following four indicators were investigated: population density (people/km^2), groundwater depletion trend (m), groundwater quality, and surface water quality (Table 2). Each indicator was classified as low, moderate, or high vulnerability according to the range of different vulnerability classifications. To categorize the population density, Zhang et al. (2020) classified megacities into three categories: high density (> 1,500 residents per km^2), moderate density (300–1,500 residents per km^2) and low density (< 300 residents per km^2). In the case of the groundwater depletion trend, a decreasing trend over the years has been categorized as low vulnerability, a moderate trend as moderate vulnerability, and increasing trend as high vulnerability. Groundwater quality with 'good' (almost all water parameters lie within the permissible range), 'moderate' (few water parameters lie within the permissible range), and 'poor' (almost all water parameters lie beyond the permissible range) has been categorized as low, moderate, and high vulnerability. To categorize the vulnerability of surface water quality, the CCME-WQI technique has been adopted. Water quality with the categories of 'good' (minor degree of threat), 'fair' (occasionally threatened), and 'poor' (almost always threatened) has been categorized as low, moderate, and high vulnerability.

Table 1 Water Quality Index (WQI) categorization (Khan et al., 2005)

WQI Values	Ranks	Measurements
95–100	Excellent	✓ Condition is very close to perfect water quality levels ✓ Absence of threat to the water quality
80–94	Good	✓ Conditions hardly ever diverge from desirable limits ✓ Small degree of threat to the water quality
65–79	Fair	✓ Conditions occasionally diverge from normal limits ✓ Water quality occasionally endangered
45–64	Marginal	✓ Conditions often diverge from normal or desirable limits ✓ Frequent threat to the water quality
0–44	Poor	✓ Conditions frequently diverge from natural or desirable limits ✓ Water quality approximately always in danger

Table 2 Vulnerability class of drinking water supply (modified and applied from Hoque et al., 2016)

	Indicators	Definition	Vulnerability Classification		
			Low	Moderate	High
1.	Population Density (people/km^2)	Number of people living per km^2 (higher will be the population density, higher will be the vulnerability).	<300 (people/km^2)	300–1500 (people/km^2)	>1500 (people/km^2)
2.	Groundwater Depletion Trend (m)	Availability of groundwater (higher will be the rate of depletion, higher will be the vulnerability).	Decreasing Trend	Moderate Trend	Increasing Trend
3.	Groundwater Quality	Current status of groundwater (higher will be the quality of groundwater, lower will be the vulnerability).	Good (Almost all Water parameters lie within the ECR permissible range)	Moderate (Few water parameters lie within the ECR permissible range)	Poor (Almost all Water parameters lie beyond the ECR permissible range)
4.	Surface Water Quality	Current status of surface water (higher will be the quality of surface water, lower will be the vulnerability).	Good (Minor degree of threat)	Moderate (Occasionally threatened)	Poor (Almost always threatened)

3 Results and discussion

3.1 Groundwater quality in Dhaka City

Groundwater quality in Dhaka for some parameters was found to be within permissible ranges of the ECR-1997 (i.e., pH, Turbidity, Total Coliforms, Fecal Coliforms, Total Dissolved Solid (TDS), Chloride, and Arsenic). Whereas, interestingly, Fe and Mn were found to be in alarming condition in different parts of Dhaka during 2015–2019 (Supplementary Appendix A, Table 1). The results also found that Fe concentration is below the Bangladesh standard of ECR-1997 permissible ranges, but it is in alarming condition. Mn concentration also exceeded the Bangladesh standard of ECR-1997 permissible ranges. One previous study performed by Bodrud-Doza et al. (2019a) noted that in Dhaka, the observed Fe concentration in groundwater samples was within the Bangladesh standard (Department of Environment, 1997), and nearly 26% of the samples exceeded the WHO standard (2011). The presence of excessive Fe in groundwater can cause disease, if ingested beyond the permissible limit. Mn can cause different neurological disorders. One study conducted by Chakraborty et al. (2022) in the rural area of Jashore, Bangladesh, noted that almost all groundwater samples (91–97%) exceeded the Bangladesh drinking water standard limits for Fe and Mn. In the case of non-carcinogenic health risk via oral exposure, about 94% of samples suggested a high category of risk for infants, and 97% of samples were found to be at high risk for children and adults.

Compared to the aforementioned findings, our study observed that excessive extraction of groundwater may lead to several negative consequences, such as deterioration of drinking water quality, depletion of water resources, degradation of surface water systems, high expenses for cleaning up contaminated water, increased costs for seeking alternative water supplies, and potential health hazards. Therefore, it is suggested to take immediate measures to safeguard and effectively manage groundwater resources against overexploitation and contamination to preserve their quality and quantity. In support of this claim, Bodrud-Doza et al. (2019b) noted that groundwater is heavily influenced by anthropogenic activities and induced by contaminate recharge from the peripheral polluted rivers. Over abstraction may induce contaminant recharge from the nearby rivers. Dhaka's peripheral rivers (i.e., Buriganga, Turag, Shitalakhya, and Balu rivers) are contaminated with trace metals due to industrial effluents, terrestrial discharge, and chemical-laden leachates. In this region, natural recharge, water supply network leakage, and the storm drainage system, which may degrade groundwater quality in Dhaka city.

3.2 Measuring water quality index (WQI) of surface water by using CCME method

Table 3 shows the results of WQI estimation based on the Canadian Council of Ministers of the Environment (CCME) method for the years 2018–2019. Six parameters (Turbidity, Total Alkalinity, Total Suspended Solids (TSS), Fe, hardness and water temperature) were failed to be within the ECR-1997 permior the Shitalakhya River. Meanwhile, fissible limit for the Shitalakhya River. Meanwhile, five parameters (Biochemical Oxygen Demand (BOD), Turbidity, TSS, Fe and color) were failed to be within the ECR-1997 permissible limit for the Dhaleshwari River (Junction Place), eight parameters (pH, BOD, Turbidity, Total Alkalinity, TDS, TSS, Fe and Color) were failed to be within the ECR, 1997 permissible limit for the Dhaleshwari River (Downstream side). Lastly, five parameters (pH, Turbidity, Total Alkalinity, Chemical Oxygen Demand (COD) and TSS) were failed to be within the ECR-1997 permissible limit for the Turag River. Table 3 displays the CCME WQI values of 39.98 (Shitalakhya River), 30.38 and 21.1 for the Dhaleshwari River (junction and downstream sides), and 29.1 (Turag River), which indicate that the water quality is 'poor and unfit' for drinking and domestic purposes in Dhaka city. As the WQI falls below 44, the water quality is deemed to be very poor (Chowdhury et al., 2021). This result was consistent with the findings of Alam et al. (2020), who determined that the Shitalakhya River's water quality is not suitable for consumption without conventional treatment. Uddin and Jeong (2021) indicated that the current water intake point as the raw water source for the drinking water treatment plant in Saidabad is not safe due to the presence of hazardous pollutants and microbiological loads, and a subsequent study by Hasan et al. (2020) determined that the Dhaleshwari River's water quality is poor. Due to the indiscriminate dumping of waste into the rivers of Dhaka, the water quality is getting worse year by year. Therefore, it can be stated that proper waste disposal is extremely important for maintaining and developing water quality in the nearby rivers of Dhaka.

3.3 Vulnerability of drinking water supply with respect to increased population and possible impact of climate change

As a result of rapid urbanization and population growth, cities in emerging nations encounter numerous environmental obstacles, and Dhaka is not an exception (Dewan et al., 2012). The population of Dhaka is growing rapidly. Figure 2 depicts the population trend in Dhaka City from 1990 to 2030. Overall, the population has experienced a consistent upward trend.

Table 3 Results of WQI of the Sithalakhya, Dhaleshwari, and Turag Rivers founded by CCME method

Time Period	River Name	No. of Failed Variables	Total no. of Variables	F1	No. of Failed Tests	Total no. of Tests	F2	Total Excursion	nse	F3	WQI Value	Water Quality Rating
2018 (Jan- Dec)	Shitalakhya	6	8	75	34	96	35.4	126.37	1.31	65.5	39.98	Poor
2018 (July- Dec) & 2019 (Jan-Feb)	Dhaleshwari (Junction Place)	5	9	55. 5	35	72	48.6	549.64	7.63	95.3	30.38	Poor
2018 (July- Dec) & 2019 (Jan-Feb)	Dhaleshwari (Downstream Side)	8	9	88	35	72	48.6	265.3	3.68	92	21.1	Poor
2018 (Dec) & 2019 (Jan-Nov)	Turag	5	8	62.5	48	96	50	813	8.4	93.3	29.1	Poor

It is projected to surpass 25 million by 2030 (Yin et al., 2021). The ever growing population of Dhaka is posing significant challenges in the management of water resources. To effectively handle the crisis, it is crucial to evaluate the current state of the groundwater level in Dhaka (Chowdhury, 2018). The situation of groundwater exploitation is strongly linked to the local population, urbanization, and city expansion (Islam et al., 2021).

The analysis found that Dhaka's water management is promoting the use of surface water to assist in relieving pressure on groundwater sources as part of their ongoing efforts to modernize the city's supply system. Evidently, regarding to the analysis of Dhaka WASA's 2018–2019 annual report found that water was in poor supply in the years 1963–2011 (Supplementary Appendix A, Table 1). The demand for water was greater than the supply capacity up to 2011. Dhaka WASA has overcome the water shortage since 2011, but the number of Deep Tube Wells (DTWs) installations has increased continuously. Figure 3 depicts the number of installed DTWs in 1963 was 47, and it rose to 887 in 2018 with the rapid increase in population. According to the 2020-2021 annual report of Dhaka WASA (2020b), the Dhaka WASA currently produces water at a rate above 2,600 million liters per day by utilizing 906 DTWs. A study conducted by Moshfika et al. (2022) noted that the groundwater was extracted from 60 m below the ground surface in 1960, but this number had grown to 375 m in 2019, and groundwater levels were declining all over the city areas at an alarming rate without any significant recovery, even during the monsoon season.

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 for supplying drinking water due to over-extraction. To support the statement, a study by Hossain and Bahauddin (2013) 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. Another study by Islam et al. (2021) also noted that the consequences of this over-extraction of groundwater may prompt environmental hazards, negative impacts on water supply, drought and ecological imbalance as well as permanently damaging the aquifers.

Mamoon et al. (2021) noted that groundwater level is declining at an alarming rate of about 2–3 m/yr in central Dhaka as settlements have been established densely, while the declining rate is much lower at the outskirts of the city due to fewer settlements and recharge from existing water bodies. Another study by Islam (2018) noted that throughout the past 30 years, Dhanmondi, Motijheel, Mirpur, Hazaribagh, and Ramna areas of Dhaka showed drastic declines in groundwater tables. Most of the southern part is affected by groundwater depletion because of the high rate of urbanization and increase in population in these areas. Moshfika et al. (2022) noted that if this decline continues and the condition of inadequate groundwater recharge persists, the average static water level in the city will fall by 161 m by 2050. Faridatul and Bari (2021) noted that the rise in urbanization has resulted in densely populated areas, which has raised concerns about groundwater depletion. 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.

In Dhaka, 68% of the water supply comes from groundwater (Moshfika et al., 2022). To compare the finding with the international context, the population of China is steadily on the rise and that approximately 90% of their water supply, used for drinking, industrial, and irrigation purposes, comes from groundwater. The study also stated that the excessive exploita-

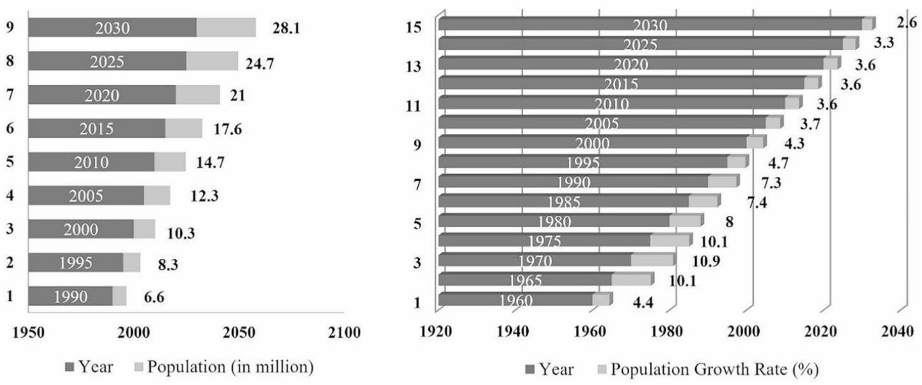


Fig. 2 Trends of the Population and Population Growth Rate in Dhaka (adapted from Yin et al., 2021)

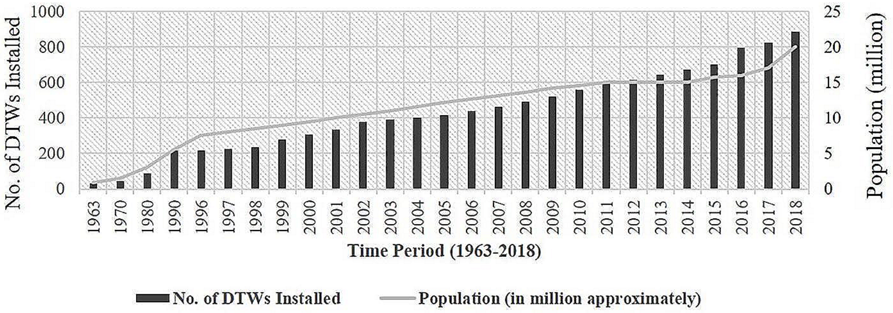


Fig. 3 Number of DTWs installation with respect to the increasing population over the years (adapted from Dhaka WASA, 2020a)

tion of groundwater is giving rise to various problems, such as ecological damage and land subsidence, which pose risks to human health. Moreover, the study revealed a troubling fact that over 60% of China's groundwater is contaminated due to inadequate management practices (Syafiuddin et al., 2020). The situation in Dhaka is likely to get worse in the future if the excessive and indiscriminate withdrawal of groundwater continues (Hossain et al., 2021c). Therefore, based on the current context of our study, immediate measures should be taken to protect and manage the groundwater of Dhaka city from being over-exploited for the betterment of ecology and human health.

Further, Parvin et al. (2019) observed that the depth of the groundwater table in Dhaka showed a declining trend, especially after 1999. While it is clear that increasing population pressure and the unregulated extraction of groundwater are the causes of the declining groundwater levels, the question is whether drought events may trigger an increase in the rate of decline. Some indications of a change in the climatic pattern (i.e., annual precipitation is decreasing while the temperature is slightly increasing) have been found in the study area. The results also showed some indication of the rate of decline of groundwater levels increasing after drought events, though this effect is not very strong. A previous study (Shourav et al., 2016) stated that the future projection of climate in Dhaka city shows a continuous rise in temperature in the 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. In the case of historical rainfall patterns, Mamoon et al., 2021 noted that the amount of rainfall in Dhaka city in the last 25–30 years has decreased by approximately 30–40% and groundwater levels will be in a decreasing pattern as population increases. Evidently, Fig. 4 shows the trend of groundwater depletion with the increase in population and temperature and the decrease in precipitation over the last 25 years in Dhaka (1990–2014). With the application of Pearson correlation of coefficient (r), our study found a strong positive relationship between groundwater depletion and growing population ($r=0.90$), a moderate positive relationship between groundwater depletion and an increase in temperature ($r=0.57$) and a negative relationship between decreased precipitation (millimeter) and groundwater depletion ($r = -0.27$). Nevertheless, Liu & Zheng, 2016 noted that groundwater has historically served as a buffer against climate variability, and our reliance on groundwater resources is likely to grow as water supplies are further stressed by a growing population, temperature rises, and climatic variability.

3.4 Assessment of vulnerability classification of drinking water supply

Population density and over-exploitation are mainly responsible for groundwater depletion (Jerin & Ishtiaque, 2015). According to World Population Review (2024), the population density of Dhaka city is 23,234 (people/km^2). Therefore, Dhaka's population density has been classified as 'high vulnerability'. In terms of groundwater depletion, it has been classified as 'high vulnerability' as a high rate of groundwater depletion. In term of groundwater quality, most of the water parameters (i.e., pH, Hardness, Turbidity, Total Coliforms, Fecal Coliforms, TDS, Chloride, and Arsenic) were within the ECR-1997 permissible ranges and have been categorized as 'low vulnerability', but the surface water quality is poor according to CCME-WQI values and has been classified as 'high vulnerability' (Table 4). Based on this analysis, the current rate of groundwater abstraction is not sustainable, and without immediate action, there may be adverse environmental, economic, and social consequences like land subsidence, drying up of wells, higher water treatment costs, increased abstraction costs, a shortfall in drinking water supply, and social unrest in the near future. Additionally, the water quality of peripheral rivers in Dhaka is poor, which could impact the supply of drinking water in the near future if prompt measures are not taken. Moreover, apart from maintaining the water quality of the water bodies, the supplied water pipes need to be improved so that there will be no leakages. A study by Hossain et al. (2015) noted that Old Dhaka is one of the densely populated areas of DSCC where piped water supply has become a major concern since the supplied water has become a major concern for the city dwellers both in terms of quantity and quality.

3.5 Respondent's perception of the quality of supplied water

The survey results revealed that 36% of the respondents claimed that the supplied water quality is 'poor' and 42% claimed that the water quality is 'average'. Only 22% claimed that the supplied water quality is 'good', and no one claimed that the water quality is 'excellent' (Fig. 5a). Local respondents who are living in the DSCC area claimed about 'poor' supplied water quality rather than those who are living in the area of DNCC. The supplied water

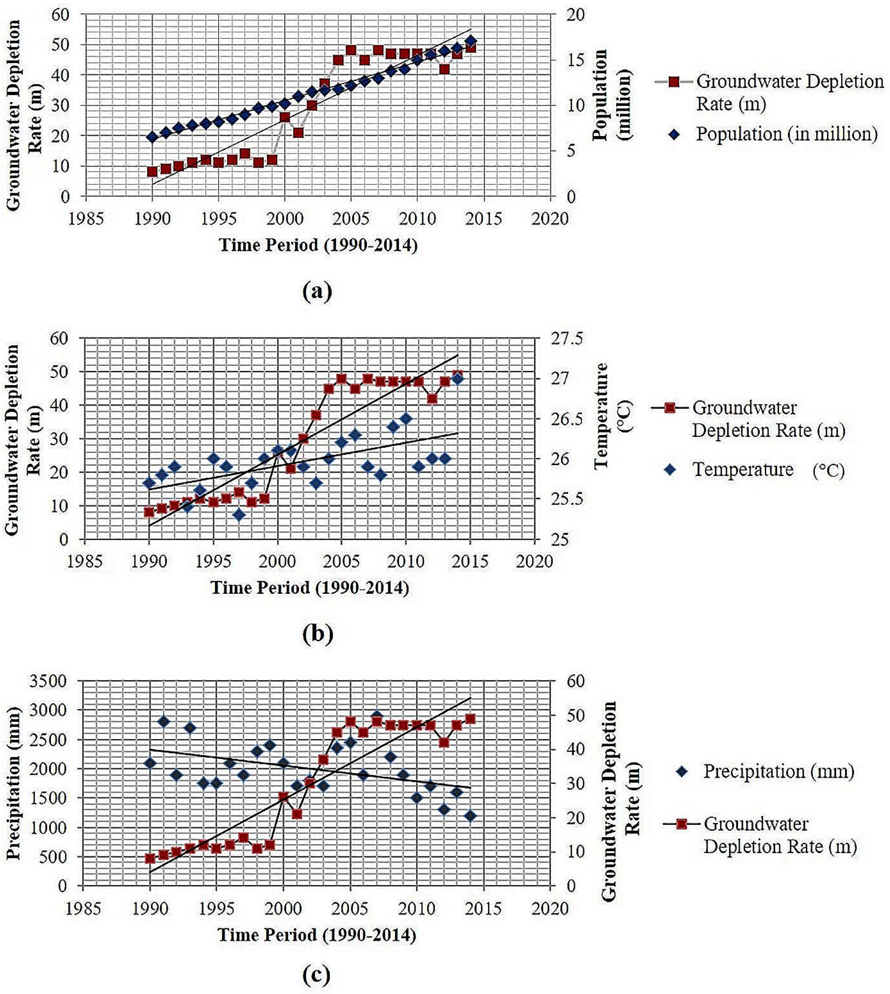


Fig. 4 Relationship between (**a**) population and groundwater depletion, (**b**) temperature and groundwater depletion and (**c**) precipitation (mm) and groundwater depletion

quality in the DSCC area might not be that much superior to the supplied water quality in the DNCC area.

To avoid any kind of water-borne diseases, the survey results of this research revealed that no one drinks the supplied water directly. Nearly all households (98%) used water purifier techniques (i.e., water filters and boiling) to prevent water-borne diseases. Overall, 36% of the respondents used both filtering and boiling techniques, about a half (48%) of the respondents adopted only filtering techniques, some respondents (14%) adopted only boiling techniques to purify the water prior to drinking, and only 2% bought their drinking water from the stores (Fig. 5b). These practices suggest that there is a latent demand for more safe and reliable water services in Dhaka. Dhaka residents often resort to costly avoidant

Table 4 Results of vulnerability classification of drinking water supply in Dhaka city

	Indicators	Definition	Vulnerability Classification			Situation in Dhaka
			Low	Moderate	High	
1.	Population Density (people/km^2)	Number of people living per km^2 (higher will be the population density, higher will be the vulnerability).	<300 (people/km^2)	300–1500 (people/km^2)	>1500 (people/km^2)	23,234 (people/km^2) (High Vulnerability)
2.	Groundwater Depletion Trend (m)	Availability of groundwater (higher will be the rate of depletion, higher will be the vulnerability).	Decreasing Trend	Moderate Trend	Increasing Trend	Increasing Trend (High Vulnerability)
3.	Groundwater Quality	Current status of groundwater (higher will be the quality of groundwater, lower will be the vulnerability).	Good (Almost all Water parameters lie within the ECR permissible range)	Moderate (Few water parameters lie within the ECR permissible range)	Poor (Almost all Water parameters lie beyond the ECR permissible range)	Good (Low Vulnerability)
4.	Surface Water Quality	Current status of surface water (higher will be the quality of surface water, lower will be the vulnerability).	Good (Minor degree of threat)	Moderate (Occasionally threatened)	Poor (Almost always threatened)	Poor (High Vulnerability)

behaviors, such as boiling, filtering, or buying bottled water to ensure safe drinking water. If a household member falls sick due to water-borne disease (diarrhea, dysentery, etc.), the family income may be used to cover medical expenses, negatively affecting their disposable income. While it cannot be definitively confirmed that these diseases are caused solely by drinking the supplied water, it is possible that water may be a contributing factor. Hossain et al. (2015) noted that the main cause of the high prevalence of water-borne diseases in Old Dhaka might be the cross contamination of leaking pipes with sewerage networks. A recent study by Parvin et al. (2022) mentioned that the water supplied by WASA in Bashabo, Sobujbag, and Badda is heavily contaminated with fecal coliforms.

Moreover, individuals from the local community showed interest in paying a higher price for improved drinking water service. With regard to the question of willingness to pay (WTP) for improved drinking water service, the survey results found that 77% of the respondents showed interest in paying more over the monthly current water bill in case of Dhaka WASA provides improved drinking water service, so that the respondents do need to purify water through filtering and boiling. Previous studies reported that ranges of 66–95.8% were expressive of willingness to pay for such improved water service (Eridadi et al., 2021; Akeju et al., 2018; Akhtar et al., 2018; Tussupova et al., 2015). Interestingly, about 23% of the respondents claimed that they could not afford an additional amount to

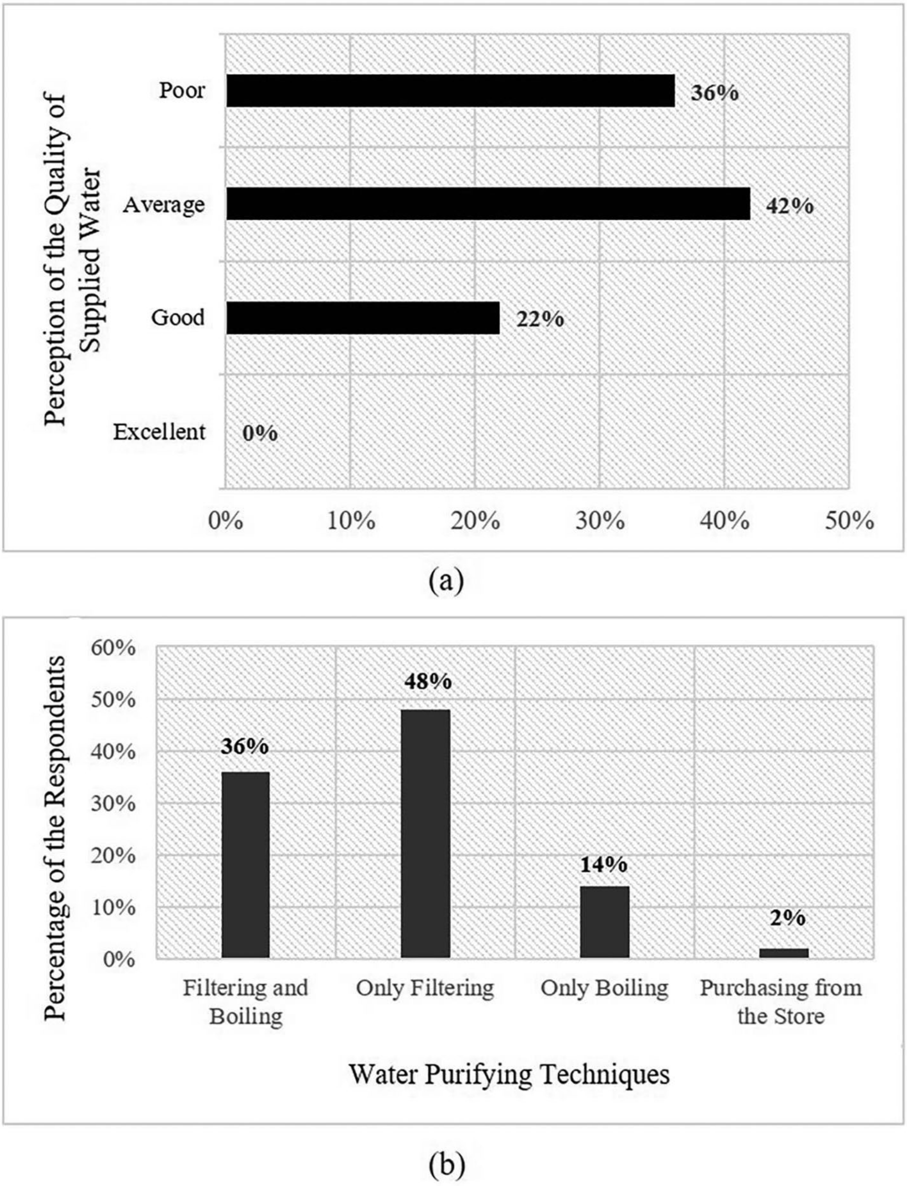


Fig. 5 Respondents' perception of (**a**) the quality of supplied water by Dhaka WASA and (**b**) water purifyng techniques used by the respondents

pay. They also stated that it is the role of the government to improve drinking water quality, and they could not ascertain the quality of drinking water service even after better payment. By providing improved drinking water based on the preferences of city residents, Dhaka WASA can enhance efficiency and profitability, as people showed an interest in paying more for receiving improved drinking water service. This will not only benefit the authority but also improve social welfare by decreasing health and other issues linked to water.

By considering all of the above analysis, the study proposes the following policy recommendations for sustainable supply of drinking water in Dhaka city.

3.5.1 Recommendations for reducing the vulnerability of groundwater and surface water

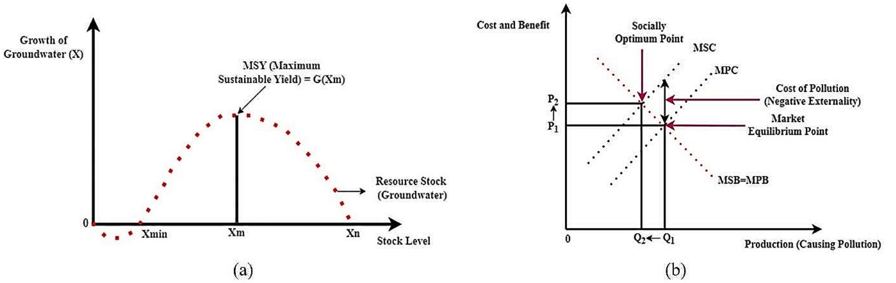
It is essential for the government to prioritize the reduction of overexploitation and wastewater discharge. This can be achieved through the implementation of innovative pollution controls, with a particular focus on groundwater conservation. Regular monitoring of groundwater quality parameters should also be conducted to ensure that they are in compliance with drinking water standards. It is necessary to reevaluate monitoring objectives and identify the most critical parameters (i.e., Fe and Mn) to be monitored. Failure to regulate groundwater extractions based on reliable information on groundwater flow mechanisms could lead to further deterioration of groundwater quality, particularly with the trend of increasing extraction from deeper aquifers. In case of improvement in surface water, the biggest change required for water quality improvement of surface water in Dhaka is the construction of sewage collection and treatment facilities is crucial. In addition, establishing a pollution source emission database that includes discharge flow, concentration, and destination is necessary. The effective implementation of the Polluter Pays Principle must be regulated to minimize overproduction by industries, which contributes to pollution emissions. Industries should adopt advanced technologies and take into account pollution abatement costs during production. The government should focus on implementing a circular economy by adopting the 3Rs approach for wastewater treatment to alleviate pressure on groundwater. The zero-discharge principle, which involves the recycling of all industrial waste and wastewater, should be actively practiced in response to the carbon-neutralization strategy.

Additionally, to reduce the impact of population pressure and pollution over water bodies in Dhaka, the government should take remedial measures such as ‘social control measures’ by shifting large and pollution emission industries to other parts of the city to increase the assimilative and carrying capacity of water bodies, restore the ecosystem, and relieve the pressure on groundwater and surface water bodies in Dhaka city. Moreover, to increase environmental quality, green technologies should be introduced in industries and building construction. Efficient management frameworks are also essential for river pollution control, and a coordinating committee or leading group that handles the legislative, judicial, and administrative aspects should be established to promote effective interventions through laws, regulations, and technologies. Lastly, prior to increasing the water bill, Dhaka WASA must address the issues of water supply adequacy, water quality assurance, and regularity to gain the trust of the residents. Residents should also keep their water reservoirs clean in order to get clean water.

3.5.2 Policies for optimal management of groundwater and surface water

One of the research objectives emphasizes the importance of managing groundwater and surface water in a sustainable manner. Two of the main factors contributing to the depletion of groundwater in Dhaka city are the growing population and over-exploitation. In Dhaka, the rate of groundwater abstraction is higher than the rate of recharge. Therefore, there is a dire need to implement the management strategies for optimal extraction of groundwater in Dhaka city. Figure 5 (a) illustrates the growth of the resource stock on the vertical axis and the stock level (X) on the horizontal axis. A sustainable yield is achieved when the level of harvest (yield) equals the growth of the stock with human intervention. To determine the Maximum Sustainable Yield (MSY) of groundwater, 'G(Xm)' should correspond to the MSY stock 'Xm'. If MSY was extracted from the stock, it will regenerate, allowing us to obtain MSY again in the next time period, and so on. Harvesting MSY annually is feasible if it regenerates yearly, whereas harvesting once every decade is necessary if it takes a decade to regenerate. MSY refers to the maximum sustainable yield that can be extracted without depleting the resource's long-term stock. The curve in the diagram starts at Xmin, the critical minimal stock level, and falls below this threshold (X_0) when the stock level is exhausted. Overuse of groundwater resources will negatively impact future generations' resource availability (Bhattacharya, 2012). Henceforth, to maintain the sustainability of groundwater supply in Dhaka, the suggested economic model can serve as policy for ensuring the sustainability of the groundwater resource. Additionally, rainwater harvesting, eliminating free rider problems, implementing backstop technologies (towards substitutes), and managing population and industrial growth are all critical factors in maintaining the sustainability of groundwater resources in Dhaka, both for present and future generations.

In Dhaka, every industry is concerned with private cost and benefit instead of social cost and benefit. In such a case, industries must take into account Marginal Social Cost (MSC) in their production processes rather than solely considering Marginal Private Cost (MPC), which overlooks negative externalities to the people and environment as well. Figure 6 (b) shows the internalization of negative externalities created by industries. To achieve the ideal output, industries must produce at the 'socially optimum point' rather than at the 'market equilibrium point'. When industry considers MSC instead of MPC at the socially optimum point, the cost of goods will increase from P_1 to P_2, and the output will be reduced from Q_1 to Q_2. When there is a reduction in output, there will be a reduction in pollution. By internalizing negative externalities, there will be no overproduction by the industries, and hence there will be a reduction in the extra discharge of solid and liquid wastes into rivers. Note that the socially optimum point represents a level of output at which there will be less pollution than that of the market equilibrium point but not zero pollution. By addressing the negative externalities created by industries, there will be no market failure or deadweight loss for



(a)

(b)

Fig. 6 (**a**) Relationship between resource stock (groundwater) and growth of groundwater (modified from Bhattacharya, 2012) and (**b**) internalization of negative externalities for water pollution (modified from Hariss & Codur, 2013) society. Therefore, this economic instrument can serve as a policy for regulating industries for the betterment of the water bodies in Dhaka. This policy of internalizing negative externalities will decrease the environmental cost in terms of ecosystem damage, the economic cost in terms of clean-up expenses, etc., and the social cost in terms of public health.

4 Conclusions

Providing safe drinking water has been considered as one of the most important public health priorities since the quality of drinking water is closely associated with human health. The current freshwater pollution situation in Dhaka could make it harder to achieve the targets of SDG 6 (clean water and sanitation) as well as those related to SDG 3 (good health and well-being) and SDG 11 (sustainable cities and communities). This study revealed that most of the groundwater quality parameters in different areas of Dhaka lie within ECR-1997 permissible range (except Fe and Mn). On the contrary, groundwater levels are declining drastically, which raises concerns about ensuring the sustainability of this resource urgently. Additionally, the water quality of the peripheral rivers in and around Dhaka is poor for drinking purposes. The Meghna River is one of the last resorts to supply quality drinking water for the citizens of Dhaka. Therefore, the Meghna River must be protected from being polluted and other water bodies in Dhaka must be restored. As climate change is unavoidable and will be amplified in Dhaka's water sector, it is time to consider both climate change adaptation options and sustainable water resource management in the meanwhile. Hence, the outcomes of this study call for related authorities (i.e., Dhaka WASA) must address the threats related to drinking water supply (i.e., the issues of rapid groundwater depletion, surface water pollution, possible leakages in supplied water pipes, etc.). The study did not include the slum communities regarding their perception of the quality of the supplied water. Hence, we call for further research to evaluate the slum area's people's perceptions of the quality of the supplied water. Prioritizing the welfare of urban inhabitants by improving drinking water service is crucial for the local authority.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Akeju, T., Oladehinde, G., & Abubakar, K. (2018). An analysis of willingness to pay (WTP) for improved water supply in Owo Local Government, Ondo State, Nigeria. *Asian Research Journal of Arts & Social Sciences*, *5*(3), 1–15. https://doi.org/10.9734/ARJASS/2018/39282.

Akhtar, S., Dean, S., Anjum, F., & Javed, M. (2018). Determination of willingness to pay for improved water supply in selected areas of Lahore. *Chinese Journal of Urban and Environmental Studies*, *6*(02), 1850013. https://doi.org/10.1142/S2345748118500136.

Alam, M. M., Rahman, M. H., & Zahid, A. A. S. (2020). Water quality assessment of Shitalakhya River. *Asian Journal of Fisheries and Aquatic Research*, *6*(1), 9–20. https://doi.org/10.9734/ajfar/2020/v6i130086.

Alom, M. M., & Habib, M. Z. (2016). Observation of water quality and supply system in Dhaka City, Bangladesh. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, *13*, 23–27. https://doi.org/10.9790/1684-1303062327.

Asia-Pacific (2021). 68 million people in Bangladesh lack access to safe drinking water: report. https://www.aa.com.tr/en/asia-pacific/68m-people-in-bangladesh-lack-access-to-safe-drinking-water-report/2292593.

Asian Development Bank (ADB) (2017). The Dhaka water services turnaround: How Dhaka is connecting slums, saving water, raising revenues, and becoming one of South Asia's best public water utilities. https://doi.org/10.22617/TCS179117-2.

Asian Development Bank (ADB) (2022). Clean and stable water for Dhaka. Partnership report 2021. https://www.adb.org/multimedia/partnership-report2021/stories/clean-and-stable-water-for-dhaka/

Bhattacharya, R. N. (2012). Economics of Natural Resources. Environmental Economics: An Indian Perspective.1–30. http://coe.mse.ac.in/dp/DISSEMINATION%20PAPER%20-%2022.pdf.

Bodrud-Doza, M., Bhuiyan, M. A. H., Islam, S. D. U., Quraishi, S. B., Muhib, M. I., Rakib, M. A., & Rahman, M. S. (2019a). Delineation of trace metals contamination in groundwater using geostatistical techniques: A study on Dhaka City of Bangladesh. *Groundwater for Sustainable Development*, *9*, 100212. https://doi.org/10.1016/j.gsd.2019.03.006

Bodrud-Doza, M., Bhuiyan, M. A. H., Islam, S. D. U., Rahman, M. S., Haque, M. M., Fatema, K. J., & Rahman, M. A. (2019b). Hydrogeochemical investigation of groundwater in Dhaka City of Bangladesh using GIS and multivariate statistical techniques. *Groundwater for Sustainable Development*, *8*, 226–244. https://doi.org/10.1016/j.gsd.2018.11.008

Chakraborty, T. K., Ghosh, G. C., Ghosh, P., Jahan, I., Zaman, S., Islam, M. S., & Khan, A. S. (2022). Arsenic, iron, and manganese in groundwater and its associated human health risk assessment in the rural area of Jashore, Bangladesh. *Journal of Water and Health*, *20*(6), 888–902. https://doi.org/10.2166/wh.2022.284.

Chowdhury, F. (2018). A study on ground water scenario in Dhaka, the capital city of Bangladesh. *Int J Innov Res Sci Eng Technol*, *7*, 10981–10989. https://doi.org/10.15680/IJIRSET.2018.0711064.

Chowdhury, R. M., Ankon, A. A., & Bhuiyan, M. K. (2021). Water Quality Index (WQI) of Shitalakshya River Near Haripur Power Station, Narayanganj, Bangladesh. *Journal of Engineering Science*, *12*(3), 45–55. https://doi.org/10.3329/jes.v12i3.57478.

Department of Environment (1997). The Environment Conservation Rules, 1997. https://faolex.fao.org/docs/pdf/bgd19918.pdf.

Dewan, A. M., Kabir, M. H., Nahar, K., & Rahman, M. Z. (2012). Urbanisation and environmental degradation in Dhaka metropolitan area of Bangladesh. *International Journal of Environment and Sustainable Development*, *11*(2), 118–147. https://doi.org/10.1504/IJESD.2012.049178.

Dhaka WASA. (2020a). Annual Report 2018–2019. http://dwasa.portal.gov.bd/sites/default/files/files/dwasa.portal.gov.bd/annual_reports/743e1a3c_035c_4f66_a5a7_6827f39f4c68/2020-11-08-13-12-fe46dfae2ee91e0cb90b9ec2fa149f5b.pdf

Dhaka WASA. (2020b). Annual Report 2020–2021. https://dwasa.portal.gov.bd/sites/default/files/files/dwasa.portal.gov.bd/page/b5e42944_f9c0_430e_add7_b0888ba9e0d2/2022-08-11-09-09-60b874cb-b0a32c32b0a65d7f60894703.pdf

Duti, B. M., Alam, R. Q., & Hossain, M. M. (2012). Changing Climate and Surface and Ground Water Related issues in Dhaka. *Journal of Engineering*, *3*(1), 161–169. https://www2.kuet.ac.bd/JES/images/files/v3/v3j19.pdf.

Eridadi, H. M., Yoshihiko, I., Alemayehu, E., & Kiwanuka, M. (2021). Evaluation of willingness to pay toward improving water supply services in Sebeta town, Ethiopia. *Journal of Water Sanitation and Hygiene for Development*, *11*(2), 282–294. https://doi.org/10.2166/washdev.2021.204.

Faridatul, M. I., & Bari, M. N. (2021). Understanding the long-term changes in Groundwater Level-A Tale of highly Urbanized City. *Journal of Geographic Information System*, *13*(4), 466–484. https://doi.org/10.4236/jgis.2021.134026.

Gizaw, Z., Gebrehiwot, M., Destaw, B., & Nigusie, A. (2022). Access to basic drinking water services, safe water storage, and household water treatment practice in rural communities of northwest Ethiopia. *Scientific Reports*, *12*(1), 20623. https://doi.org/10.1038/s41598-022-25001-y.

Global Water Partnership (2019). Rapid Assessment of Greater Dhaka Groundwater Sustainability. Bangladesh Water Partnership. https://2030wrg.org/wp-content/uploads/2019/11/GW-Report-Final-Peer-Reviewed.pdf.

Hariss, J. M., & Codur, A. M. (2013). Microeconomics and the Environment. https://www.researchgate.net/publication/277305299_Microeconomics_and_the_environment.

Hasan, M. M., Ahmed, M. S., & Adnan, R. (2020). Assessment of physico-chemical characteristics of river water emphasizing tannery industrial park: A case study of Dhaleshwari River, Bangladesh. *Environmental Monitoring and Assessment*, *192*, 1–24. https://doi.org/10.1007/s10661-020-08750-z.

Hoque, M. A., Scheelbeek, P. F. D., Vineis, P., Khan, A. E., Ahmed, K. M., & Butler, A. P. (2016). Drinking water vulnerability to climate change and alternatives for adaptation in coastal South and South East Asia. *Climatic Change*, *136*, 247–263. https://doi.org/10.1007/s10584-016-1617-1.

Hossain, T., Sikder, M. T., & Jakariya, M. (2015). Assessment of public health affected by municipal piped water supply in Old Dhaka, Bangladesh. https://doi.org/10.11648/j.ijepp.s.2015030201.11.

Hossain, M. J., Chowdhury, M. A., Jahan, S., Zzaman, R. U., & Islam, S. L. U. (2021a). Drinking water insecurity in southwest coastal Bangladesh: How far to SDG 6.1? *Water*, *13*(24), 3571. https://doi.org/10.3390/w13243571

Hossain, M. I., Khanam, S., & Rahman, M. A. (2021b). Assessment of Water Quality Parameters and Associated Health Impacts of Supplied Drinking Water in Mohakhali and Banani Area of Dhaka City, Bangladesh. https://www.researchgate.net/publication/352835567.

Hossain, M. Z., Nikam, B. R., Srivastav, S. K., & Gupta, P. K. (2021c). Estimating groundwater resource and understanding recharge processes in the rapidly urbanizing Dhaka City, Bangladesh. *Groundwater for Sustainable Development*, *12*, 100514. https://doi.org/10.1016/j.gsd.2020.100514

Islam, M. S. (2018). Spatial disparity of groundwater depletion in Dhaka City. https://www.researchgate.net/publication/325390176_Spatial_Disparity_of_Groundwater_Depletion_in_Dhaka_City.

Islam, M. S., Uddin, M. K., Tareq, S. M., Shammi, M., Kamal, A. K. I., Sugano, T., & Kuramitz, H. (2015). Alteration of water pollution level with the seasonal changes in mean daily discharge in three main rivers around Dhaka City, Bangladesh. *Environments*, *2*(3), 280–294. https://doi.org/10.3390/environments2030280.

Islam, M., Van Camp, M., Hossain, D., Sarker, M. M. R., Khatun, S., & Walraevens, K. (2021). Impacts of large-scale groundwater exploitation based on long-term evolution of hydraulic heads in Dhaka city. *Bangladesh Water*, *13*(10), 1357. https://doi.org/10.3390/w13101357

Jerin, T., & Ishtiaque, A. (2015). Groundwater Depletion in Dhaka City, Bangladesh: A Spatio-temporal Analysis. In *AGU Fall Meeting Abstracts* (Vol. 2015, pp. H51K-1532). https://www.researchgate.net/publication/312522437.

Khan, H., Khan, A. A., & Hall, S. (2005). The Canadian water quality index: a tool for water resources management. In *MTERM International Conference* (Vol. 8). https://www.researchgate.net/publication/242689965.

Kirby, M., & Mainuddin, M. (2022). The impact of climate change, population growth and development on sustainable water security in Bangladesh to 2100. *Scientific Reports*, *12*(1), 22344. https://doi.org/10.1038/s41598-022-26807-6.

Liu, J., & Zheng, C. (2016). Towards integrated groundwater management in China. *Integrated Groundwater Management: Concepts, Approaches and Challenges*, 455–475. https://link.springer.com/chapter/10.1007/978-3-319-23576-9_18.

Mamoon, W., Qadir, A., Mohib, K., Munir, M., Haque, A., & Billah, M. (2021). Analysis of groundwater level fluctuations in Dhaka city. In *Proceedings of the 5th International Conference on Advances in Civil Engineering, CUET, Chattogram, Bangladesh*, 22. https://www.researchgate.net/publication/348752376

Moshfika, M., Biswas, S., & Mondal, M. S. (2022). Assessing groundwater level declination in Dhaka city and identifying adaptation options for sustainable water supply. *Sustainability*, *14*(3), 1518. https://doi.org/10.3390/su14031518.

Parvin, M., Hossain, S., & Rahman, A. (2019). Unsustainable groundwater depletion of Madhupur tract aquifer underneath Dhaka city and its relation to climate change. In *International Conference on Sustainability in Natural and Built Environment (iCSNBE2019)* (Vol. 19, p. 22). https://www.researchgate.net/publication/330554685.

Parvin, F., Haque, M. M., & Tareq, S. M. (2022). Recent status of water quality in Bangladesh: A systematic review, meta-analysis and health risk assessment. *Environmental Challenges*, *6*, 100416. https://doi.org/10.1016/j.envc.2021.100416.

Rahman, A., Jahanara, I., & Jolly, Y. N. (2021). Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh. *Water Science and Engineering*, *14*(2), 139–148. https://doi.org/10.1016/j.wse.2021.06.006.

Sehreen, F., Masud, M. M., Akhtar, R., & Masum, M. R. A. (2019). A contingent valuation approach to evaluating willingness to pay for an improved water pollution management system in Dhaka City, Bangladesh. *Environmental Monitoring and Assessment*, *191*, 1–15. https://doi.org/10.1007/s10661-019-7595-9.

Shourav, M. S. A., Mohsenipour, M., Alamgir, M., Pour, S. H., & Ismail, T. (2016). Historical trends and future projection of climate at Dhaka city of Bangladesh. *Jurnal Teknologi*, *78*, 6–12. https://doi.org/10.11113/jt.v78.9234.

Syafiuddin, A., Boopathy, R., & Hadibarata, T. (2020). Challenges and solutions for sustainable groundwater usage: Pollution control and integrated management. *Current Pollution Reports*, *6*, 310–327. https://doi.org/10.1007/s40726-020-00167-z.

Tussupova, K., Berndtsson, R., Bramryd, T., & Beisenova, R. (2015). Investigating willingness to pay to improve water supply services: Application of contingent valuation method. *Water*, *7*(6), 3024–3039. https://doi.org/10.3390/w7063024.

Uddin, M. J., & Jeong, Y. K. (2021). Urban river pollution in Bangladesh during last 40 years: Potential public health and ecological risk, present policy, and future prospects toward smart water management. *Heliyon*, *7*(2). https://doi.org/10.1016/j.heliyon.2021.e06107.

Uddin, S., Parvej, M., Afrin, M. N., & Alam, M. A. (2018). Climate Change Impacts and Pollution Status of Buriganga River, Bangladesh. https://www.academia.edu/66831335/Climate_Change_Impacts_and_Pollution_Status_of_Buriganga_River_Bangladesh.

World Population Review (2024). Dhaka Population 2024. https://worldpopulationreview.com/world-cities/dhaka-population.

Yeazdani, S. M. G. (2016). State of drinking water and its management aspects in Dhaka city. *Journal of Nepal Geological Society*, *50*(1), 59–64. https://doi.org/10.3126/jngs.v50i1.22865.

Yin, H., Islam, M. S., & Ju, M. (2021). Urban river pollution in the densely populated city of Dhaka, Bangladesh: Big picture and rehabilitation experience from other developing countries. *Journal of Cleaner Production*, *321*, 129040. https://doi.org/10.1016/j.jclepro.2021.129040.

Zhang, L., Wilson, J. P., MacDonald, B., Zhang, W., & Yu, T. (2020). The changing PM2. 5 dynamics of global megacities based on long-term remotely sensed observations. *Environment International*, *142*, 105862. https://doi.org/10.1016/j.envint.2020.105862.

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