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Impact of climate-induced extreme events and demand–supply gap on water resources in Bangladesh

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ABSTRACT

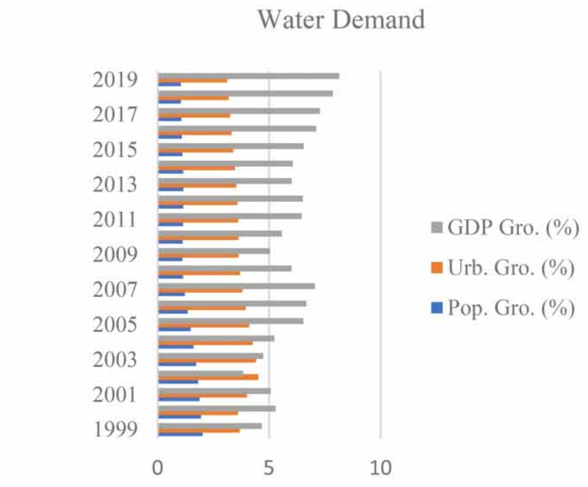
Agriculture, domestic users, and industry rely on water resources systems for fulfilling water demand, while water resources systems face both climate-induced extreme events and management and governance problems. These constraints lead to a mismatch between demand and supply of water for those sectors. This study applies central tendency and variability to analyze data and a mixed methods approach to interpret the result. From 1999 to 2019, the growth rates of population, gross domestic product, and urban population are -1.354, 6.084, and 3.70%, respectively, contributing to increased water demand. However, the average groundwater depletion increased from 2.455 km^3 (1989–1990) to 4.9016 km^3, while the average flood-affected areas enhanced by 8,644 km^2 in 2014–2018 compared to 1987–1991. Furthermore, salt-affected areas incremented by 222,810 ha in 2009 contrasted to 1973, whereas the mean wind speed of cyclones increased by 30.02 km in 2015–2020 compared to 1988–1995. The mean sea-level rise increased by 16.8 and 169.2 cm in 1995–2000 compared to 1979–1983 in *Cox's Bazar* and the *Char Changa* station, respectively. The Mann–Kendall test was applied to detect the trend. This study urges policymakers, water experts, and academics to promote rainwater harvesting that is sustainable to govern rainwater and mitigate water and economic poverty.

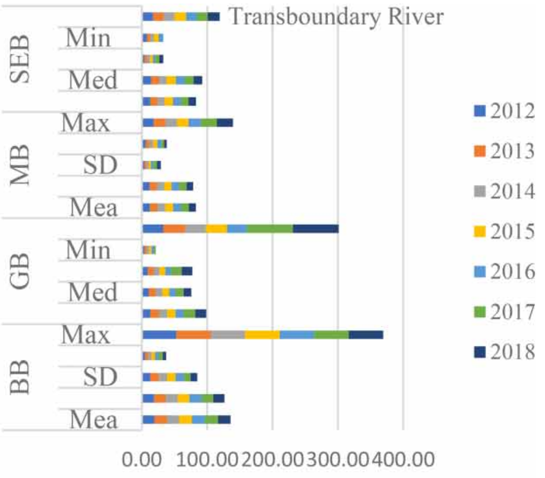
Key words: Bangladesh, climate-induced extreme events, demand–supply gap, Mann–Kendall test, water resources

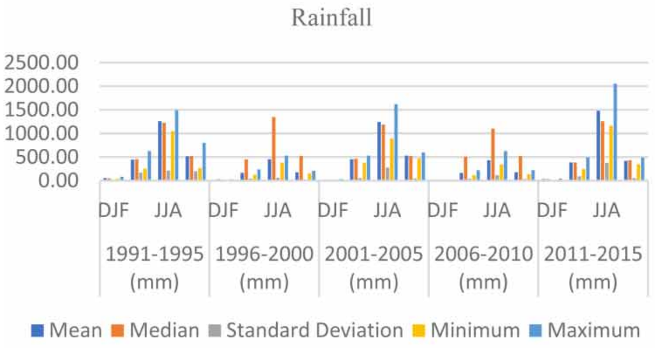
HIGHLIGHTS

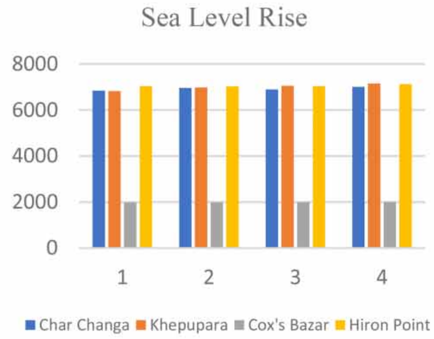
- The study used secondary data that quantify the water demand and supply.
- How is the demand and supply gap created?
- How are climatic extreme events responsible for this gap?

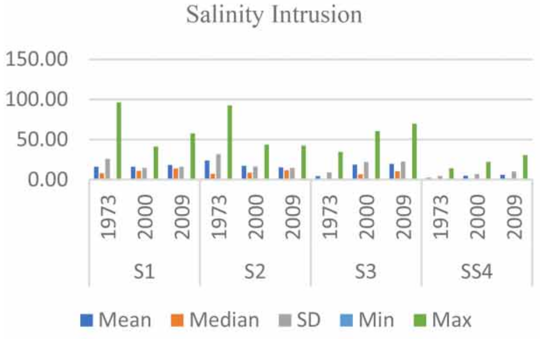
GRAPHICAL ABSTRACT

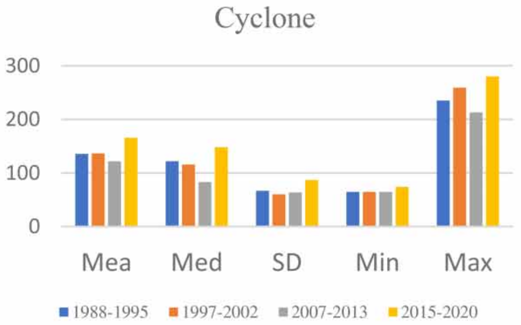


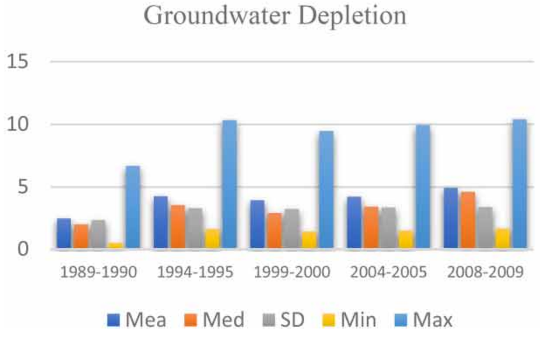


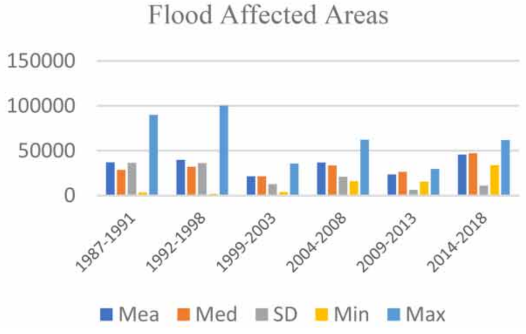












INTRODUCTION

Water is a vital component of the planet, and water resources are intricately connected to climate change dynamics (Bates *et al.* 2008; IPCC 2014). Water systems are vulnerable to man-made, natural, and climatic extreme events such as floods, cyclones, drought, heatwaves, rainfall, storm surges, and sea-level rise. However, over the past 100 years, global water consumption altogether in households, industry, and agriculture has increased by a factor of six and continues to increase steadily at a rate of 1% per year due to population growth, change in consumption patterns, and economic advancement (Wada & Bierkens 2014; UN-Water 2020). However, the supply of water is more erratic and uncertain (UNU Water 2013; FAO 2017; IPCC 2018) due to climate change that directly and indirectly changes the hydrological systems that are disturbing water quality, volume, and change in demand of water (Timmerman *et al.* 2020). This mismatch between demand and supply of water (Liu *et al.* 2017) leads to a water crisis that is more severe in Bangladesh.

Therefore, the water crisis is a crucial challenge in Bangladesh due to (a) growing demand throughout the country that creates immense pressure on groundwater sources (Chowdhury 2010); (b) an alarming increase in water pollution due to unplanned industrialization and dire sanitation circumstances (World Bank 2005); (c) water resource management that is the sole responsibility of a few organizations[1] and does not have good coordination between them (Chan *et al.* 2016); (d) upstream water diversion through different dams and barrages[2] in the transboundary rivers, which inhibits the ability to mitigate the water crisis (Chan *et al.* 2016); and (e) adverse impacts of climate change[3] (Asaduzzaman *et al.* 2010).

There is a lack of investigation in Bangladesh through analyzing the national-level data and quantifying the level of change in extreme events that affect water resources. A study of the whole country is needed and important for better understanding of the factors responsible for rising water demand and supply-side response. The main objective of this paper is to advance the literature on factors responsible for rising water demand, quantify water sources response to this, and quantify the intensity of extreme that affects water resources by analyzing national-level data. This will help the national and global community to advance water resources management for climate change adaptation and sustainable economic development. It will also urge finding and accommodating a sustainable approach to reducing the water demand–supply gap. This study is relevant for various government organizations dealing with water resources management,[4] policymakers, and professionals in water resources management and governance.

METHODOLOGY

Study site

Bangladesh is not a large country in terms of area (147,570 km^2) but is ranked 8th and 5th in the World and Asia, respectively, in terms of population size (163 million). The area attributes to 18,290 km^2 (water) and 130,170 km^2 (land). Figure 1 shows that it is located on the Bay of Bengal in South Asia surrounded by India (west, north, and east) and Myanmar (south-east). The topography of the country is characterized by a broad alluvial plain (southern, rising toward the north), a hilly region (northeastern and southeastern), and terraced land (central and northwestern) (Shahid 2010). The topography and geographical locations make the country more susceptible to climate-induced hazards (Bhowmik *et al.* 2021). A major part of this country (80%) consists of the floodplain of the Ganges, Brahmaputra, and Meghna (GBM), and some other rivers (Brouwer *et al.* 2007).

Water resources in Bangladesh can be categorized into two groups, namely surface and groundwater. The surface water is attributed to transboundary water flow, rainwater, water on seasonal wetlands, and water on standing water bodies (Ahmed & Roy 2007). Water flows from these sources substantially vary between monsoon and dry seasons. Major responsible factors for these variations are water flow in GBM and rainfall patterns. For instance, more than 75% of annual rainfall takes place in the monsoon and via water management practices of upstream countries (e.g., planned interventions and anthropogenic actions) (Shahid 2010; Kolås *et al.* 2013).

Since the country stands on the Northern Tropic, its climate is tropically characterized by high temperature, heavy seasonal rainfall, high humidity, and distinguished seasonal variations (Thomas *et al.* 2013). Rainfall varies from 1,400 mm (west) to >4,300 mm on the east side of the country (Shahid 2010). According to Shahid (2010), seasons can be divided into four

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[1] Bangladesh Water Development Board, Ministry of Agriculture, Ministry of Environment and Forest.

[2] *Farrakka* Barrage, National River Linking Project of India.

[3] Drought, heatwave, floods, sea-level rise, and other extreme events.

[4] Ministry of Water Resources, Water Development Board, Institute of Water Modeling, Water Resource Planning, and Organization.

Figure 1 | Geographical map of Bangladesh (*Source*: https://www.google.com/maps/place/Bangladesh/@23.4905831,88.1002603,7z/data=!3m1!4b1!4m5!3m4!1s0×30adaaed80e18ba7:0xf2d28e0c4e1fc6b!8m2!3d23.684994!4d90.356331).

categories such as pre-monsoon and hot summer (March–May); rainy or monsoon season (June–September); dry winter (December–February); and post-monsoon and autumn season (October–November). Therefore, to manage the water resources within the country and come outside of the country, different laws, policies, and acts emerged in Bangladesh. Figure 2 provides a summary of water governance and management mechanisms in Bangladesh.

Research question

Climate-induced extreme events occur almost every year in the country. For this reason, the country is recognized as one of the most climate-vulnerable countries (Climate Central 2019; Kulp & Strauss 2019). It has been estimated that 3 feet rise in sea level by 2050 will submerge 20% of the land and displace more than 30 million people (Glennon 2017), particularly from the coastal settings. Therefore, biophysical factors such as flat, low-lying land, and climatic component variations, and socio-economic factors such as high dependence on natural resources, poverty, population density, population growth, education, and poor health conditions make disasters more impactful (Thomas *et al.* 2013; Ayers *et al.* 2014; Bhowmik *et al.* 2021). In this context, the research questions of this study are: What factors are responsible for the rising water demand? How supply-side respond to fulfill the water demand? How are climate-induced extreme events[5] affecting water resources in Bangladesh?

Data sources

The extreme events inhibit water supply in two different ways, creating physical water scarcity and contaminating water. For instance, arsenic contamination creates quality problems, while lack of rainfall creates physical scarcity. To understand the supply of water to meet up demand, it needs to collect and sort out data from different reliable sources. In this study, data are collected from Flood Forecasting and Warning Centre, World Bank, World Bank Group Climate Change Knowledge Portal, Soil Resource Development Institute, Commonwealth Scientific and Industrial Research Organization, Water Resource and Planning Organization, Institute of Water Modeling, Centre for Environmental and Geographical Information System, Ministry of Water Resources, and Bangladesh Water Development Board.

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[5] Rainfall, flood, sea-level rise, cyclone, temperature, and arsenic contamination. Here, climate-induced extreme events to imply rainfall, sea-level rise, cyclone, flood, and arsenic contamination that affect water resources in Bangladesh.

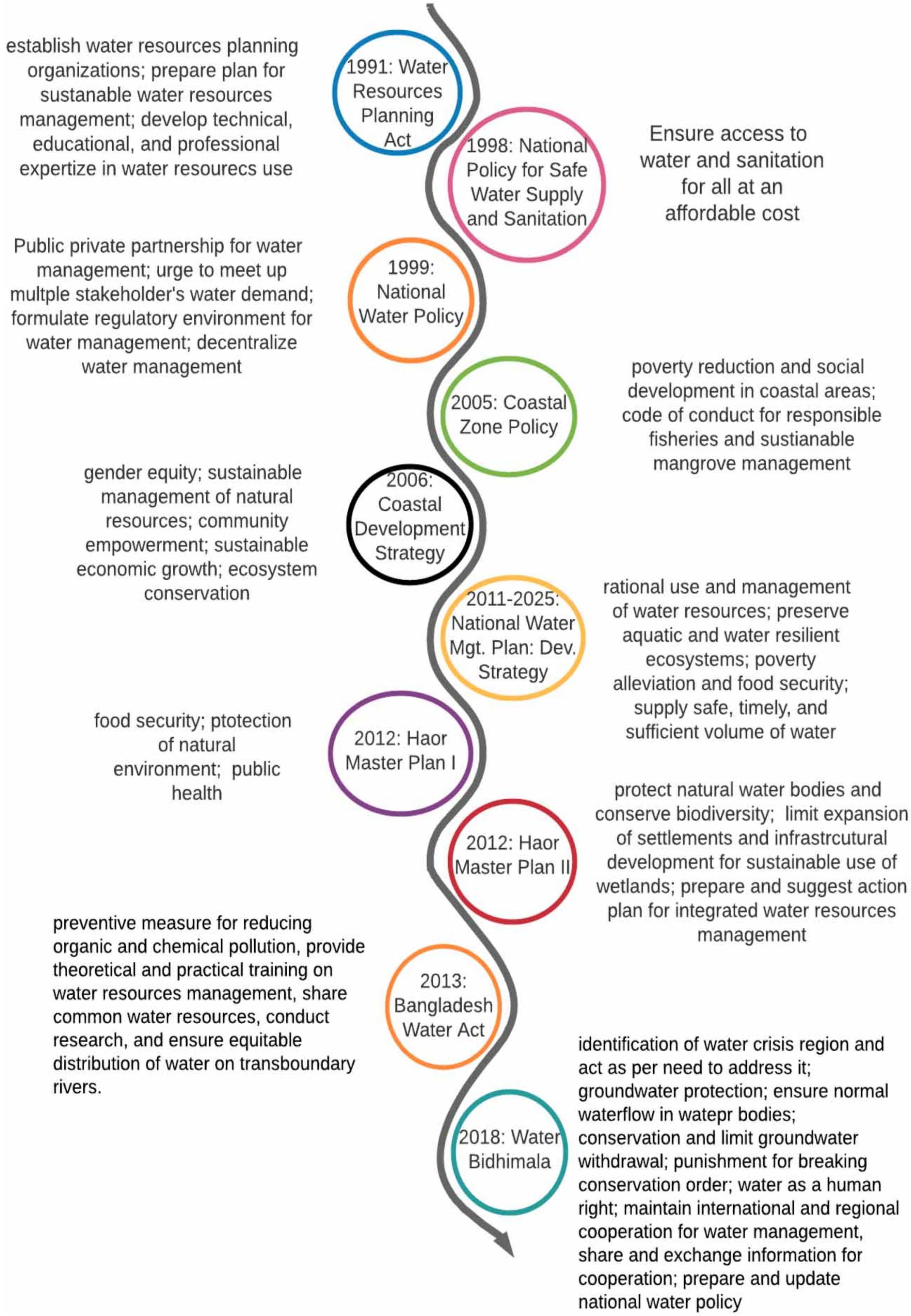

Figure 2 | History of water resources management mechanism in Bangladesh (*Source*: Ministry of Water Resources, https://mowr.gov.bd/ (accessed 5, 7, and 11 July 2021).

METHODS

This study follows a mixed-method approach to analyze the data. This study employs central tendency and a measure of variability to analyze data. Measures of central tendency include mean and median, while variability attributes to standard deviation, minimum, and maximum.

These components help to understand the intensity, frequency, and average change in climate-induced extreme events that affect water resources. To identify the trend, the Mann–Kendall (MK) test (Mann 1945; Kendall 1975) was applied that is widely employed in hydrological (Yue & Wang 2004; Machiwal & Jha 2012) and climatological (Mavromatis & Stathis 2011) time-series data. As per this test, the null hypothesis (H_0) is that there is no trend, while the alternative hypothesis (H_1) is that there is a presence of trend (Onoz & Bayezit 2003). The 'R' software was employed to perform the MK test. This study uses the following hypotheses for this test (Table 1).

Analytical framework

Climate change exposes itself as enhancing the frequency and intensity of extreme events that influence the quality and quantity of water in multiple ways (Bates *et al.* 2008). For example, water quality is degraded through higher water temperature, reduced dissolved oxygen, rising pollutant concentration during drought, water pollution, deterioration of groundwater quality due to saltwater intrusion in coastal settings, disruption of water treatment facilities during floods (IPCC 2014; UNEP 2016), pathogen contamination by floods, and thus a reduced self-purifying capacity of freshwater bodies (Smakhtin *et al.* 2020), arsenic contamination in groundwater,[6] while erratic rainfall affects the availability of water. These impacts add challenges to the sustainable management of water resources (WWAP/UN-Water 2018) that threaten the enjoyment of human rights to water and sanitation for potentially billions of people (UN Water 2020), particularly in developing countries like Bangladesh.

Different studies have shown the adverse impact of climate change on water resources in Bangladesh (IPCC 2007; WHO 2008; CCC 2009; Rabanni *et al.* 2012; Abedin *et al.* 2014; Chan *et al.* 2016) that lead to the deficiency of water. The water resources system of the country is exposed to vulnerability of different types of regional climate variability such as rising temperature, the erratic nature of rainfall, droughts, floods, the rise of sea level, cyclones and storm surge, saltwater intrusion (Khan *et al.* 2011; Rabanni *et al.* 2012), and arsenic contamination (Chan *et al.* 2016) that adversely affect the supply of water. At the same time, rapid economic and population growth, and urbanization in Bangladesh cause water demand to rise in household, industry, and agriculture. In this context, it is high time to quantify the factors responsible for rising water demand, the response of water sources to this change, and climatic extremes on water resources in Bangladesh. Figure 3 explores the connection between climatic extreme events, mismatch between demand and supply, and water resources systems in Bangladesh.

RESULTS

Demand side of water

The current population of Bangladesh is about 160 million and Population Reference Bureau (PRB) estimates 250 million by 2050 based on the natural growth rate is 1.90% per annum (Streatfield & Karar 2008). This growth rate is based on crude death rate (CDR) 8/1000 and crude birth rate (CBR) 27/1000, which is more realistic (Streatfield & Karar 2008). Figure 4

Table 1 | Hypotheses in detecting trend

Factor	Hypotheses
Water demand	H_0: there is no trend in water demand factors H_1: there is a trend in water demand factors
Water supply	H_0: there is no trend in water supply sources H_1: there is a trend in water supply sources
Extreme events	H_0: there is no trend in climate-induced extreme events that limit water supply and affect water resources in Bangladesh H_1: there is a trend in climate-induced extreme events that limit water supply and affect water resources in Bangladesh

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[6] Particularly in Bangladesh and India.

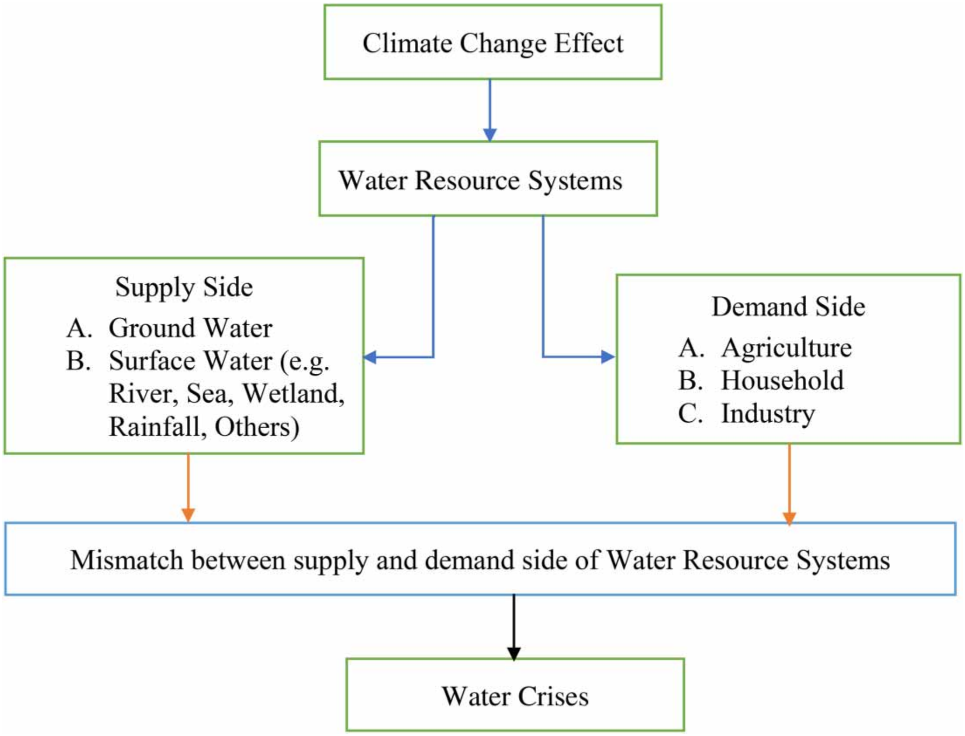

Figure 3 | Analytical framework of connection between climate change and demand–supply gap of water that led to water crisis (developed by the author).

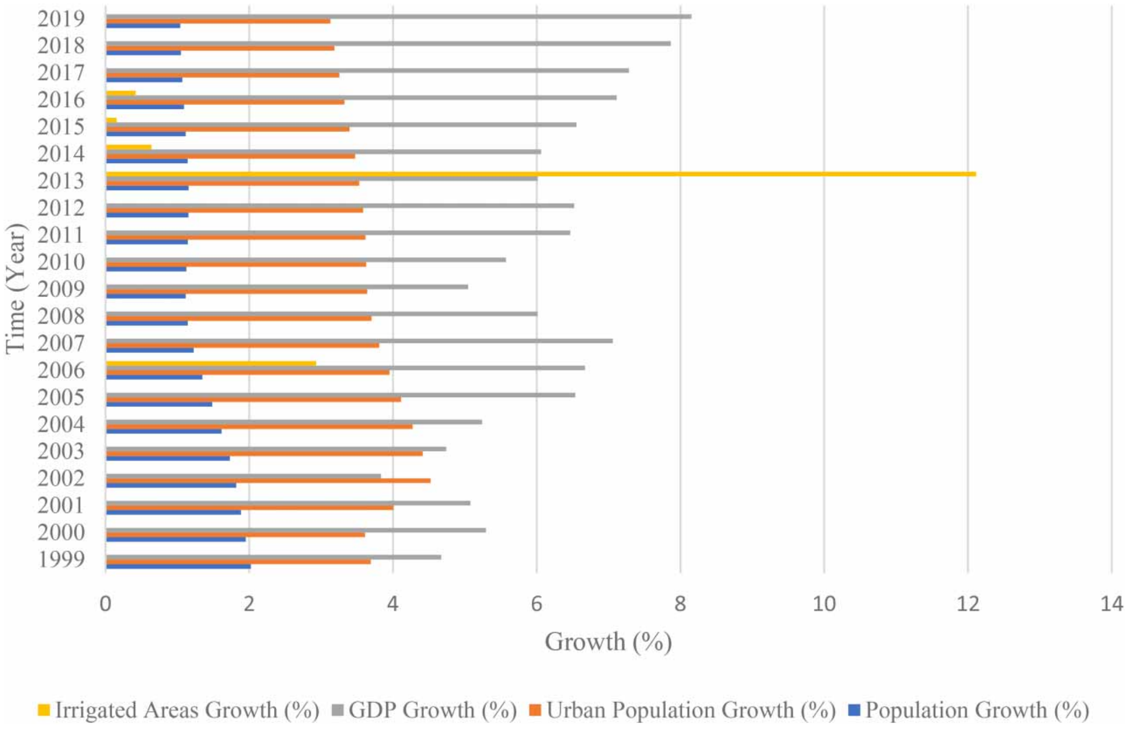

Figure 4 | Growth rate in total population, GDP, urban population, and irrigated areas in Bangladesh (*Source*: World Bank, https://databank.worldbank.org/home.aspx (accessed 15 March 2020)).

presents that the total population increases each year, which commenced at 2.02% in 1999 and shrunk to 1.04% in 2019. It grows an average of 1.354% per year. This growing population is taking a toll on water demand in two different ways. First, household water demand where they need water for their use includes washing, drinking, bathing, and so on. Secondly, the extra population needs extra food and other products and services that also require water to produce. Figure 4 shows the growth rate in total population, GDP, urban population, and irrigated areas that increase the demand for water in Bangladesh.

Figure 4 shows that the urban population increases by an average of 3.708% over the last 21 years. At the same time, GDP (Gross Domestic Product) grew on an average of 6.0846% per annum, which was 4.67% in 1999, and rose to 8.15% in 2019. The GDP has gone up more than 6% every year after 2010. This high growth of the economy intensifies the pressure on water resources to supply more water to maintain the growth. However, the growth of the urban population along with economic wealth can raise the demand for water-intensive foods such as meat, milk, egg, pulse, nuts, and cereals, which ultimately leads to increased water demand. However, the country used 51.346% of the total land in 2004 for agricultural production and it rose to 59.711% in 2016 to ensure food security. This growth reveals that water demand also increases in the agriculture sector to ensure food security for the extra population. To fulfill the demand for water for the growing population, economy, and industry, it needs to ensure a stable water supply from different sources. Otherwise, it will create a water crisis and constrain economic development.

Supply side of water

Transboundary river water flow

The Ganges, Brahmaputra, Meghna (GBM), and Southeastern Basin (SEB) drain large volumes of rainwater that occur within and outside of the country. During this passage, it creates and records the peak level of water in each basin every year. This peak level data is used and analyzed to interpret the stability of the water supply from this source.

Table 2 shows the central tendency and variability of peak water flow for the Brahmaputra River basins from 2012 to 2018. It shows that the mean peak water level was 19.37 m (2012), 18.85 m (2013), 19.26 m (2014), 19.24 m (2015), 19.41 m (2016), 20.46 m (2017), and 19.14 m (2018), while the total volume of water flow was 310.03 m in 2012, which rose to 429.86 m in 2017 and 401.98 m in 2018. Moreover, the minimum and maximum water flows demonstrate the water flow during the dry

Table 2 | Central tendency and variability for observed peak water flows (in m) in Brahmaputra, Ganges, Meghna, and southeastern Basin during the period of 2012–2018

River Basin		2012	2013	2014	2015	2016	2017	2018
Brahmaputra Basin (BB)	Mean	19.38	18.85	19.26	19.24	19.41	20.47	19.14
	Median	18.63	17.86	18.27	18.02	18.74	17.96	16.91
	SD	13.02	12.91	12.81	12.94	12.72	10.24	10.30
	Minimum	4.95	4.92	5.11	5.20	5.21	6.77	5.13
	Maximum	52.70	52.70	52.74	52.85	52.65	53.05	52.71
Ganges Basin (GB)	Mean	13.01	13.37	12.61	12.54	12.45	17.76	16.75
	Median	10.63	10.61	10.34	10.46	9.66	12.21	11.81
	SD	9.01	9.30	8.65	9.09	8.31	16.71	16.40
	Minimum	3.71	3.61	3.76	3.73	3.87	2.69	0.00
	Maximum	32.85	33.50	31.47	32.47	30.28	70.81	69.95
Meghna Basin (GB)	Mean	12.32	11.59	11.89	12.00	11.97	11.94	11.13
	Median	11.84	11.18	11.47	11.25	11.11	11.65	10.02
	SD	3.64	3.61	3.14	3.48	3.70	5.61	5.93
	Minimum	5.96	5.52	6.05	6.14	6.00	4.59	3.81
	Maximum	18.20	17.84	17.85	17.56	18.76	24.86	24.31
Southeastern Basin (SEB)	Mean	12.70	10.93	11.25	12.86	12.05	11.49	11.80
	Median	14.28	11.98	11.18	14.73	13.37	13.79	13.29
	SD	4.05	4.06	4.40	4.41	4.04	5.73	6.01
	Minimum	7.60	5.50	5.30	7.33	7.00	0.00	0.00
	Maximum	17.05	16.32	16.93	17.45	16.32	16.85	18.36

Source: Flood Forecasting and Warning Centre, Bangladesh Water Development Board, http://ffwc.gov.bd/ (accessed 15 May 2020).

and monsoon seasons, respectively, which reveals that water flow during the dry season is very low and during monsoon is very high. This high difference between maximum points out unstable water supply and makes it difficult to fulfill water demand through this source. Another attribute is the standard deviation, which points out that water flow is not stable. This high standard deviation means that the actual flow is far away (−/+) from the mean.

Table 2 shows some indicators that measure unstable water supply in the Ganges River Basin in terms of peak water flow. The first one is the mean that began at 13.007 m in 2012 and reached 17.758 m in 2017 and 16.7472 m in 2018. There is a big difference between 2018 and 2017 compared to 2012. The following indicator is the standard deviation, and its increasing trend indicates that river water flow is becoming more abnormal per year, particularly in recent years (2017 and 2018) with respect to 2012. The third indicator is the sum of transboundary water flow each year, which commenced at 130.07 m in 2012 and reached the highest at 443.95 m in 2017 and the second highest at 418.68 m in 2018. However, the gap between maximum and minimum was 29.14 m in 2012 and reached 69.95 m in 2018, which was more than double contrasted to 2012. This large extension of the gap is not a good sign for a stable supply of water for the basin people, aquatic system, marine communities, and the economy.

The water flow in the Meghna basin is more stable than other basins in terms of standard deviation, range, and mean but a big change is shown in total volume. The first measures average peak water flows at less than 12 m but more than 11 m except in 2012, while standard deviation ranges from 3 to 6 m. However, total peak water flow increases significantly from 147.86 m in 2012 to 310.45 m in 2017 and 289.34 m in 2018. Another significant change is in the difference between maximum and minimum, which indicates that the gap between monsoon and dry season water flows is widening. For instance, it started at 12.24 m in 2012 and reached 20.5 m in 2018. This extension of the gap is not a good sign for water supply from this river because it suggests increasing water supply during monsoon and a decrease in the dry season.

The central tendency and variability of the Southeastern Basin in Table 2 show that no big change has been taking place regarding standard deviation, while it takes place majorly in total water flows, the difference between the maximum and minimum peak water flow. The mean peak level of water flow was reduced by 7.07% in 2018 balanced to 2012. The volume of peak water flow ranges from 87.43 to 106.22 m, which is not a good sign. The range started at 9.45 m in 2012 and reached 18.36 m in 2018, which is increased by 94.29% compared to 2012. This high variability in peak water flow in the river basin along with erratic rainfall increases the probability of more reliance on groundwater that is also responsible for causing a mismatch between demand and supply of water.

Groundwater

Groundwater is another main source of water. The use of this source is more intense during the dry season for fulfilling the demand than during the monsoon season. Easier accessibility and being less expensive make this source more useful than other sources. Due to these advantages, people are more reliant and overexploit this source. This overexploitation makes this source no more reliable, and the groundwater table is going down with time.

Table 3 shows the historical depletion of groundwater at different time intervals. The intensity of depletion of the country is very high and it is growing. The mean and median levels of depletion enlarge by 100 and 132% in 2008–2009, respectively, in comparison to 1989–1990. At the same time, the range[7] positively adjusted by 41.49% in 2008–2009. All of these attributes indicate the intensity of growth in groundwater exhaustion. This depletion reduces the availability of water for different sectors and makes it more challenging to meet the demand.

Rainfall

Rainfall is one of the main weather factors that indicate climate change and is also one of the main sources of water. A deeper understanding of rainfall variability in Bangladesh can help to address the demand and supply gap of water at different times over the year. Figure 5 points out that a major portion of rainfall takes place in JJA (June, July, and August) and SON (September, October, and November) and remains in DJF (December, January, and February) and MAM (March, April, and May). It is assumed that JJA and SON are called 'wet', whereas DJF and MAM are 'dry' seasons. Figure 6 postulates that the wet and dry seasons are getting more and less rainfall since the mean rainfall in wet and dry seasons increases and decreases by 119.94 and 84.13 mm, respectively, in 2011–2015 compared to 1991–1995.

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[7] Difference between maximum and minimum.

Table 3 | Central tendency and variability in groundwater depletion (km^3)

	1989–1990	1994–1995	1999–2000	2004–2005	2008–2009
Mean	2.455	4.231	3.92	4.191	4.901
Median	1.98	3.525	2.895	3.41	4,59
Std. Dev.	2.318	3.275	3.206	3.330	3.375
Minimum	0.5	1.61	1.41	1.49	1.66
Maximum	6.67	10.31	9.45	9.93	10.39

Source: CSIRO, WARPO, BWDB, IWM, BIDS, CEGIS (2014).

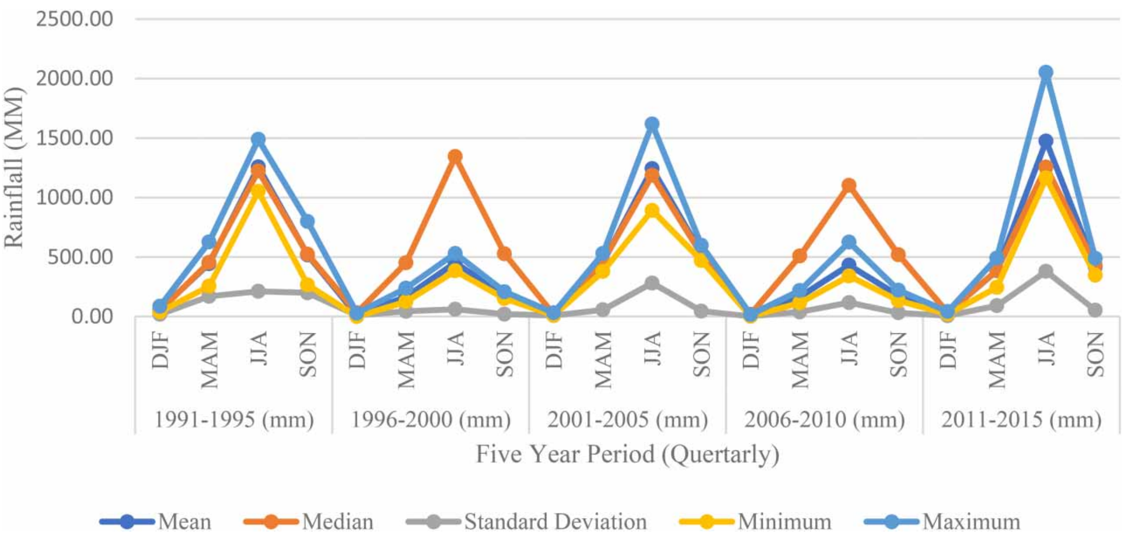

Figure 5 | Observed central tendency and variability of rainfall (in mm) in 1991–1995, 1996–2000, 2001–2005, 2006–2010, and 2011–2015 (*Source*: World Bank Group Climate Change Knowledge Portal, https://climateknowledgeportal.worldbank.org/download-data (accessed 21 April 2020)).

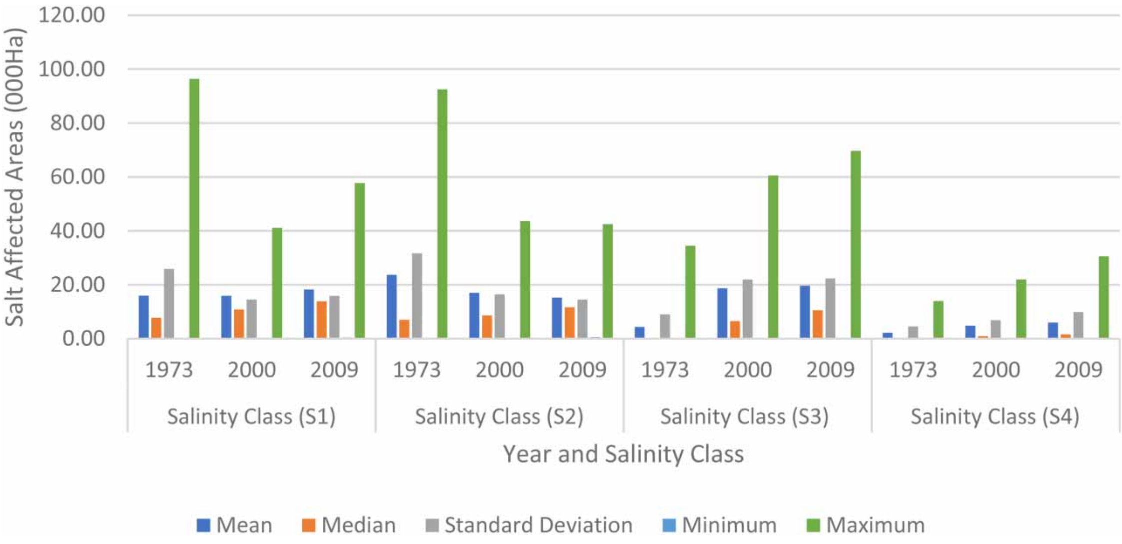

Figure 6 | Observed central tendency and variability of Salinity Classes S1, S2, S3, and S4 in 1973, 2000, and 2009 ('000) (*Source*: Soil Resource Development Institute, http://srdi.portal.gov.bd/sites/default/files/files/srdi.portal.gov.bd/publications/bc598e7a_d-f21_49ee_882e_0302c974015f/Soil%20salinity%20report-Nov%202010.pdf (accessed 15 June 2020)).

Figure 5 presents the central tendency and variability of rainfall over the years. The mean rainfall in 1996–2000 changed by 43.71 mm (DJF), 278.06 mm (MAM), 804.40 mm (JJA), and 340.25 mm (SON) contrasted to 1991–1995, while it negatively changed by 23.89 mm (DJF), 219.09 mm (MAM), 1044.15 mm (JJA), and 242.79 mm (SON) in 2011–2015 compared to 2006–2010.

The gap between minimum and maximum rainfall in each season is extending over the period[8], which indicates a rise in intensity. It also demonstrates that precipitation is becoming less evenly distributed over the season and is more erratic day by day. Moreover, between 1996 and 2000, the standard deviation changed by 8.31 mm (DJF), 125.50 mm (MAM), 151.69 mm (JJA), and 178.67 mm (SON) compared to 1991–1995. At the same time, it negatively changed by 4.71 mm (DJF), 52.31 mm MAM), 263.50 mm (JJA), and 2.87 mm (SON) in 2011–2015 compared to 2006–2010. In addition, the total volume of rainfall in 1991–1995 is 285.64 mm (DJF), 2,222.85 mm (MAM), 6,288.35 mm (JJA), and 2,591.01 mm (SON) but changed by 125.69 mm (−), 294.95 mm (−), 1,092.05 mm (+), and 492.06 mm (−) in 2011–2015, respectively.

Climate-induced extreme events on water supply and resources

Flood

Flood is a rainfall-driven climate-induced problem in Bangladesh. The probability of occurrence of rainfall-driven climate hazards (e.g., flood) is getting higher and higher due to changes in the pattern of rainfall that adversely affects the hydrological process. To determine the impact of floods and to address this, it is necessary to understand the pattern and intensity of floods. Table 4 shows the flood-affected areas (in km^2) in a 5-year time span from 1988 to 2018. It can be assumed that if flood-affected areas crossed 30,000 km^2 or 20% of total areas of the country, they can be considered extreme floods. With this indication, Table 4 exhibits that the country faces extreme floods in every 5-year time period[9] except 1999–2003 and 2009–2013 after 1987. Moreover, if we consider the maximum value as an extreme flood indicator with the assumption, it attributes that the country faces extreme floods at least once in every period.

Table 4 presents the central tendency and variability of flood-affected areas. The mean and median flood-affected areas in the 1994–1998 period changed by 2,664.4 and 3,400 km^2 compared to 1988–1993, while 13,341.4 and 7125 km^2 negatively changed in 2009–2013 contrasted to 2004–2008. Moreover, the mean and median levels of flood positively adjust with 22,083.4 and 20,670 km^2 in 2014–2018 compared to 2009–2013, respectively. The difference between minimum and maximum indicates the scale of the flood. It began with 86,470 km^2 in the first period and changed by 11,780 km^2 in the second period. In addition, it negatively moved by 66,550 and 31,975 km^2 in 1999–2003 and 2009–2013, respectively, related to the respective previous period. This high level of floods severely affects the water supply by contaminating water sources and damaging water supply infrastructure.

Salinity level

Different levels of salinity in the soil, surface water, and groundwater are tolerable for vegetation, crops, and aquatic communities. For instance, soil salinity level of <4 dS/m[10] is within the range of tolerance for crops and vegetation (SRDI 2001). For

Table 4 | Central tendency and variability of flood-affected areas (km^2)

	1987–1991	1992–1998[a]	1999–2003	2004–2008	2009–2013	2014–2018
Mean	37,094	39,758.4	21,640	36,996	23,654.6	45,738
Median	28,600	32,000	21,500	33,655	26,530	47,200
SD	36,624.74	36,339.21	12,848.07	21,069.42	6,518.29	11,089.42
Minimum	3,500	2,000	4,000	16,175	15,650	33,941
Maximum	89,970	100,250	35,700	62,300	29,800	61,979

Sources: Flood Forecasting And Warning Centre, Bangladesh Water Development Board, http://ffwc.gov.bd/ (accessed 15 May 2020).

[a] No data for 1992 and 1994.

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[8] Five years time span .

[9] Five year time period such as 1988–1993, 1994–1998, 1999–2003, 2004–2008, 2009–2013, and 2014–2018 .

[10] Decisiemens per meter.

surface water, an electric conductivity of 5 dS/m is considered as bearable for freshwater vegetation and aquatic communities as per the national standard of Bangladesh. However, the salinity level in groundwater is 600 mg. Chloride is acceptable but ESCAP/UN (1987) recommended 1,000 mg/l of chloride equal to a threshold level of 2 dS/m.

Table 5 shows the mean and median soil salinity levels are 8.656 and 6 dS/m, respectively. These values indicate that soil is not suitable for crops and vegetation. In a large part of the region, people cannot cultivate their land due to salinity. The difference between the maximum and minimum soil salinity levels (18.67 dS/m) points out that a major part of land shifted into barren and will add more in the coming future. However, the mean surface water salinity level (4.65 dS/m) is within the tolerant level (5 dS/m) for freshwater vegetation and marine communities. If we add the standard deviation (3.65 dS/m) with this mean value that crosses the limit that indicates that some places where surface water is not safe for freshwater vegetation, and maritime society.

However, the value of the mean groundwater salinity level (2.78 dS/m) is beyond the tolerant level (2 dS/m) for vegetation and aquatic communities. The gap between the highest and lowest level (11.97 dS/m) demonstrates that the salinity level in groundwater is high in some places that is severely damaging the quality of groundwater and making it unusable. This high level of salinity penetrates to a lower level or no salinity and converts the lower level into a high level and no salinity to lower-level salinity. In this way, it is possible to facilitate the salinity problem and it will go beyond the coastal region of the country. In this context, the analysis of the different years in terms of areas and class of salinity will give a clearer picture and provide evidence about the overall situation of salinity regarding the conversion of low salinity areas into high salinity areas, and the growth of salt-affected areas in coastal Bangladesh.

Table 6 shows the central tendency and variability of salt-affected areas in the coastal belt of Bangladesh. The total areas of salinity increased from 833,450 ha in 1973 to 1,020,750 ha in 2000 and 1,056,260 ha in 2009. It demonstrates that salt-affected areas increased by 22.47% in 2000 and 26.73% in 2009 compared to 1973. In 1973, there were some districts where there are no salinity problems, but in 2000 and 2009 it increased to 1,190 and 720 ha, respectively. Furthermore, mean salt-affected areas increased by 10,400 ha in 2000 compared to 1973, and 1,972 ha in 2009 compared to 2000. The standard deviation and maximum salinity areas grew up by 5,900 and 8,830 ha in 2009, respectively, related to 1973. With this salt-affected area, the division of areas as per the class of salinity can give more understanding regarding the salinity areas in coastal Bangladesh.

Figure 6 points out the salinity areas in terms of salinity classes in the coastal setting of Bangladesh. The first issue is that the salinity area is increasing. For instance, the mean area of salinity was 15,960 ha in 1973 and reached 18,250 ha in 2009, while the total area increased from 287,370 to 328,430 ha in the same year for Salinity Class (S1). On the other hand, the mean level of S2 reduced from 23,690 to 15,230 ha in 2009. It can reasonably assume that S1 salinity areas convert into S2. To get a more specific understanding, we want to see two more Salinity Classes S3 and S4.

Figure 6 shows that the mean level of S3 increased from 4,350 to 19,590 ha, while the range[11] of salinity-affected areas increased from 34,500 ha in 1973 to 69,720 ha in 2009. More importantly, the areas of S3 increased by more than four times in 2009 compared to 1973. Both indicators in S3 demonstrate that salinity-affected areas are converting from lower

Table 5 | Central tendency and variability of salinity level in soil, surface, and groundwater in coastal Bangladesh

	Salinity level (dS/m)		
	Soil	**Surface Water**	**Ground Water**
Mean	8.655	4.652	2.784
Median	6	3	1.33
SD	5.163	3.655	3.039
Minimum	1.33	1.33	1.33
Maximum	20	13.3	13.3

Source: PDO-ICZMP (2003).

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[11] Difference between maximum and minimum.

Table 6 | Central tendency and variability of salinity-affected areas (000'ha) in Bangladesh

	1973	2000	2009
Mean	46.302	56.708	58.681
Median	30.815	37.57	43.655
SD	50.285	54.213	56.188
Minimum	0	1.19	0.72
Maximum	146.35	147.08	155.18

Source: Soil Resource Development Institute, http://srdi.portal.gov.bd/sites/default/files/files/srdi.portal.gov.bd/publications/bc598e7a_df21_49ee_882e_0302c974015f/Soil%20salinity%20report-Nov%202010.pdf (accessed 15 June 2020).

levels to higher levels of salinity. However, the mean and total areas were 2,210 and 39,900 ha but rise to 4840 and 87,140 ha in 2000, respectively, for S4. In the next 9 years, the mean level and total areas increased by 1,150 and 14,780 ha, respectively, in 2009, which highlights the high intensity. Moreover, maximum areas of S3 and S4 rise from 34,500 and 14,000 ha to 69,720 and 30,570 ha in 2009 compared to 1973. It indicates that areas of these salinity levels more than doubled during that time (from 1973 to 2009). Therefore, some factors are responsible for increasing this salt-affected area with this high intensity. Tidal fluctuation is one of them.

Tidal movement

Tidal movement is the fluctuation between high and low levels of water in the coastal region. To analyze data regarding the tidal movement in coastal settings, it can be categorized as regular tidal movement (between 0.3 and 1 m), high tidal movement (1–2 m), and very high tidal movement (>2 m). The latter two are most responsible for causing saltwater intrusion and floods that deter water supply. To calculate the tidal movement in coastal Bangladesh, 0.3 m is considered as the threshold value. Out of 147 subdistricts, 63 fall in the range between 2.38 and 3.07 m tidal movement. Figure 7 presents a histogram of tidal movement in coastal Bangladesh. It demonstrates that the major part (42.85%) of coastal Bangladesh is in the very high tidal movement category. However, 46 and 38 out of 147 subdistricts fall in the high tidal and regular tidal movement category, respectively. The latter is a less responsible factor for water crisis than the former, but climate change can change the equation and turn the regular tidal movement into high, and high can shift to a very high tidal movement area category.

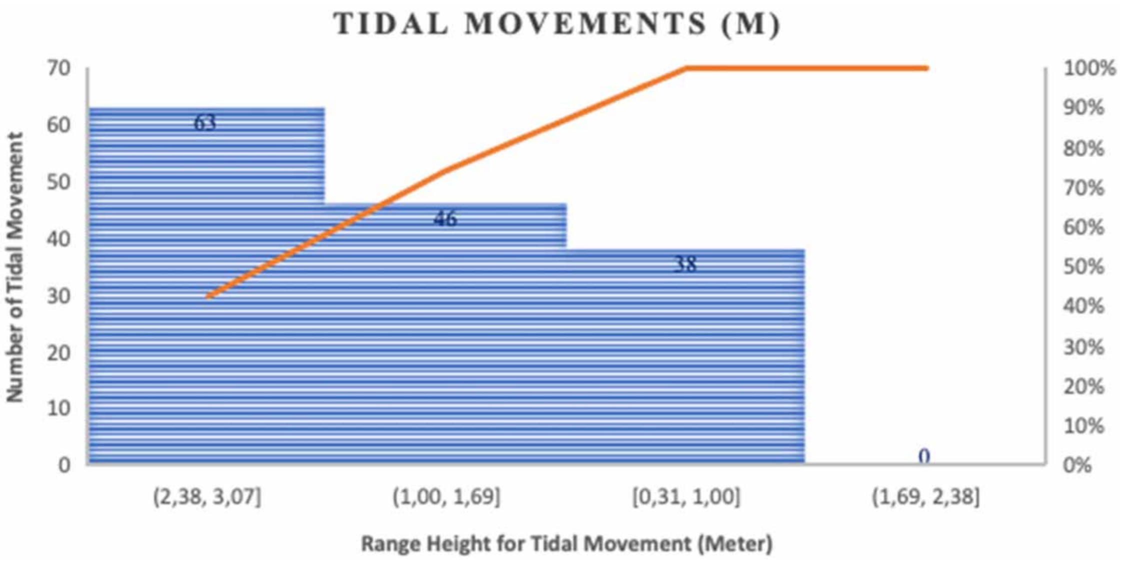

Figure 7 | Observed tidal movement in coastal Bangladesh (m) (*source*: Soil Resource Development Institute, http://srdi.portal.gov.bd/sites/default/files/files/srdi.portal.gov.bd/publications/bc598e7a_df21_49ee_882e_0302c974015f/Soil%20salinity%20report-Nov%202010.pdf (accessed 21 June 2020)).

Temperature

To analyze historical data regarding temperature in Bangladesh, this study uses central tendency and variability that give a better understanding regarding monthly temperature over the year. It also gives a clear picture concerning the distribution of temperature over the period. To compare the monthly temperature over the year, data divide into five periods that is the first (1991–1995), second (1996–2000), third (2001–2005), fourth (2006–2010), and fifth (2011–2015) period.

Table 7 reveals that temperature is not in a similar pattern throughout 1991–2015. The mean and median temperature levels escalate by 0.91 and 0.953 °C in the fourth period compared to the first, respectively. At the same time, mean and median temperature levels decline by 0.88 and 1.08 in 2011–2015 compared to 2006–2010. The temperature variation is increasing since the difference between the minimum and maximum increases by 1.5427 and 0.1676 in 2011–2015 compared to 2006–2010 and 1991–1995, respectively. The water demand facilitates since temperature variation and average temperature increase.

Cyclone

Due to global warming, cyclones are more intense and frequent, and are directly and indirectly responsible for the water crisis. First, they damage the water management and supply infrastructure, which constrain the water supply. Secondly, they pollute water (e.g., facilitating saltwater intrusion through flooding and storm surges). This intensity of cyclones is held responsible for damaging water supply, management infrastructure, and polluting water, which cause scarcity of water.

The result in Table 8 shows that the mean and median wind speeds rise by 22.16 and 21.21% in 2015–2020 compared to 1988–1995. It is reasonably assumed that when the maximum wind speed is above 150 km/h, it is considered as an extreme level cyclone. With this assumption, we can observe that during the first 14 years, five extreme-level tropical cyclones take place where the average speed is 192.03 km/h. During the last 14 years, five cyclones hit the country, where the average wind speed is 223.1 km/h. It implies that the intensity of cyclones increased significantly in the latter compared to the earlier.

Sea-level rise

Several contributing factors are responsible for changes in sea level that include the expansion of seawater by melting glaciers and ice sheets due to global warming. This study includes four stations, *Hiron Point*, *Khepupara*, *Cox's Bazar*, and *Char Changa*, to measure sea level. Table 9 shows that the mean and median sea levels rose by 73.55 and 80 cm in 1999–2003 compared to 1983–1986, respectively, at *Hiron Point*. However, Table 10 displays the central tendency and variability of

Table 7 | Central tendency and variability of temperature during 1991–2015 (°C)

	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015
Mean	24.984	25.264	25.503	25.894	25.018
Median	26.906	27.148	27.446	27,860	26.778
SD	3.776	3.671	3.514	3.485	3.909
Minimum	17.419	17.770	17.939	18.679	16.849
Maximum	29.296	29.509	29.143	29.181	28.894

Source: World Bank Group Climate Change Knowledge Portal, https://climateknowledgeportal.worldbank.org/download-data (accessed 15 March 2020).

Table 8 | Observed central tendency and variability in the maximum wind speed of cyclone (km) throughout 1988–2020

	1988–1995	1997–2002	2007–2013	2015–2020
Mean	135.5125	136.437	121.571	165.541
Median	122.1	115.625	83.25	148
SD	66.839	60.099	63.735	86.946
Minimum	64.75	64.75	64.75	74
Maximum	234.95	259	212.75	280

Source: World Bank, https://datacatalog.worldbank.org/dataset/cyclone-dataset (accessed 27 May 2020).

Table 9 | Observed sea level (cm) at the *Hiron Point* Station

	1983–1986	1987–1990	1991–1994	1995–1998	1999–2003
Mean	7,048.25	7,040	7,028.25	7,038.5	7,121.8
Median	7,049	7,029.5	7,028	7,064	7,129
SD	33.718	29.200	48.383	65.795	76.273
Minimum	7,007	7,018	6,978	6,941	7,034
Maximum	7,088	7,083	7,079	7,085	7,227

Source: Permanent Service for Mean Sea Level, https://www.psmsl.org/data/obtaining/ (accessed 25 July 2020).

Table 10 | Observed sea level (cm) at the Khepupara station

	1979–1983	1984–1988	1989–1994	1994–1999
Mean	6,822	6,980.2	7050.2	7,149.25
Median	6,838	7,002	7,017	7,136
SD	102.545	39.695	71.391	48.849
Minimum	6,659	6,923	6,995	7,111
Maximum	6,912	7,017	7,164	7,214

Source: Permanent Service for Mean Sea Level

ocean levels in the *Khepupara* station. The result shows that the sea level heightens following the preceding period. For instance, the mean sea level increased by 58.2, 70, and 90.05 cm in 1984–1988, 1989–1994, and 1994–1999, respectively, connected to 1979–1983. Moreover, the median sea level goes up by 298 cm in 1994–1999 compared to 1979–1983.

Table 11 exposes that the average sea level increased by 16.8 cm in 1995–2000 compared to 1979–1983, while the median sea level adjusted by 17 cm at *Cox's Bazar* station. This station is steadier than the other station concerning the mean and median of sea-level rise. At the same station and time, the maximum water level in the ocean enhanced by 17 cm in 1995–2000 related to 1979–1983, while standard deviation positively evolves by 0.34. Table 12 presents the central tendency and variability of sea level at the *Char Changa* station for 1979 and 2000. It reveals that the mean and median sea levels go up by 169.2 and 103 cm in 1995–2000 compared to 1979–1983. It indicates that the sea-level rise in this station is more intense than in the other station. This rise is facilitated due to climate change in the coming future.

MK test

The MK test statistics indicate that water demand factors GDP has an increasing monotonic trend, while population and urban population growth have a decreasing trend. However, the MK test statistics in Table 13 present that water supply sources such as rainfall in JJA and transboundary river water do not show a trend but rise, while rainfall in DJF, MAM, and SON is shrinking. At the same time, groundwater depletion is also rising. The climatic disasters such as flood-affected

Table 11 | Observed sea level (cm) at Cox's Bazar Station

	1979–1983	1984–1989	1990–1994	1995–2000
Mean	1,981	1,986.6	1,992	1,997.8
Median	1,981	1,987	1,992	1,998
SD	1.581	2.073	1.581	1.923
Minimum	1,979	1,984	1,990	1,995
Maximum	1,983	1,989	1,994	2,000

Source: Permanent Service for Mean Sea Level.

Table 12 | Observed sea level (cm) at the *Char Changa* Station

	1979–1983	1984–1989	1990–1994	1995–2000
Mean	6,839.4	6,957.2	6,894.6	7,008.6
Median	6,878	6,959	6,897	6,981
SD	65.071	68.968	38.630	100.231
Minimum	6,757	6,871	6,835	6,876
Maximum	6,894	7,046	6,941	7,143

Source: Permanent Service for Mean Sea Level.

Table 13 | MK test to detect trend in water demand factors, water supply sources, and extreme events

Factors	MK statistics	Kendall's τ	Variance (S)	*p*-value	*Z*	Test interpretation
GDP	131.000	0.625	1,095.667	0.000	3.927	Accept H_1
Population Growth	−181.000	−0.872	1,091.000	0.000	−5.449	Accept H_1
Urban Population	−164.000	−0.780	1,096.000	0.000	−4.922	Accept H_1
Rainfall (DJF)	−74.000	−0.246	1,833.333	0.088	−1.704	Accept H_0
Rainfall (MAM)	−32.000	−0.106	1,833.333	0.469	−0.724	Accept H_0
Rainfall (JJA)	24.000	0.080	1,833.333	0.591	0.537	Accept H_0
Rainfall (SON)	−58.000	−0.193	1,833.333	0.183	−1.331	Accept H_0
Groundwater (NC)	6.000	0.600	16.667	0.086	1.714	Accept H_0
Groundwater (NE)	6.000	0.600	16.667	0.220	1.224	Accept H_0
Groundwater (NW)	6.000	0.600	16.667	0.220	1.224	Accept H_0
Groundwater (SC)	8.000	0.800	16.666	0.086	1.714	Accept H_0
Groundwater (SE)	7.000	0.737	15.666	0.129	1.515	Accept H_0
Groundwater (SW)	8.000	0.800	16.666	0.086	1.714	Accept H_0
Transboundary River Water (BB)	11.000	0.523	44.333	0.133	1.501	Accept H_0
Trans. Ri. W. (GB)	9.000	0.428	44.333	0.229	1.201	Accept H_0
Trans. Ri. W. (MB)	9.000	0.428	44.333	0.229	1.201	Accept H_0
Trans. Ri. W. (SEB)	13.000	0.619	44.333	0.071	1.802	Accept H_0
Temperature	74.000	0.246	1,833.333	0.088	1.704	Accept H_0
Flood-affected Areas	0.370	0.091	0.002	0.499	0.675	Accept H_0
Salt-affected Areas	3.000	1.000	3.666	0.296	1.044	Accept H_0
Salinity Class (S1)	1.000	0.333	3.666	1.000	0.000	Accept H_0
Salinity Class (S2)	−3.000	−1.000	3.666	0.296	−1.044	Accept H_0
Salinity Class (S3)	3.000	1.000	3.666	0.296	1.044	Accept H_0
Salinity Class (S4)	3.000	1.000	3.666	0.296	1.044	Accept H_0
Cyclone	19.000	0.101	942.333	0.557	0.586	Accept H_0
SLR (*Hiron Point*)	40.000	0.190	1,096.666	0.238	1.177	Accept H_0
SLR (*Khepupara*)	119.000	0.777	697.000	0.000	4.4469	Accept H_1
SLR (*Cox's Bazar*)	30.000	0.157	950.000	0.346	0.940	Accept H_0
SLR (*Char Changa*)	70.000	0.368	950.000	0.025	2.238	Accept H_1

areas, SLR (*Hiron Point*, *Cox's Bazar*), cyclone, salt-affected areas, and salinity class (S1, S3, and S4) do not have a trend but rise. At the same time, SLR (*Khepupara*, *Char Changa*) has a trend and rising, while S2 does not have a trend and shrink. The *S* statistics for *Khepupara* is stronger than the other station.

DISCUSSION

This research contributes to the present understanding of how water supply sources respond to the demand and climate-induced extreme limit supply and affect water resources in Bangladesh. Water demand in Bangladesh is increasing due to population, economic, and urban population growth. The results are similar to Ahmed *et al.* (2015), Asaduzzaman *et al.* (2010), Chowdhury (2010), and World Bank (2005), who found that water resources in Bangladesh have been facing some challenges that include but are not limited to (a) rise in pollution due to unplanned urbanization and industrial growth; (b) adverse impact of climate change that roughly affects 160 million people directly and indirectly; and (c) growing demand of water that creates pressure on groundwater.

The factors such as economic growth, population, and urban population are responsible for increasing water demand and putting more pressure on water resources. The MK test result (Table 13) expresses that GDP growth is an increasing trend and statistically significant. This result leads to accepting the alternative hypothesis. However, population and urban population are still growing (Figure 4) but have a decreasing trend (Table 13) and are statistically significant. Therefore, it rejects the null hypothesis. These three factors are constantly laying down more stress on water supply systems. The finding is similar to WWAP/UN Water (2018), who argued that rising water demand follows economic and population growth. The finding enriches the argument of Liu *et al.* 2017. They mentioned ‘population growth, economic development, and dietary shift (toward more animal products) have resulted in ever increasing water demand, and consequently pressures on water resources’ (Liu *et al.* 2017, p. 545).

With an increase in water demand, supply from different water sources is decreasing, unstable, and unreliable in Bangladesh. As a result, the groundwater has been overexploited since its depletion almost doubled (99.66%) from 1989–1990 to 2008–2009 in Bangladesh. This depletion intensifies the pressure on aquifers and ultimately provides less time to reduce the gap between withdrawal and recharge, limiting this source’s water supply. This result is similar to Collins (2008), Hidalgo *et al.* (2009), and Piao *et al.* (2010), who investigated the adverse impact on aquifer recharge in the Karst region and found that the groundwater level has been going down.

Concerning the water supply from rainfall, the result indicates that rainfall has been more erratic in recent years than in the past. For example, the range[12] of rainfall in the JJA[13] and DJF[14] seasons increased by 102.706% and shrank by 55.66% in 2011–2015 compared to 1991–1995. The result advances literature such as Goswami *et al.* (2006), Lau & Wu (2007), and Rajeevan *et al.* (2008), who found a pattern of change in rainfall that includes an increase in heavy precipitation and a decrease in moderate rainfall. Moreover, this finding also enriches the literature by Lu & Fu (2010) and Chen *et al.* (2012), where they found a significant rise in interannual rainfall variability and that precipitation will be more extreme. However, the temperature increased by 0.5745 °C in 2001–2010 compared to 1991–2000. This result is consistent with Frich *et al.* (2002), who observed that every decade has been hotter than the previous decade since the later part of the 20th century. In addition, the result is also similar to IPCC (2013), which found that the average global air temperature surged by 0.85 °C (0.65–1.06 °C) over the period 1880–2012.

In terms of the salinity problem in coastal Bangladesh, salt-affected areas enhanced by 26.733% from 1973 to 2009. This result is consistent as well as contrary in terms of intensity to Shrivastava & Kumar (2015), who argued that salinized areas are increasing at the rate of 10% per year due to low precipitation, poor cultural practices, high surface evaporation, and irrigation with saline water. If the rate[15] of salt-affected areas remains the same in Bangladesh, it will rise to 1,338,598.298 ha in 2045. This is 17.222% of the total arable land[16] in Bangladesh. At the same time, salt-affected areas of S3 and S4 incremented by 329.05 and 170.532% in 2009 compared to 1973, respectively. The result is consistent with Jamil *et al.* (2011), who estimated that more than 50% of arable land will be salinized by 2050. The result also strengthens the salinity study by SRDI (2010) and Rasel *et al.* (2013). The high salinity-affected areas S3 and S4 increased by 354.57 and 155.43% in 2009 compared to 1973. This finding enriches the literature of Shrivastava & Kumar (2015). They observed that 20% of total cultivated and 33% of irrigated agricultural land areas are affected by high salinity worldwide. The result indicates that salt-affected areas

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[12] Difference between maximum and minimum.

[13] Considers as monsoon/rainy season.

[14] Considers as dry season.

[15] Salt-affected areas in 2009 compared to 1973.

[16] As per World Bank data, total arable land was 7,772,300 ha in 2018. https://data.worldbank.org/indicator/AG.LND.ARBL.HA?locations=BD.

will not be limited to coastal areas. Moreover, the intensity of growth will not be the same due to climate change impact and the geographical boundary.

For the transboundary river water flow, climate change is a concern (Milman *et al.* 2013) and has a significant impact on the water supply from those rivers. Moreover, Čerkasova *et al.* (2018) conducted a study on the Vilija River basin using climate scenarios based on the IPCC AR5 RCP4.5 model (Collins *et al.* 2013). They found that yearly transboundary river water discharge increased to 53.7%, where the expected rise was to 47.6%. However, the present finding concerning transboundary water flow is contrary to Collins *et al.* (2013) since mean water flows decreased by 1.212, 7.329, and 7.056% in 2018 compared to 2012 in *Brahmaputra*, *Meghna*, and *Southeastern* Basin, respectively.

The average and intensity of flood increased since mean and maximum flood-affected areas increased by 93.357 and 107.98% in 2014–2018 compared to 2009–2013. This is in line with the previous findings. Tabari (2020) found that flood intensity enhances in all climate regimes. However, the intensity of cyclone facilitates since maximum wind speed facilitates by 19.17% in 2015–2020 contrasted to 1988–1995, while the range is positively adjusted by 21.03%. The output (Table 8) is in agreement with previous studies by Kossin *et al.* (2020), Emanuel (2000), and Kossin *et al.* (2013).

Nevertheless, the sea level has risen with different intensities in Bangladesh. Sequentially, the mean sea level increased by 8.02 and 0.795 cm per year during 1979–2000 in *Char Changa* and *Cox's Bazar*. Moreover, the rate is more intense in *Khepupara* (16.3624 cm) and *Hiron Point* (3.667 cm). The result is consistent with Douglas (1991), Cazenave & Llovel (2010), Golledge (2019), and Rahmstorf (2007) but indicates different intensities. Moreover, this result reinforces the finding of Glennon (2017), who estimated that 3 feet of the sea level will rise by 2050 but with a different magnitude. For example, if the sea level continues, seawater's height will rise by 2 m by 2013 in *Khepupara*, 2025 in *Char Changa*, 2055 in *Hiron Point*, and 2252 in *Cox's Bazar*.

This study provides insight to understand further the link between factors for rising water demand, water supply sources, and extreme events that limit water supply in Bangladesh. It will help decision-makers take action for climate change adaptation, displacement, water crisis, and economic stability. Furthermore, it can be an ideal study to anticipate the future scenario for other climate-vulnerable countries (e.g., Philippines, Myanmar, Vietnam, India, Indonesia, and Pakistan) concerning the linkage between climatic extreme events and water. For instance, the salinity level and the intensity of the cyclone are not only increasing in coastal Bangladesh but also possibly extend into the Indian coastal region. It will help them prepare for adaptation since they understand the intensity of extremes and the interlinking sectors. It is also necessary to find alternative sources of water, and make efficient and effective use of limited water resources. Finally, it will draw the attention of policymakers, water managers, and academics for further investigation into coping with extreme climate events that affect water sources, displaced people, and damage economic and environmental resources.

CONCLUDING REMARKS

This study and its underlying research objective are to find the factors that contribute to rising water demand, the response of water sources to fulfill this demand, and the impact of climatic extreme events on water resources in Bangladesh. Economic development, urbanization, and population growth cause more demand for water. The total population and urban population have grown 1.35 and 3.70% per year over the last 21 years in Bangladesh, while the growth rate of GDP was more than 6% over the last 10 years. The test result in Table 13 shows that there is an increasing trend in GDP growth (131.000), and a decreasing trend in population (−181.000) and urban population (−164.000) growth. The alternative hypothesis for these factors is accepted. These are the major responsible factors for growing water demand in the country. For this growing demand, the supply side is under stress to fulfill this demand.

Water supply from different river basins has decreased periodically. For example, the mean level was 19.37, 12.32, and 12.69 in 2012 in the *Brahmaputra*, *Meghna*, and *Southeastern* Basins, respectively, and went down by 0.23, 1.19, and 0.89 m in 2018. The alternative hypothesis is accepted for the entire river basins. It means that there is no trend that implies water supply from this source is unstable. However, the water supply through rainfall is not stable. From 1991 to 1995, the mean level rainfall was 57.12 mm in DJF, 444.57 mm in MAM, 1,257.67 mm in JJA, and 518.20 mm in SON, and it reached 31.99, 385.58, 1,476.08, and 419.79 mm, respectively, in 2011–2015. The MK test statistics results in Table 13 show a similar pattern that rainfall surges in JJA (24.000), while going down in DJF (−74.000), MAM (−32.000), and SON (−58.000). However, groundwater is another major water supplier and its depletion rate doubled within two decades (1989–2009). The average depletion was 2.455 km^3 in 1989–1990 and rises to 4.90 km^3 in 2008–2009. The MK test result indicates no trend in groundwater depletion but increasing in every region of the country, which includes NC (6.000), NE (6.000), NW (6.000), SC (8.000), SE (7.000), and SW (8.000). This result in Table 13 exposes that the intensity of groundwater depletion is greater in southern than the northern part of the country.

The intensity of climatic disasters' impact on water resources is increasing. From 1988 to 1993, mean and median flood-affected areas were 37,094 and 28,600 km^2 and reached 45,738 and 47,200 km^2 in 2014–2018. For cyclones, the mean and median levels of the maximum wind speed were 135.51 and 122.1 km in 1988–1995 which go up by 30.03 and 25.9 km in 2015–2020, respectively. In addition, salt-affected areas and the areas of different salinity classes are also increasing. For example, salt-affected areas increased by 222,810 ha in 2009 compared to 1973, while the mean areas of S4 rose from 2,220 ha in 1973 to 5,990 ha in 2009. At the same time, the average area S3 also increased by 15,240 ha. The MK test results exhibited in Table 13 also indicate the rise of these climatic disasters that include cyclones (19.000), salt-affected areas (3.000), and salinity class (S1=1.000, S3=3.000, and S4=3.000).

The sea level is rising in the different stations in Bangladesh. At *Hiron Point*, the mean level of sea level was 7,048.25 cm in 1983–1986 and reached 7,121.8 cm in 1999–2003. This station does not have a rising trend but rise (40.000). Moreover, at *Khepupara (*119.000) and *Char Changa (*70.000), the result in Table 13 exposes that the height of sea level has an increasing trend and is strong compared to other factors. Therefore, these extreme events directly and indirectly affected the demand and supply of water and affected total water resources systems in Bangladesh.

This study unequivocally presents the five issues for future programs and actions. First, groundwater is depleting fast, rainfall is more erratic,[17] and water supply from the riverine system is not stable. To address these issues, it could be better to use rainwater for domestic, industrial, and agricultural purposes through rainwater harvesting since the country is one of the most rain-intensive countries (average rainfall of 2,400 mm/year). Rainwater harvesting can be promoted and on the priority list to address the water demand–supply gap. This program is more applicable in the southern part of the country since groundwater depletion is more potent than in the northern part. Previous studies found that rainwater harvesting is a sustainable approach to govern rainwater and address economic poverty and water crisis in the southern part of Bangladesh (Islam 2018, 2019). Secondly, climatic disasters are rising (some have a monotonic rise), affecting water resources, people, the economy, and the environment. It is high time to combine water, climate change, economy, and people as a whole, not each of these as an isolated issue. Moreover, water and climate change issues should not be confined to the Ministry of Water Resources and the Environment.

Thirdly, decisions are based on data and science. Lack of updated data constraint study leads to wrong decisions regarding water resources management and climate change adaptation. For example, in this study, the latest data for SLR is 2003, while salinity intrusion and groundwater depletion are 2009. Even some stations (e.g., Khepupara, Cox's Bazar, and Char Changa) do not have data for 2003. Recent data could contribute more conclusive findings significantly. The country needs to collect and upload updated data (for the whole country) in the concerned ministry and departmental website to help make better decisions for socio-economic development, water resources management, and climate change adaptation. Fourthly, more diplomatic effort needs to bring stability in supplying water through the transboundary river. Because agricultural productivity in Bangladesh largely relies on the transboundary river's water supply. The fifth issue is efficiency. As there is a widening gap between demand and supply of water and climatic extremes will facilitate this gap, the efficient use of limited supply could limit this gap. This study urges boosting of the water-use efficiency in Bangladesh. This can be done by promoting less water-intensive foods and diversifying crop production that requires less water to produce. For example, meat (beef) and rice are two of the most water-intensive foods and crops. Both of these agricultural products are popular in the country. Since the country faces a demand–supply gap for water and climatic extreme will facilitate it, there is no time to waste to bring efficiency in water use.

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[17] The MK test statistics indicate that rainfall decreases in DJF, MAM, and SON, while it surges in JJA.

CONFLICT OF INTEREST

There is no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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