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Review Article

Water pollution in Bangladesh and its impact on public health

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ABSTRACT

Bangladesh – one of the most densely populated countries of the world— has plentiful water sources, but these sources are being polluted continuously. Both surface water and groundwater sources are contaminated with different contaminants like toxic trace metals, coliforms as well as other organic and inorganic pollutants. As most of the population uses these water sources, especially groundwater sources which contain an elevated amount of arsenic throughout the country; health risk regarding consuming water is very high. Death due to water-borne diseases is widespread in Bangladesh, particularly among children. Anthropogenic sources such as untreated industrial effluents, improper disposal of domestic waste, agricultural runoffs are the main contributors regarding water pollution. A total water pollution status of this country, as well as the sources of this severe condition, is crucial to evaluate public health risk. For this purpose, we reviewed hundreds of well recognized international and national journals, conference proceedings and other related documents to draw a complete picture of recent water pollution status and its impact on public health; also the sources of water pollution are identified.

1. Introduction

Why are we able to live in this planet? Why are other animals and plants allowed to live here? If we endeavor to find out the answer of these inquisitions, we may easily perceive that water is the spring of life. According to biologists, all life form came from the sea means water. We are living on this planet due to the blessing of water. From the dawn of civilization to till now, humans (cave dwellers to city dwellers) have been using water for various seminal purposes: drinking, bathing, watering animals, and irrigating lands. However, this limited resource means source of life under threat from the population, chiefly generated by human factors. Almost 71% of the earth's total surface is covered with water, only 2.5% of this amount can be considered as freshwater (Shiklomanov, 1993). At present, 1.6 billion of people are facing economic water shortage, and two-thirds of the world's population is experiencing water scarcity at least one month in a year (FAO, 2007; Mekonnen and Hoekstra, 2016). Recently scientists have found that 21 of the world's 37 largest aquifers around the world have crossed their sustainability tipping points (Richey et al., 2015). The condition of water stress and scarcity will be worsened. Almost 1.8 billion people living in various regions all over the world may face absolute water scarcity by 2025 (WWAP, 2012).

However, these limited water resources are under threat from the pollution, chiefly generated by human factors. The agricultural sector, industrial production, mining, power generation, and other factors are some of the contributors to the pollution of water bodies, which will eventually affect humans in general (UN-Water, 2001). Diseases: cholera, diarrhea, dysentery, hepatitis A, etc. are directly linked to the unhygienic and contaminated potable water. It is estimated that each year more than 842,000 people die from diarrhea globally (WHO, 2017a,b). Arsenic pollution is one of the major groundwater contaminations, and it affects nearly 70 million people worldwide (UNESCO, 2009).

Like the rest of the third world country, Bangladesh (Fig. 1), one of the most densely populated countries, is facing severe water pollution and scarcity. Although 97% of the total population has access to water, the quality of water is always questionable (WHO, 2018). Bangladesh is a riparian country, consisting of more than 230 large and small rivers (Figs. 2 and 3). But these rivers are now choked by the pollution caused by mainly human intervention (Majumder, 2009). Groundwater is not also safe as the threat of arsenic contamination is very high all over the country. 97% of the total population in rural areas depend on the tubewells for drinking water; as a result, 35 to 77 million people have been chronically exposed to arsenic in the first decade of the millennium (Flanagan et al., 2012). 8.5% of the total death in Bangladesh is caused by

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Fig. 1. Administrative map of Bangladesh [source: (Map, 2019)].

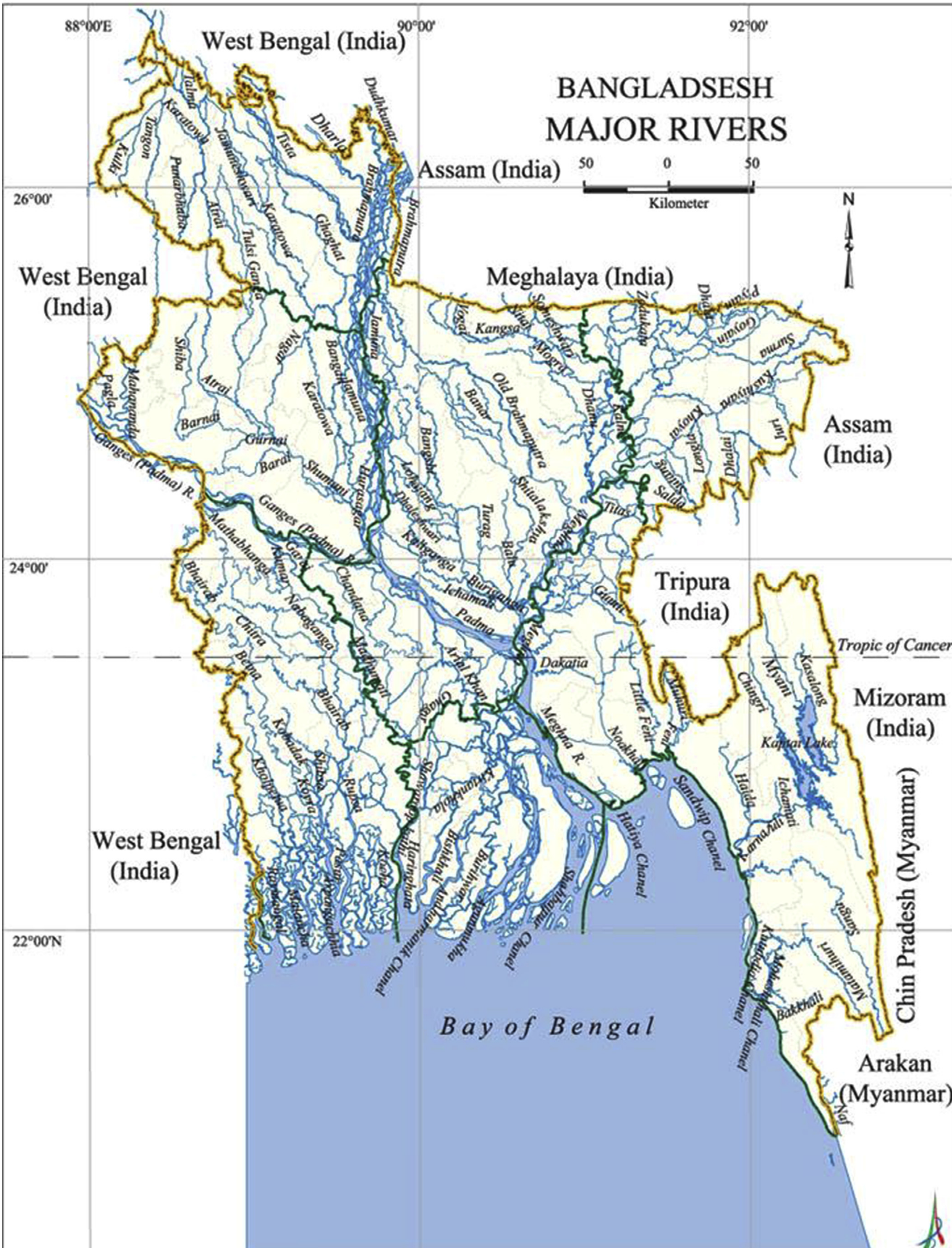

Fig. 2. Rivers of Bangladesh [Source: (Banglapedia, 2019)].

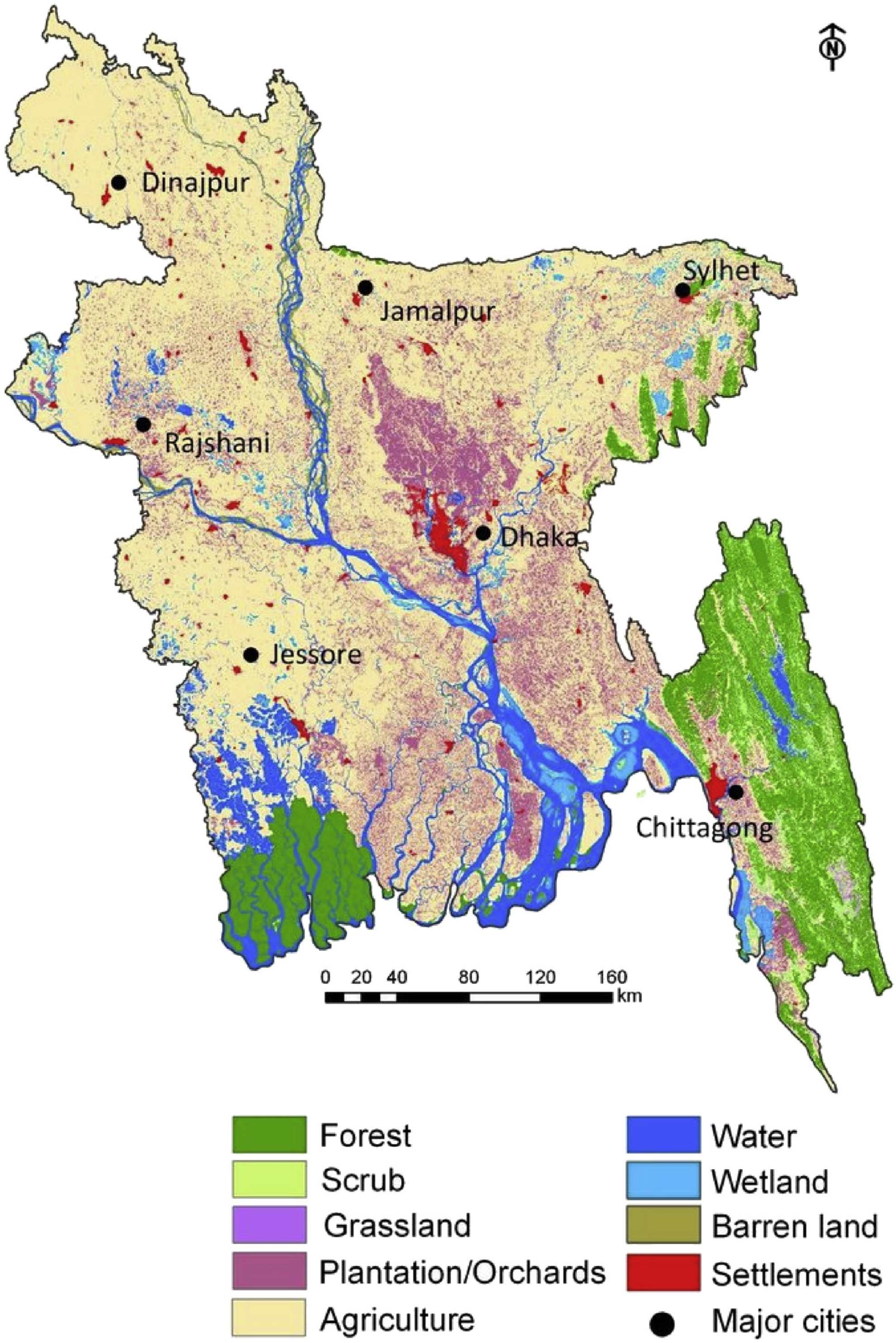

Fig. 3. Land usage of Bangladesh (Reddy et al., 2016).

water, sanitation and hygiene-related issues (UN-Water, 2013).

Adequate knowledge about the pollution status of all the water sources is thus crucial for ensuring safe and hygiene potable water. A detailed country wide drinking water quality survey was conducted by Bangladesh Bureau of Statistics which was titled as 'Bangladesh National Drinking Water Quality Survey' (BNDWQS) of 2009 with the technical help from UNICEF. Samples were collected from 300,000 household sources in 15,000 randomly selected clusters around the country. The report suggested that 97.8 of the population were using safe drinking water and 13.4% of the samples exhibited a higher concentration of arsenic (Statistics, 2009). But various individual studies on smaller scale revealed the much severe condition of water pollution. The Department of Environment (DoE) of Bangladesh regularly monitor the surface and groundwater quality of the country. These year-long monitoring programs have shown the increasing pollution rates in rivers and other surface water sources over time (DoE, 2014).

The complete picture of overall water pollution situation of Bangladesh is of great importance from every perspective. In this paper, we have compiled the recent data in this regard. Hundreds of journal articles, conference proceedings, reports published by renowned organizations, books and other reliable national and international materials have been reviewed to extract meaningful information about the present pollution status which is then arranged and presented systematically. Furthermore, the impact of this pollution on the public health of Bangladesh is also discussed in detail.

2. Main text

2.1. Physicochemical properties of water sources

The physicochemical properties of water can influence the development of biological life form in water and subsequently can cause an impact on the quality of water (Soja and Wiejaczka, 2014). Physical properties such as temperature, turbidity, electrical conductivity and chemical properties for instance dissolved oxygen (DO), Biological oxygen demand (BOD), Chemical oxygen demand (COD), all come under this group.

Biological Oxygen Demand (BOD, or more specifically BOD_5) can be used as an indication of the extent of organic pollution in the aquatic systems, which adversely affect the water quality (Jonnalagadda and Mhere, 2001). Though there is no guideline value of BOD set by WHO, Bangladesh Standard doesn't allow more than 0.2 mg/L BOD in drinking water. A very high value of BOD can be seen in heavily polluted surface water of Bangladesh. Many studies found the elevated value of BOD in water sources in Barapukuria, Dinajpur (Bhuiyan et al., 2010), Dhaka-Narayanganj-Demra (D.N.D) Embankment (Sultana et al., 2009), Buriganga river (Ahmed et al., 2011b). Chemical Oxygen Demand (COD) is also a very practical parameter in the determination of polluted water (Zuane, 1996). WHO didn't set any guideline value for COD, but Bangladesh Standard for COD is maximum 4 mg/L. Only one study calculated the COD value of groundwater which was slightly higher than the recommended value (Table 1). Dissolved Oxygen (DO) is also measured in water quality testing. For drinking water, Bangladesh Standard described its maximum allowable concentration at 6 mg/L. The maximum concentration DO (12.77 mg/L) was found in the surface water near Barapukuria coal mine area, Dinajpur (Bhuiyan et al., 2010). A high concentration of DO (above 12–14 mg/L) can cause ‘gas bubble disease’ in fishes of the water body (Puri & Kumar, 2012); whereas a low concentration of DO has a direct effect on the corrosion of water supply line pipe and psychological results for consumers (Zuane, 1996).

The temperature of the water should be 20–30 °C according to WHO standard. The temperature of water influences the aquatic life, solubility of solids, taste and odor, dissolved oxygen (DO), etc (Zuane, 1996). Although pH has no direct impact on the consumer, it is one of the most necessary operational water quality parameters (WHO, 2011). WHO recommended that the pH of the water be within 6.5–8.5. All studies found the pH of water sources within a suitable range. Total dissolved solids (TDS) constitute inorganic salts and small amounts of organic matter that are dissolved in water. TDS less than 600 mg/L is suitable for drinking water; but if the concentration level exceeds 1000 mg/L, the water becomes unpalatable (WHO, 2011). Some of the studies have found TDS level above the recommended limit. The conductivity of water can indicate the presence of minerals. Potable waters usually register conductivity from 50 to 500 micromhos/cm, but with mineralized water registering values over 500 (Zuane, 1996). No guideline value was proposed by WHO or Bangladesh Standard. A variety of conductivity value can be seen in different water sources based on various studies.

2.2. Major pollutants

2.2.1. Trace metals pollution

Trace element contamination of water is now a primary worldwide concern because even at low concentration these elements can show an adverse effect on living beings (Demira et al., 2015). Natural substances leached from the soil, run-off from agricultural activities, controlled discharge from sewage treatment works and industrial plants, and uncontrolled releases or leakage from landfill sites and chemical accidents or disasters are the sources of both surface and groundwater pollution (Leeuwen, 2000). Some of the trace elements are found to be essential for the human body (Bogden, 2000), but a negative impact on the living organism can be seen if the permissible limit is exceeded (Izah et al., 2016). In Bangladesh, trace elements in ground and surface water often exceed the guideline values recommended by WHO. Table 2 comprises the result of different studies on trace elements in water, which was conducted in the various area of Bangladesh in a different time.

Chromium (Cr) presents in nature chiefly in two oxidation states, Cr (III) and Cr (VI), which possess contrasting physiological effects (Aranda et al., 2010). According to WHO and Bangladesh standards, the maximum concentration of chromium in drinking water is 0.05 mg/L. BNDWQS report showed that 97.7% of the total samples contained less than 0.005 mg/L of Cr. Other individual studies reported that surface water in different location exceeds the maximum concentration value and it varied from 0.005 to 1.02 mg/L; whereas in groundwater, the values remain in between less than 0.0002–0.093 mg/L of Cr (Table 2). Balu river and Buriganga river shows a higher concentration of chromium. Ahmed et al. (2011b) found that the average concentration of chromium is 0.587 mg/L in river Buriganga. A study conducted by Hasan et al. (2014) in Balu river showed that the concentration of chromium is in between 0.62 to 1.37 mg/L in the dry season, but absent in rainy season. A selected few studies focused on the chromium content in groundwater. The highest chromium concentration (0.093 mg/L) in groundwater was found in Singair Upazila, Manikgonj (Halim et al., 2014). Overall, surface water contains significantly more chromium than that of groundwater. Chromium in its Cr(VI) oxidation state, is responsible for lung cancer, nasal irritation, nasal ulcer, hypersensitivity reactions, and contact dermatitis when it entered into human bodies via dermal and inhalation routes (Shrivastava et al., 2002).

Copper (Cu) is an indispensable trace element which shows a significant role in the biochemistry of all living organisms (Bremner and Beattie, 1990). WHO prescribed the maximum acceptable concentration of 2 mg/L for Cu. BNDWQS (2009) report suggested that 100% of the samples had less amount of Cu than the WHO and Bangladesh standards. Various studies calculated the Cu content in both surface and groundwater throughout the country, but concentration never exceeded the maximum limit. The highest mean concentration of Cu in surface water (0.239 mg/L) and groundwater (0.08 mg/L) was reported from Buriganga river (Bhuiyan et al., 2015) and Rajshahi city (Mostafa et al., 2017), respectively. Excess copper accumulation leads to copper toxicosis which results in hepatic cirrhosis, hemolytic anemia, and degeneration of the basal ganglia (Harris and Gitlin, 1996).

Iron (Fe) is one of the most abundant trace elements found in earth's crust, but iron deficiency is a global concern (Quintero-Gutiérrez et al., 2008). It was calculated that only 60% of water samples were below the Bangladesh standard (1.0–0.3 mg/L) in BNDWQS (2009) report. This survey also indicated the high average concentration of Fe present in the shallow (2.65 mg/L) and deep tubewell (1.37 mg/L) water throughout the country. Various individual studies also showed the exceeding present of iron in water of Bangladesh. High degree of Fe contamination in surface water has been reported in the rivers near Barapukuria coal mine, Dinajpur due to anthropogenic inputs (3.1 mg/L) (Bhuiyan et al., 2010), followed by Surman river during monsoon (1.834 mg/L) (Alam et al., 2007). Groundwater Fe contamination is even more severe; the concentration range varies from 0.02 to 28.9 mg/L. The maximum average Fe concentration (28.9 mg/L) was determined in the arsenical well water of Chuadanga (Nahar et al., 2014). Table 2 shows that groundwater of different districts from different parts of Bangladesh is severely contaminated with Fe. Overdosing of iron is potentially hazardous and plays a vital role in causing diabetes (Swaminathan et al., 2007), anemia and hemochromatosis (Toyokuni, 2009), lung and heart disease (Milman et al., 2001).

Table 1
Physicochemical properties parameters in Bangladesh in surface water and groundwater. Data are extracted from various individual studies and arranged chronologically based on year of publication of the reviewed articles. Values given represent the mean values or mean values plus-minus standard deviation (S.D.), where the values with ± in the parenthesis () represents average ± S.D.

Samples Location	BOD (mg/L)	COD (mg/L)	DO (mg/L)	Temperature (°C)	pH	TDS (mg/L)	Conductivity (μ-mhos/cm)	Reference
Surface Water								
Halda River	–	–	6.874	27.02	6.72		66.32	(Patra and Azadi, 1985)
Surma River (Dry)	(1.00 ± 3.8)	(1.53 ± 0.52)	(5.52 ± 1.40)	–	(6.13 ± 0.29)	(139.30 ± 38.40)	–	(Alam et al., 2007)
Surma River (Monsoon)	(0.88 ± 0.31)	(1.34 ± 0.40)	(5.72 ± 1.42)	–	(6.09 ± 0.33)	(129.50 ± 37.44)	–	(Alam et al., 2007)
Mouri River	21.268	348.275	5.537	23.23	–	283.5	176	(Kamal et al., 2007)
Surface Water near D.N.D Embankment	(584.75 ± 249.66)	(1264.67 ± 534.86)	(0.84 ± 0.75)	(33.75 ± 1.71)	(8.70 ± 0.72)	(1369.33 ± 780)	(2076.58 ± 892.55)	(Sultana et al., 2009)
Sadar ghat, Buriganga River (Rainy Season)	–	54.9	–	29.88	7.1	–	–	(Saha et al., 2009)
Sadar ghat, Buriganga River (Winter Season)	9.1	22.3	–	19.33	7.05	–	–	(Saha et al., 2009)
Barapukuria, Dinajpur (Drainage Water)	16.87	260.1	12.77	34.1	6.75	–	–	(Bhuiyan et al., 2010)
Barapukuria, Dinajpur (Ground Water)	19.9	233.9	9.82	30.2	8.85	–	–	(Bhuiyan et al., 2010)
Buriganga River, Dhaka (Different Seasons)	44.69	–	–	–	–	671.83	–	(Ahmed et al., 2011b)
Katrnatoli River, Savar, Dhaka (Different Seasons)	33.99	–	–	–	–	249.44	–	(Ahmed et al., 2011b)
Ashulia, Dhaka	(0.89 ± 0.86)	(56.57 ± 27.13)	(4.72 ± 1.1.3)	(27.28 ± 1.80)	(7.47 ± 0.18)	(838.33 ± 374.47)	(983.25 ± 210.82)	(Bhuiyan et al., 2011)
Amin Bazar, Dhaka	(0.72 ± 0.65)	(50.01 ± 33.14)	(4.95 ± 1.28)	(28.00 ± 2.10)	(7.46 ± 0.19)	(673.33 ± 195.88)	(1100.33 ± 131.42)	(Bhuiyan et al., 2011)
Tejgaon area, Dhaka (Wet Season)	17	130.5	0.1	–	7.1	303.1	852.7	(Mondol et al., 2011)
Tejgaon area, Dhaka (Dry Season)	0.5	104	0.2	–	7.1	483.3	835.9	(Mondol et al., 2011)
Karatoa river	–	–	–	–	(7.28 ± 0.16)	(324.87 ± 107.55)		(Zakir et al., 2012)
Shitalakshyaa River	–	120	–	25.15	8.1	737.5	1087.5	(Sikder et al., 2013)
Turagh River	–	35	–	21.55	7.45	410.5	579.5	(Sikder et al., 2013)
Bongshi River	–	35	–	20.87	7.433	420.33	594	(Sikder et al., 2013)
Turag river (2006)	2.8	58	6	–	7.1	342	98	(Banu et al., 2013)
Turag river (2010)	22	102	0	–	7.5	812	1800	(Banu et al., 2013)
Karnaphuli River, Chittagong (Summer)	–	–	(8.07 ± 2.63)	–	(7.89 ± 0.31)	–	–	(Ali et al., 2016)
Karnaphuli River, Chittagong (Winter)	–	–	(9.92 ± 2.78)	–	(8.17 ± 0.49)	–	–	(Ali et al., 2016)
Ground Water								
Mymensingh (Different types of Tubwells)	–	4.636	1.123	–	7.077	–	369.615	(Ahmed et al., 2010)
Cox's Bazar paleobeach area	–	–	3.27	27	7.1	677	–	(Seddique et al., 2016)
Rajshahi City (Shallow Tubwells)	–	–	–	(27.39 ± 0.68)	(6.91 ± 0.18)	(297.44 ± 49.7)	(445.44 ± 49.41)	(Mostafa et al., 2017)
Rajshahi City (Deep Tubwells)	–	–	–	(27.2 ± 0.54)	(7.0 ± 0.14)	(241.65 ± 21.7)	(454.98 ± 52.47)	(Mostafa et al., 2017)
Panchbibi, Joypurhat	–	–	–	–	(7.935 ± 0.46)	(270.48 ± 104.78)	(422.63 ± 163.73)	(Islam et al., 2017d)
Barguna (Shallow Tubewell)	–	–	–	27.76	7.42	4829	8973	(Islam et al., 2017d)
Bangladesh Standards (Drinking water)	0.2	4.0	6.0	20–30	-	1000	-	(DPHE, 2018)
Bangladesh Standard (Industrial Effluent)	50	200	4.5–8.0	40–45	6–9	2100	1200	(DoE, 2008)

Manganese (Mn) has been reported to be exigent in every animal species studied (Goldhaber, 2003). In Bangladesh, none of the studies indicated any Mn contamination is surface water (Table 2); however, the existence of Mn above the WHO standard limit (0.5 mg/L) was reported in ground water throughout the country. The highest mean concentration of Mn in groundwater was found in the water sample of the tubewell water in Singair, Manikgonj (Halim et al., 2014). An elevated level of Mn was found in shallow tubewell (1.87 mg/L) in Cox's Bazar area; the deep water sample collected from the same area also showed a significant presence of Mn due to high rock-groundwater interaction (Seddique et al., 2016). A study conducted in Greece reported that individuals who consumed drinking water containing more than 1.8 mg/L Mn, exhibited

Table 2
Trace elements concentration (mg/L) in Bangladesh in surface water and groundwater. Data are extracted from various individual studies and arranged chronologically based on year of publication of the reviewed articles. Values given represent the mean values or mean values plus-minus standard deviation (S.D.), where the values with ± in the parenthesis () represents average ± S.D.

Sampling Location	Cr	Cu	Fe	Mn	Ni	Zn	Cd	Pb	Reference
Surface Water									
Surma River (Monsoon Season)	0.0376	0.0042	1.8340	–	–	0.0042	–	0.0130	(Alam et al., 2007)
Surma River (Dry Season)	0.0388	0.0042	0.3340	–	–	1.1540	–	0.0130	(Alam et al., 2007)
Dhaleswari River	(0.4413 ± 0.0425)	(0.1547 ± 0.0305)	–	–	(0.0072 ± 0.0014)	–	(0.0065 ± 0.0009)	(0.0501 ± 0.0193)	(Ahmed et al., 2009)
Wetlands nearby Barapukuria, Dinajpur (Drainage Water)	<0.0720	0.2100	5.1000	0.1950	0.1800	0.4310	–	0.2300	(Bhuiyan et al., 2010)
Wetlands nearby Barapukuria, Dinajpur (River Water)		0.1000	3.1000	0.1630	–	0.5800	–	0.0700	(Bhuiyan et al., 2010)
Buriganga River, Dhaka	(0.587 ± 0.0441)	(0.1631 ± 0.0335)	–	–	(0.0088 ± 0.001)	–	(0.0093 ± 0.0015)	(0.0655 ± 0.0048)	(Ahmed et al., 2010)
Karatoa River	(0.005 ± 0.002)	Trace	(0.495 ± 0.247)	(0.101 ± 0.067)	(0.005 ± 0.003)	Trace	–	Trace	(Zakir et al., 2012)
Khiru River, Mymensingh	–	(0.0037 ± 0.001)	–	(0.0953 ± 0.110)	–	(0.0061 ± 0.003)	(0.1748 ± 0.340)	(0.0107 ± 0.008)	(Rashid et al., 2012)
Shitalakhya (2012)	0.0050	–	–	–	0.0050	0.1060	0.0030	0.0050	(Rahman et al., 2013)
Different Rivers near Dhaka	(0.0233 ± 0.0134)	(0.0147 ± 0.0148)	(0.0421 ± 0.0754)	(0.0312 ± 0.0399)	–	(0.002 ± 0.0017)	(0.0047 ± 0.0009)	(0.0041 ± 0.0008)	(Sikder et al., 2013)
Dhanmondi Lake, Dhaka	–	0.0110	–	0.0528	–	0.0404	0.0097	0.0009	(Mokaddes et al., 2013)
Romna Lake, Dhaka	–	0.0110	–	0.0700	–	0.0379	0.0090	0.0013	(Mokaddes et al., 2013)
Crescent Lake, Dhaka	–	0.0110	–	0.0798	–	0.0189	0.0720	0.0009	(Mokaddes et al., 2013)
Samshad Lake, Dhaka	–	0.0168	–	0.0893	–	0.0238	0.0660	0.0007	(Mokaddes et al., 2013)
Gulshan Lake, Dhaka	–	0.0133	–	0.0904	–	0.0163	0.0277	0.0009	(Mokaddes et al., 2013)
Bonani Lake, Dhaka	–	0.0164	–	0.0896	–	0.0178	0.0102	0.0010	(Mokaddes et al., 2013)
Sutrapur Lake, Dhaka	–	0.0143	–	0.1020	–	0.6983	0.0834	0.0031	(Mokaddes et al., 2013)
Rampura Lake, Dhaka	–	0.0162	–	0.0916	–	0.6250	0.0044	0.0052	(Mokaddes et al., 2013)
Airport Lake, Dhaka	–	0.0129	–	0.1085	–	1.2801	0.2210	0.0007	(Mokaddes et al., 2013)
Tongi Lake, Dhaka	–	0.1150	–	0.0987	–	0.9980	0.0030	0.0014	(Mokaddes et al., 2013)
Balu River (Winter Season)	(1.02 ± 0.24)	(0.16 ± 0.04)	(0.16 ± 0.02)	–	–	(0.38 ± 0.08)	–	–	(Hasan et al., 2014)
Balu River (Rainny Season)	–	(0.08 ± 0.04)	(0.04 ± 0.02)	–	–	(0.05 ± 0.02)	–	–	(Hasan et al., 2014)
Dhalai Beel and Bangshi River	(0.093 ± 0.032)	(1.05 ± 0.22)	–	(0.088 ± 0.017)	(0.035 ± 0.012)	(3.32 ± 0.62)	(0.007 ± 0.001)	(0.108 ± 0.031)	(Rahman et al., 2014))
Paira River (Winter)	0.0579	0.0351	–	–	0.0406	–	0.0009	0.0288	(Islam et al., 2015a)
Paira Rive (Summer)	0.0326	0.0240	–	–	0.0279	–	0.0005	0.0214	(Islam et al., 2015a)
Korotoa River, Bogra (Summer)	(0.073 ± 0.027)	(0.061 ± 0.028)	–	–	(0.032 ± 0.019)	–	(0.008 ± 0.006)	(0.027 ± 0.015)	(Islam et al., 2015b)
Korotoa River, Bogra (Winter)	(0.083 ± 0.027)	(0.073 ± 0.033)	–	–	(0.039 ± 0.023)	–	(0.011 ± 0.008)	(0.035 ± 0.019)	(Islam et al., 2015b)
Buriganga River, Dhaka	0.1140	0.2390	0.6120	0.1570	0.1500	0.3320	–	0.1190	(Bhuiyan et al., 2015)
Karnaphuli River, Chittagong (Summer)	(0.0696 ± 0.0170)	–	–	–	–	–	(0.0065 ± 0.003)	(0.0099 ± 0.0048)	(Ali et al., 2016)
Karnaphuli River, Chittagong (Winter)	(0.0869 ± 0.0174)	–	–	–	–	–	(0.0106 ± 0.0045)	(0.0168 ± 0.0062)	(Ali et al., 2016)
Turag River	0.0070	Trace	–	–	–	0.0900	0.0010	0.0090	(Rabbi et al., 2016)
Ground Water									
Rajarampur, Chapai Nawabgonj	–	0.0002	–	–	<0.00006	0.03	–	0.0002	(Islam et al., 2000)
Shamta, Jessore	<0.0002	–	–	–	<0.00006	0.027	–	0.0005	(Islam et al., 2000)
Mainamoti, Comilla	0.0031	0.0006	–	–	0.001	0.053	–	0.001	

(continued on next page)

Table 2 (*continued*)

Sampling Location	Cr	Cu	Fe	Mn	Ni	Zn	Cd	Pb	Reference
									(Islam et al., 2000)
Andulia, Jhenidah	–	–	–	–	<0.00006	0.078	–	0.0007	(Islam et al., 2000)
Supply groundwater of Banani	–	–	0.04	0.02	–	–	–	–	(Nahar et al., 2014)
Supply groundwater of Tejgaon	–	–	0.11	0.05	–	–	–	–	(Nahar et al., 2014)
Supply groundwater of Dhanmondi	–	–	0.03	0.1	–	–	–	–	(Nahar et al., 2014)
Supply groundwater of Hazaribagh	–	–	0.02	0.09	–	–	–	–	(Nahar et al., 2014)
Well water in Dhamrai	–	–	15.9	0.86	–	–	–	–	(Nahar et al., 2014)
Well water in Chuadanga	–	–	28.9	0.29	–	–	–	–	(Nahar et al., 2014)
Tube wells of Singair, Manikgonj	0.093	0.0223	7.11	2.08	0.043	0.0643	–	0.019	(Halim et al., 2014)
Pumping well of Faridpur	–	–	(5.9516 ± 4.9312)	(0.0006 ± 0.0007)	(0.0033 ± 0.0023)	(0.0104 ± 0.0102)	–	(0.0006 ± 0.0004)	(Bodrud-Doza et al., 2016)
Shallow Tubewells of Cox's Bazar paleobeach area	–	–	1.81	1.87	–	–	–	–	(Seddique et al., 2016)
Deep Tubewells of Cox's Bazar paleobeach area	–	–	2.67	1.37	–	–	–	–	(Seddique et al., 2016)
Different types of well in Lakshimpur	–	–	(3.235 ± 3.868)	(0.652 ± 0.583)	(0.0002 ± 0.0001)	–	–	(0.00004 ± 0.0001)	(Bhuiyan et al., 2016)
Deep Tubwell of Rajshahi City	–	(0.08 ± 0.06)	(3.1 ± 0.64)	(1.47 ± 0.78)	–	(0.19 ± 0.07)	(0.014 ± 0.01)	(1.167 ± 0.14)	(Mostafa et al., 2017)
Sylhet district	–	–	(6.832 ± 6.046)	(0.281 ± 0.217)	–	–	–	–	(Islam et al., 2017a)
Rangpur	–	–	(7.7264 ± 6.5593)	(0.6845 ± 0.7547)	–	(0.0333 ± 0.03899)	–	–	(Islam et al., 2017b)
WHO Standards	0.05	2.00	0.30*	0.5	0.02	3.00	0.003	0.01	
Bangladesh Standards (Drinking water)	0.05	1.00	0.30–1.00	0.1	0.10	5.00	0.005	0.05	
Bangladesh Standards (Industrial effluents)	0.50	0.50	2.00	5.00	1.00	5.00	0.05	0.10	(DoE, 2008)

neurologic symptoms which are similar to Parkinson's disease (Kondakis et al., 1989). Hallucinations, memory impairment, disorientation, and emotional instability also caused by Mn overdose (Gupta and Gupta, 1998).

Nickel (Ni) is a nutritionally essential trace element for humans as well as other animal species and plants. But Ni can affect the mass population through contaminated drinking water and food intake (Cempel and Nikel, 2005). According to WHO standards, Ni concentration should not exceed 0.02 mg/L in drinking water; whereas Bangladesh standard allows the presence of Ni up to 0.1 mg/L in drinking water and 1 mg/L for industrial discharge. Studies suggested the average concentration ranges between 0.005-0.18 mg/L and >0.00006–0.043 mg/L in surface water and groundwater, respectively. The maximum average concentration (0.18 mg/L) of this trace element was found in the wetlands near Barapukuria coal mine, Dinajpur (Bhuiyan et al., 2010). Nickel hypersensitivity also responsible for asthma, conjunctivitis, inflammatory reactions to nickel-containing prostheses and implants (Nielsen et al., 1999). Moreover, Nickel compounds can cause cancer (Bal et al., 2000).

Zinc (Zn) is a natural trace element found in all plants and animals which maintaining the healthy growth of the human body, especially for infants and young children's growth and development (Askary et al., 2011). Bangladesh standard and WHO permissible limit of Zn for drinking water is 5 mg/L and 3 mg/L respectively for drinking water. The highest level of Zn was found in the Dhalai Beel and Bangshi River which was slightly above (3.32 mg/L) the WHO limit. Ingestion of acute zinc can cause vomiting, diarrhea, neurological damage ("Zn shakes") (Gupta and Gupta, 1998) and chronic exposure to Zinc is responsible for depressed Cu utilization (Sandstead, 1978), Fe deficiency, lowered levels of HDL cholesterol (Hooper, 1980).

Cadmium (Cd) is considered as a very toxic trace metal because of its extremely long half-life (Jihen et al., 2008). According to WHO standards, its concentration should not exceed 0.003 mg/L in drinking water. But, in Bangladesh separate investigation showed a significant amount of Cd present throughout the country in different forms of surface water (Table 2). Although there are almost no data about the condition of Cd contamination in groundwater, a recent study reported the mean concentration of Cd almost five times higher (0.014 mg/L) than the WHO limit in the tubewell water in Rajshahi city (Mostafa et al., 2017). The maximum concentration of Cd (0.221 mg/L) was reported in the Airport lake of Dhaka city (Mokaddes et al., 2013).

Lead (Pb) is a ubiquitous trace metal and significant public health concern, particularly in developing countries (Flora et al., 2012). The highest admissible concentration set by WHO and Bangladesh standard for Pb in drinking water is 0.01 mg/L and 0.05 mg/L respectively. In some region of Bangladesh, water sources contain a much higher amount of Pb than WHO permissible limit. The ranges of Pb concentration varied between 0.00 to 0.23 mg/L for surface water and 0.00004–1.167 mg/L for groundwater. Bhuiyan et al. (2010) evaluated trace metals in the wetlands near Barapukuria, Dinajpur and indicated exceed the amount of Pb (0.23 mg/L) in the analyzed samples. Rivers like Buriganga (Bhuiyan et al., 2015), Korotoa (Islam et al., 2015b), Paira (Islam et al., 2015a), Khiru (Rashid et al., 2012), Bangshi (Rahman et al., 2014) showed elevated amount of Pb. In groundwater, however, the maximum mean concentration of Pb was more than hundred times (1.167 mg/L) that of WHO limit which was found in deep tubewell water of Rajshahi city (Mostafa et al., 2017).

2.2.1.1. Arsenic pollution. Arsenic is a fatal element (Lindsay and Maathuis, 2017) which is named as a category 1 carcinogenic element by WHO (Driscoll et al., 2004). The first survey done in Bangladesh to identify arsenic was in late 1990s (Ravenscroft, 2011). In 1999, groundwater from 64 districts of Bangladesh was analyzed where 52 districts contained arsenic levels greater than 0.01 mg/L, and 42 districts where the level was greater than 0.042 mg/L (Uttam and Chowdhury, 2000). The allowable concentration of arsenic for drinking water indicated by WHO is 0.01 mg/L where 0.05 mg/L is permitted in Bangladesh but studies found that 8.4% tube-wells in Bangladesh contain more than 0.3 mg/L arsenic (Smith et al., 2000).

Several local and foreign organization examined the level of arsenic contamination in Bangladesh. Among them, BBS/UNICEF (2011) found that 8% of samples they tested, surpassed the Bangladesh standard value and 18% samples surpassed the WHO guideline value according to their research center information. According to the Digital Arsenator data, they also found that 13.4% and 32% samples surpassed the Bangladesh standard value and WHO guideline value respectively. Similarly, another survey collected samples throughout the whole nation and found that 12.6% of samples surpassed the Bangladesh standard value (BBS/UNICEF, 2010).

In Bangladesh, groundwater from "tableland" territory contains more arsenic than "flood plain" and "delta" area. Deposition of Holocene sediments may be the possible reasons behind this difference (Chakraborti et al., 2015). Pond water also is not free from high level of arsenic (Yokota et al., 2001). Arsenic contamination level in different cities/districts of Bangladesh is summarized in Table 3.

In short, arsenic pollution is a genuine risk to drinking water in Bangladesh, overexposure of arsenic not only increases the probability of diseases like lung cancer, renal cancer, skin cancer but also it may create a generation like "arsenic orphans" (Flanagan et al., 2012).

2.2.2. Major cations and anions

Water of surface and ground sources contain several cations and anions; among those, cations like sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), ammonium (NH_4^+) and anions like chloride (Cl^-), fluoride (F^-), nitrates (NO_3^-), bicarbonate (HCO_3^-), sulfates (SO_4^{2-}), phosphates (PO_4^{3-}) etc. are found to be essential for humans. Nevertheless, an excess amount of these ions can make the water unsuitable for humans as well as other living organisms. Table 4 represents the summarized data of the condition of different ions in various water sources, which are extracted from numerous studies throughout the country.

2.2.2.1. Cations. Sodium (Na^+) is very common is drinking water and mostly found as $NaHCO_3$ and Na_2SO_4 (Whelton et al., 2007). WHO and Bangladesh standard for the maximum Na^+ concentration is 200 mg/L. A few studies found Na^+ limit above the standard in many water sources; mostly in groundwater sources. In case of surface water, the highest mean concentration of Na+ (252.78 mg/L) throughout the different season was found in Buriganga river (Ahmed et al., 2011b). Although most of the studies reported a mild concentration of Na^+ in selected groundwater, water in some territory showed a higher amount of Na^+. The maximum level of Na+ (863 mg/L) in groundwater was reported in the shallow tube well of Barguna district (Islam et al., 2017d). Sodium is one of the leading constituents of the blood plasma of humans and because of that reason alteration of its normal concentration in the human body may have direct and vital effects on the osmotic pressure of the plasma, on plasma and interstitial fluid volumes, on acid-base balance, on the maintenance of the electrical activity of body cells, and on the responsiveness of the cardiovascular system to circulating endogenous pressor agents (Grollman, 1961).

The amount of potassium (K^+) found in water is less than other major cations, and it is mostly present in water as $KHCO_3$, K_2SO_4 and KCl (Whelton et al., 2007). 93% of the tested sample collected from all over the country reported in BNDWQS (2009) result did not surpass the Bangladesh standard value for K^+. This particular report also indicated that Jhaloka, Noakhali, Chuadanga, and Meherpur were the four districts, which exhibited a higher concentration of K^+ than the standard value in drinking water. Individual investigations also agreed with the BNDWQS report on K^+ contamination in Bangladesh. Same as Na+, Buriganga river water contained the highest amount of K^+, which is more than thrice that of standard value (40.25 mg/L) (Ahmed et al., 2011b). Apart from the water of the Karatoa river, most of the surface water sources contained an insignificant amount of K^+ (Table 4). Shallow tube well water in Khulna showed the highest concentration of K^+ (17.05 mg/L) found in groundwater sources (Islam et al., 2017e). Potassium enters into the human body mostly through the intake of different solid foods, and this metal helps to decrease blood pressure and also reduces cardiovascular disease. But high potassium intake may result in Hyperkalaemia, which eventually can lead to cardiac arrhythmias (He and MacGregor, 2008).

Calcium (Ca^{2+}) is the amplest mineral in the human body, and this metal plays a vital role in cellular activities, hormones, cancer, heart disease, and muscle and neurodegenerative diseases, as well as the descent of the testis (Tandouan and Ulusu, 2005). None of the studies found Ca^{2+} above the safe limit in surface water; however, some of the groundwater sources showed an excess amount of Ca^{2+}. 294 mg/L of Ca^{2+} was found in the water of arsenates well of Chuadanga district (Nahar et al., 2014). Individual studies and BNDWQS report showed the similar condition of Ca^{2+} in the water of districts like Rajshahi, Faridpur, Dhaka, Munshiganj, which are above the recommended limit. The significant side effects from excessive consumption of calcium are hypercalcemia, hypercalciuria, urinary tract calculi, calcification in a variety of soft tissues, notably in the kidney and in arterial walls, and suppression of bone remodeling (Heaney et al., 1982).

Magnesium (Mg^{2+}) is a vital nutrient for human as well as other animals, and it is the second most abundant mineral in the human body (Vallee et al., 1960). Higher concentration of Mg^{2+} in any source of water is uncommon in Bangladesh. Studies suggested that water of Khulna and Chittagong territory possessed a higher amount of Mg^{2+} in both surface and groundwater (Table 4). Although very little data can be found regarding the Mg^{2+} in surface water, one study conducted in the river Mouri situated in Khulna, reported the excess amount of Mg^{2+} (48.33 mg/L) in that stream (Kamal et al., 2007). In addition, investigation in the water of shallow tubewell of Khulna showed 78.28 mg/L mean concentration of Mg^{2+} (Islam et al., 2017e). But the highest average concentration of Mg^{2+} (155 mg/L), which is almost five times that of standard value; was found in the shallow tube well of Barguna district which is also situated in Khulna division (Islam et al., 2017d).

The non-ionized ammonia (NH^3) and ionized ammonium (NH^{4+}) in the environment originate from metabolic, agricultural and industrial processes, and from disinfection with chloramine (WHO, 2011). There is no specific guideline value for NH^{4+} set by WHO. A few studies calculated the amount of NH^{4+} present in the water of Bangladesh. According to the studies, the highest concentration (9.48 mg/L) of ammonium was found in the groundwater of Chandpur (Zahid et al., 2008). Ammonia does not directly affect health, but it can compromise the disinfection efficiency of water (WHO, 2011).

2.2.2.2. Anions. Chloride (Cl^-) is a naturally occurring anion, which can be found in every water sources, and it is a relatively minor contaminant (Kelly et al., 2012). In case of Cl^-, there is no guideline value provided by WHO, whereas Bangladesh standard for Cl^- ranges between 150-500 mg/L for drinking water and 600 mg/L for industrial effluent discharge. Different studies on water sources revealed the amount of Cl^- in water. The highest mean concentrations of Cl^- have been reported from surface water near D.N.D (Dhaka- Narayanganj-Demra) embankment which was 3699.83 mg/L; more than six times higher than the standard industrial discharge limit because of the high discharge rate of the textile dyeing effluents (Sultana et al., 2009). In case of groundwater, the highest amount of Cl^- (1776.74 mg/L) was recorded from the shallow tube well in Khulna area (Islam et al., 2017e). Different studies also found an elevated amount of Cl^- in the groundwater sample of Noakhali (Ahmed et al., 2011a) and Chandpur (Zahid et al., 2008). Chloride is present in water can increase the rate of metal corrosion in the

Table 3
Arsenic contamination in various cities/districts of Bangladesh. All values are given in μg/L. Source: (Chakraborti et al., 2010)

Division	City/district name	Total no. of samples	Distribution of total samples in different as concentration (μg/L) ranges								Maximum concentration detected (μg/L)
			<10	10 to 50	51 to 99	100 to 299	300 to 499	500 to 699	700 to 1000	>1000	
Dhaka	Dhaka	574	449	29	26	63	7	-	-	-	352
	Faridpur	707	243	171	67	142	40	24	12	8	1630
	Gazipur	3386	3312	33	8	16	16	1	-	-	533
	Gopalgonj	384	86	74	55	146	19	2	2	-	920
	Jamalpur	144	89	30	7	6	2	2	6	2	1172
	Madaripur	2309	453	480	336	622	316	76	21	5	1200
	Kishoreganj	1328	527	429	238	133	1	-	-	-	365
	Manikganj	282	79	101	44	55	2	1	-	-	586
	Munshiganj	151	10	6	12	80	36	7	-	-	529
	Mymensingh	1825	1705	101	12	6	1	-	-	-	330
	Narayanganj	412	54	42	34	147	68	36	26	5	1750
	Narshingdi	336	252	16	7	23	24	10	4	-	1000
	Netrokona	533	201	180	84	49	13	6	-	-	580
	Rajbari	174	79	72	5	15	1	-	2	-	714
	Shariatpur	152	63	29	20	26	12	2	-	-	580
	Sherpur	303	191	100	7	5	-	-	-	-	275
	Tangail	597	443	131	21	2	-	-	-	-	224
Chittagong	Bandarban	41	41	-	-	-	-	-	-	-	-
	Brahmanbaria	47	12	9	9	17	-	-	-	-	210
	Chandpur	1165	50	36	30	675	294	54	21	5	1318
	Chittagong	366	319	26	13	8	-	-	-	-	275
	Comilla	545	113	26	29	128	123	75	25	26	1769
	Cox's Bazar	58	58	-	-	-	-	-	-	-	-
	Feni	186	58	53	40	28	5	1	1	-	1000
	Khagrachari	39	39	-	-	-	-	-	-	-	-
	Lakshmipur	2262	304	235	339	852	421	246	177	88	2030
	Noakhali	843	5	36	92	413	80	79	48	90	4730
	Rangamati	47	47	-	-	-	-	-	-	-	-
Rajshahi	Bogra	767	607	125	17	16	1	-	-	1	1040
	Dinajpur	2641	2612	28	1	-	-	-	-	-	77
	Gaibanda	1233	863	308	40	17	4	1	-	-	512
	Joypurhat	398	388	10	-	-	-	-	-	-	32
	Kurigram	539	467	72	-	-	-	-	-	-	50
	Lalmanirhat	464	434	30	-	-	-	-	-	-	50
	Naogaon	537	527	10	-	-	-	-	-	-	22
	Natore	117	91	22	4	-	-	-	-	-	63
	Nawabganj	1902	920	434	173	273	57	23	12	10	1600
	Nilphamari	523	505	18	-	-	-	-	-	-	50
	Pabna	5117	1595	1807	807	691	124	52	25	16	2108
	Panchagarh	462	458	4	-	-	-	-	-	-	15
	Rajshahi	2698	2197	266	105	121	8	1	-	-	524
	Rangpur	464	285	114	19	20	15	9	2	-	939
	Sirajganj	278	187	79	8	4	-	-	-	-	216
	Thakurgaon	461	416	38	6	1	-	-	-	-	130
Khulna	Bagherhat	371	90	72	34	79	67	17	12	-	958
	Chuadanga	457	124	223	73	11	11	13	2	-	841
	Jessore	5465	4227	248	317	457	105	76	32	3	1120
	Jhenaidaha	388	185	142	24	27	6	4	-	-	592
	Khulna	1000	518	233	55	138	39	6	5	6	3143
	Kusthia	2065	1082	557	154	168	42	33	13	16	2190
	Meherpur	1024	526	271	95	95	27	5	4	1	1230
	Magura	496	243	168	44	33	5	-	-	3	1050
	Narail	371	96	56	35	164	20	-	-	-	375
	Satkhira	532	32	73	56	236	133	1	1	-	750
Barisal	Barguna	43	35	8	-	-	-	-	-	-	15
	Barisal	803	179	113	40	227	106	75	47	16	1770
	Bhola	74	57	17	-	-	-	-	-	-	50
	Jhalakati	42	17	16	3	5	1	-	-	-	310
	Patuakhali	15	13	2	-	-	-	-	-	-	10
	Pirojpur	124	42	41	8	24	8	-	1	-	731
Sylhet	Habiganj	103	59	37	6	1	-	-	-	-	100
	Moulavi Bazar	152	72	65	12	3	-	-	-	-	133
	Sunamganj	89	6	34	29	17	3	-	-	-	302
	Sylhet	391	331	44	14	2	-	-	-	-	177
Total		**52202**	**29768**	**8230**	**3714**	**6487**	**2263**	**938**	**501**	**301**	**-**
Percentage (%)			57	15.8	7.1	12.4	4.3	1.8	1	0.6	

Table 4

Cation and anion concentration (mg/L) in Bangladesh in surface water and groundwater. Data are extracted from various individual studies and arranged chronologically based on year of publication of the reviewed articles. Values given represents the mean values or mean values plus-minus standard deviation (S.D.), where the values with ± in the parenthesis () represents average ± S.D.

Samples Location	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH4$^+$	Cl^-	F^-	NO_3^-	HCO_3^-/ CO_{2^-}	SO_4^{2-}	PO_4^{2-}	References
Surface Water												
Surma River (Dry)	—	—	—	—	(0.18 ± 0.09)	—	—	—	—	—	—	(Alam et al., 2007)
Surma River (Monsoon)	—	—	—	—	(0.12 ± 0.07)	—	—	—	—	—	—	(Alam et al., 2007)
Mouri River	25.968	3.68	69.717	48.33	—	—	—	1.277	—	49.507	7.765	(Kamal et al., 2007)
Sadar ghat, Buriganga River (Rainy Season)	—	—	—	—	—	—	—	Trace	—	—	—	(Saha et al., 2009)
Sadar ghat, Buriganga River (Winter Season)	—	—	—	—	—	—	—	Trace	—	—	—	(Saha et al., 2009)
Surface Water near Dhaka-Narayanganj-Demra (D.N.D) Embankment	—	—	—	—	—	(3699.83 ± 2136.28)	(3.33 ± 3.53)	(55.80 ± 66.81)	—	(1443.87 ± 1962.82)	(292.89 ± 66.68)	(Sultana et al., 2009)
Barapukuria, Dinajpur (Drainage Water)	—	7.37	26.2	—	—	—	—	—	—	—	—	(Bhuiyan et al., 2010)
Barapukuria, Dinajpur (Ground Water)	—	2.13	7.11	—	—	—	—	—	—	—	—	(Bhuiyan et al., 2010)
Buriganga River, Dhaka (Different Seasons)	252.78	40.25	27.547	—	—	68.74	—	1.715	—	—	2.13	(Ahmed et al., 2011b)
Katrnatoli River, Savar, Dhaka (Different Seasons)	113.43	7.11	20.37	—	—	26.407	—	1.333	—	—	3.803	(Ahmed et al., 2011b)
Ashulia, Dhaka	—	—	—	—	—	(81.67 ± 21.38)	—	(7.42 ± 3.35)	—	(94.42 ± 33.71)	(4.62 ± 1.24)	(Bhuiyan et al., 2011)
Amin Bazar, Dhaka	—	—	—	—	—	(93 ± 38.01)	—	(7.61 ± 3.64)	—	(78.75 ± 30.82)	(5.38 ± 1.28)	(Bhuiyan et al., 2011)
Tejgaon area, Dhaka (Wet Season)	—	—	—	—	—	—	—	6.7	—	—	—	(Mondol et al., 2011)
Tejgaon area, Dhaka (Dry Season)	—	—	—	—	—	—	—	198.3	—	—	—	(Mondol et al., 2011)
Karatoa river	(15.94 ± 2.88)	(15.03 ± 2.34)	(44.32 ± 9.04)	(15.84 ± 5.53)	—	(3.12 ± 0.66)	—	—	(2.59 ± 1.12)	(7.43 ± 5.19)	(1.58 ± 0.37)	(Zakir et al., 2012)
Turag river	—	—	—	—	—	34	—	—	—	—	—	(Banu et al., 2013)
Shitalakshyaa River	—	—	—	—	—	67.5	—	1	—	—	0.825	(Sikder et al., 2013)
Turagh River	—	—	—	—	—	7.5	—	1.5	—	—	1.75	(Sikder et al., 2013)
Bongshi River	—	—	—	—	—	10	—	2	—	—	0.983	(Sikder et al., 2013)
Karnaphuli River, Chittagong (Summer)	—	—	—	—	(0.193 ± 0.09)	—	—	—	—	—	—	(Ali et al., 2016)
Karnaphuli River, Chittagong (Winter)	—	—	—	—	(0.3 ± 0.11)	—	—	—	—	—	—	(Ali et al., 2016)
Ground Water												
Chandpur	347.4417	7.624	64.733	45.488	9.48	602.213	—	0.553	286.917	20.268	4.547	(Zahid et al., 2008)
Sirajdikhan, Munshiganj	(64.751 ± 73.634)	(10.106 ± 5.224)	(87.493 ± 41.445)	(44.336 ± 24.636)	—	(69.027 ± 96.983)	—	(3.930 ± 6.931)	(478.231 ± 181.080)	(5.230 ± 2.312)	(1.761 ± 1.603)	(Halim et al., 2009)

(continued on next page)

Table 4 (*continued*)

Samples Location	Na^+	K^+	Ca^{2+}	Mg^{2+}	$NH4^+$	Cl^-	F^-	NO_3^-	HCO_3^-/ CO_2-	SO_4^{2-}	PO_4^{2-}	References
Bagerhat (Deep Tubewell)	437.5	6.15	16.77	18.19	—	167.67	—	5.87	270.44	6.43	—	(IWM, 2009)
Sonargaon, Narayanganj	22.743	3.578	67.992	16	1.049	35.458	—	0.0822	272.55	1.542	3.55	(Bhattacharya et al., 2009)
Chandina, Comilla	123.456	9.52	24.267	33.7	9.288	153.878	—	0.104	307.111	0.5289	8.1578	(Bhattacharya et al., 2009)
Mymensingh (Different types of Tubwells)	—	—	37.917	—	0.963	—	—	—	—	—	0.823	(Ahmed et al., 2010)
Ishwardi Municipal Area, Pabna (Dry Season)	26.129	7.014	65.031	41.531	—	74.656	—	1.421	386.861	2.952	5.856	(Hossain et al., 2010)
Ishwardi Municipal Area, Pabna (Wet Season)	31.051	7.344	70.230	45.780	—	70.451	—	1.760	398.818	2.813	6.270	(Hossain et al., 2010)
Eastern region of Bangladesh	(90.41 ± 206.67)	(9.14 ± 12.53)	(36.75 ± 23.19)	(23.88 ± 21.78)	—	(135.36 ± 311.96)	—	(9.1 ± 12.54)	(166.84 ± 123.27)	(11.26 ± 31.73)	(3.24 ± 1.69)	(Halim et al., 2010)
Noakhali (Shallow Tubewell)	—	—	—	—	—	875.61	—	3.91	305.12	4.39	—	(Ahmed et al., 2011a)
Satkhira (Deep Tubewell)	221.96	13.4	62.8	14.13	—	409.6	—	12.05	224.32	11.79	—	(Rahman et al., 2011)
Mirpur, Dhaka city	15.1	2.1	14.6	0.41	—	12.9	—	8.9	66	0.3	—	(Nahar et al., 2014)
Banani, Dhaka city	16.8	1.7	27.3	6.69	—	13	—	3.8	81	0.7	—	(Nahar et al., 2014)
Tejgaon, Dhaka city	24.3	2	27.7	9.02	—	56.7	—	20.5	86	19.5	—	(Nahar et al., 2014)
Dhanmondi, Dhaka city	32	1.9	54.4	1.69	—	50.1	—	9.7	174	15.5	—	(Nahar et al., 2014)
Hazaribagh, Dhaka city	43.5	1.9	45	16.9	—	46.8	—	0.03	179	31.6	—	(Nahar et al., 2014)
Motijhil, Dhaka city	21.9	2	29.6	11.9	—	25.4	—	10.1	122	14.6	—	(Nahar et al., 2014)
Armanitola, Dhaka city	27.6	2.4	49.5	19.3	—	41.2	—	0.03	222	7.2	—	(Nahar et al., 2014)
Savar, Dhaka	7.5	2	6.4	1.54	—	2.8	—	9	27	0.1	—	(Nahar et al., 2014)
Dhamrai, Dhaka	25.2	3	78.1	24.3	—	40.9	—	0.3	399	16.8	—	(Nahar et al., 2014)
Chuadanga (Arsenates well water)	117.9	9.5	294	70.9	—	632	—	0.03	700.2	0.1	—	(Nahar et al., 2014)
Singair, Manikgonj	27.3	8.8	72.3	36.4	0.5	38.1	—	1.4	179	17.7	2.6	(Halim et al., 2014)
Faridpur	13.598	8.788	120.032	28.22	—	17.288	—	2.371	616.359	6.20725	—	(Bodrud-Doza et al., 2016)
Gupalganj (Deep Tubewell)	180.77	3.47	53.08	22.81	—	96.52	—	—	—	39.35	0.93	(Shammi et al., 2016)
Lakshmipur (Deep Tubewell)	159.78	10.89	55.76	46.14	—	227.2	—	—	430.18	16.14	—	(Bhuiyan et al., 2016)
Rajshahi City (Shallow Tubwells)	(23.12 ± 1.96)	(5.66 ± 0.57)	(78.35 ± 7.6)	(27.02 ± 2.13)	—	(55.315 ± 9.9)	—	(1.60 ± 0.48)	(245.30 ± 29.59)	(38.76 ± 5.2)	—	(Mostafa et al., 2017)
Rajshahi City (Deep Tubwells)	(22.77 ± 2.24)	(5.63 ± 0.52)	(78.54 ± 0.38)	(26.22 ± 1.66)	—	(44.9 ± 9.7)	—	(1.67 ± 0.51)	(188.36 ± 2.28)	(36.6 ± 2.92)	—	(Mostafa et al., 2017)
Sylhet	(47.167 ± 30.962)	(2.396 ± 1.782)	(7.183 ± 6.354)	(4.156 ± 3.083)	—	(12.331 ± 15.738)	—	(3.188 ± 7.320)	(147.659 ± 72.066)	(2.952 ± 5.214)	—	(Islam et al., 2017a)
Panchbibi, Joypurhat	(12.168 ± 2.102)	(0.301 ± 0.094)	(54.708 ± 4.385)	(4.036 ± 1.276)	—	—	(0.052 ± 0.022)	—	(136.971 ± 20.336)	(1.513 ± 0.242)	—	(Islam et al., 2017c)
Khulna (Shallow Tubewell)	647.2	17.05	101.5	78.28	—	1776.74	—	2.61	510.05	4.97	—	(Islam et al., 2017e)
Patuakhali (Deep Tubewell)	78.99	3.8	12.47	9.34	—	298.13	—	11.57	391.02	12.5	—	(Islam et al., 2017f)
Barguna (Shallow Tubewell)	863	16.16	136	155	—	3513	—	4.12	254	19.48	—	(Islam et al., 2017d)
WHO Standards	200	—	100	150	—	250	—	50	—	500	—	(WHO, 2011)

(*continued on next page*)

Table 4 (*continued*)

Samples Location	Na^+	K^+	Ca^{2+}	Mg^{2+}	$NH4^+$	Cl^-	F^-	NO_3^-	HCO_3^-/ CO_{2}-	SO_4^{2-}	PO_4^{2-}	References
Bangladesh Standards (Drinking water)	200	12	75	30–35	0.2	150–600	1	10	–	400	6	(DPHE, 2018)
Bangladesh Standards (Industrial effluent)	–	–	–	–	–	600	7–15	–	–	–	–	(DoE, 2008)

distribution pipeline. Also, the excess amount of chloride can change the natural odor and taste of water (WHO, 2011).

Fluoride (F^-) is often found in minerals, and it can be leached out due to erosion by rainwater, which leads to contamination of ground and surface waters; also, industrial effluents contribute increasing the amount of F^- (Sun et al., 2011). The average concentration of the F- present in the water according to BNSWQS (2009) report is only 0.20 mg/L. Only two individual studies investigated F^- content in surface and groundwater respectively. An article on the highly polluted surface water of D.N.D embankment found 3.33 mg/L mean concentration of fluoride (Sultana et al., 2009).

Nitrate (NO_3^-) is a naturally occurring ion, which is concerned with the nitrogen cycle (Fewtrell, 2004). Contamination of drinking water supplies with NO_3^- and nitrite (NO_2^-) is one of the three major water-quality problems today, ranking with contamination of water with bacteria and toxic chemicals (Johnson and Kross, 1990). WHO guideline value for NO_3^- and NO_2^- is 50 mg/L and 3 mg/L respectively whereas Bangladesh standard for this ion is maximum of 10 mg/L. Tejgaon is one of the major industrial areas of Dhaka city which is severely polluted. One study was undertaken in this area showed a very high average concentration of NO_3^- in the nearby lagoon, which was 198.3 mg/L (Mondol et al., 2011). Another study conducted in another industrial area near Dhaka found NO_3^- concentration just above the safe limit in surface water (Sultana et al., 2009). None of the studies found and groundwater containing NO_3^- above the WHO standard, but several areas exceeded Bangladesh standard. Bacterial conversion of the relatively innocuous nitrate ion to nitrite can lead to the development of Methemoglobinemia, which can be the cause of infant death (Winton et al., 1971). Many types of research have shown the relation between consumption of high nitrate containing drinking water and the incidence of different cancers.

Bicarbonate (HCO_3^-) is a simple single carbon molecule that plays surprisingly vital roles in diverse biological processes (Casey, 2006). HCO_3^- is associated with the hardness of water; hardness of water is usually expressed as milligrams of calcium carbonate per liter (WHO, 2011). There is no particular guideline value for bicarbonate ion. Different studies found the bicarbonate content in groundwater varied from 27 mg/L to 700.2 mg/L (Table 4). Sulfate (SO_4^{2-}) is another naturally occurring mineral, which can be found in surface and groundwater. There is no definite guideline value set by WHO for SO_4^{2-}, but more than 500 mg/L of sulfate in drinking water is not recommended (WHO, 2011). In Bangladesh, both surface and groundwater sources showed an insignificant amount of SO_4^{2-} present in water. The only surface water of D.N.D embankment areas exhibited a very high concentration of SO_4^{2-}, which was 1443.87 mg/L (Sultana et al., 2009). Higher concentration of sulfate present in drinking water can cause a mild laxative effect manifested by slightly looser and heavier stools and may lead to disease like diarrhea (Heizer et al., 1997). Phosphate (PO_4^{3-}) in water bodies can cause eutrophication, hence the amount of PO_4^{3-} should be low (Zhang et al., 2011). WHO hasn't established any guideline value for this particular ion. Only one investigation found overplus amount of PO_4^{3-} (292.89 mg/L) in the surface water near D.N.D embankment (Sultana et al., 2009).

2.2.3. Bacteriological contamination

Microbial examination of water is typically occurred to identify mostly fecal coliforms (Azizullah et al., 2011). Generally, fecal coliforms found in the dung of different warm-blooded species like human, domestic animals (Geldreich, 1996). Scientist uses it as an indicator of water pollution as the presence of waterborne human disease-causing bacteria is indicated by this coliform (Shiekh, 2006). WHO standard for fecal and total coliforms for drinking water is 0 coliform per 100mL of water samples (WHO, 2004). A considerable lot of the revealed types of bacteria can cause serious medical issues in Table 5. Numerous examinations uncover overwhelming bacteriological contamination of drinking water in the country which is summarized in Table 6.

Most of the rural people in Bangladesh use tube-well water for drinking purposes, but this tube-well water is contaminated by microorganisms (Islam et al., 2001). In Gakulnagar village in the Dhaka district, 60% of tube-well water is contaminated by coliform bacteria (Rahman, 2009). Moreover, another study found three tube-wells are highly contaminated with total coliforms in Sardarkandi village under Dhaka district (Ferguson et al., 2011). Similarly, from Comilla, Brahmanbaria and Sirajganj districts 207 samples of tube-well water were collected, and among them, 41% samples were polluted by total coliforms, also 29% samples by thermos-tolerant coliforms and 13% samples by *Escherichia coli* (Luby et al., 2008). Another study collected samples from 21 shallow tube-wells from Shinduria village under Savar sub-district of Dhaka district and found total coliforms ranging from 1.5×10^1 to 4.98×10^4 cfu/100mL and fecal coliforms 0 to 3.49×10^3 cfu/100mL (Rahman, 2013). A recent study collected 53 tube-well water

Table 5
List of bacteria reported in drinking water in Bangladesh and their possible health effects.

Bacteria	Possible health effects	References
Aeromonas hydrophila	Variety of diseases like septicemia, gastroenteritis in young children and elderly	(Ahmed, 2013)
Enterobacter aerogenes	Cause infections in urinary and respiratory tracts	(De Gheldre, 1997)
Enterococcus species	Cause infection in urinary tract	(Felmingham, 1992)
Escherichia coli	Cause food poisoning, gastroenteritis, urinary tract infections	(Todar, 2007)
Klebsiella species	An astute pathogen that ordinarily causes nosocomial contaminations in the urinary tract, respiratory tract, lung, wound destinations	(Chung, 2016)
Listeria species	Variety of diseases like meningitis, endocarditis and has high mortality rate	(Acharjee, 2011; Sauders et al., 2012)
Pseudomonas aeruginosa	Causes diseases in newborns and elderly patients	(Ahmed, 2013)
Salmonella species	Typhoid	(Farooqui, 2009)
Shigella species	Cause abdominal pain, tenesmus, watery diarrhea	(Baron, 1996)
Staphylococcus species	Cause superficial skin lesions, food poisoning	(Baron, 1996)
Vibrio cholerae	Cholera	(Herrington, 1988; Alam, 2006)

Table 6
Bacteriological contamination of drinking water in different areas of Bangladesh. Data are collected from various studies done in Bangladesh.

Sampling Location	No. of Samples	Total Coliforms Counts/ 100mL	Fecal Coliforms Counts/100 mL	References
Tube-well water, Matlab, Chandpur	5	5	3	(Islam et al., 2001)
Buriganga River	6	–	5.25×10^5	(Shiekh, 2006)
Turag River	6	–	6.08×10^4	(Shiekh, 2006)
Balu River	6	–	4.08×10^4	(Shiekh, 2006)
Dhanmondi Lake, Dhaka	6	–	2.55×10^4	(Shiekh, 2006)
Gulshan Lake, Dhaka	6	–	2.39×10^5	(Shiekh, 2006)
Nobab-bari Pond, Dhaka	6	–	5.77×10^5	(Shiekh, 2006)
Jatrabari Pond, Dhaka	6	–	5.57×10^5	(Shiekh, 2006)
Airport Road Pond, Dhaka	6	–	3.57×10^3	(Shiekh, 2006)
Curzon Hall Pond, Dhaka	6	–	2.65×10^4	(Shiekh, 2006)
Sher-E-Bangla Agriculture University Pond, Dhaka	6	–	2.16×10^3	(Shiekh, 2006)
Institute of Public Health Pond, Dhaka	6	–	5.53×10^5	(Shiekh, 2006)
River Water, Dhaka City	18	2.4×10^4	2.4×10^4	(Parveen, Microbial Contamination of Water in Around Dhaka City, 2008)
Pond Water, Dhaka City	18	2.4×10^4	2.4×10^4	(Parveen, Microbial Contamination of Water in Around Dhaka City, 2008)
Tube-well water, Dhaka city	19	1.0×10^1	0	(Parveen, Microbial Contamination of Water in Around Dhaka City, 2008)
Household Water of Dhaka city	45	1.7×010^2	1.7×010^2	(Parveen, Microbial Contamination of Water in Around Dhaka City, 2008)
Mineral Water, Dhaka City	9	0	0	(Parveen, Microbial Contamination of Water in Around Dhaka City, 2008)
Different locations of Chittagong city	14	2.01×10^2	1.4×10^1	(Zuthi, 2009)
Tube-well water, Gakulnagar, Savar, Dhaka	20	3	–	(Rahman, 2009)
Tubewell Water in Dhaka City	19	1.0×10^1	–	(Islam, 2010)
Mineral Water in Dhaka City	8	1.7×10^1	–	(Islam, 2010)
Filtered Water in Dhaka City	8	2.90×10^2	–	(Islam, 2010)
Municipal Tap Water in Dhaka City	10	6.32×10^2	–	(Islam, 2010)
Different locations of Dhaka city	18	1	1	(Acharjee, 2011)
Samples from RWHSs (dry season)	20	–	4.65×10^2	(Islam, 2011)
Samples from RWHSs (wet season)	23	–	1.5×10^3	(Islam, 2011)
Samples from CRWHSs (dry season)	14	–	1.7×10^2	(Islam, 2011)
Samples from CRWHSs (wet season)	14	–	8.56×10^2	(Islam, 2011)
Samples from PSFs (dry season)	17	–	2.99×10^2	(Islam, 2011)
Samples from PSFs (wet season)	14	–	4.14×10^2	(Islam, 2011)
Ponds (dry season)	39	–	2.01×10^3	(Islam, 2011)
Ponds (wet season)	39	–	4.44×10^3	(Islam, 2011)
WASA supplied water, Dhaka city	20	5.53×10^2	2.60×10^2	(Sabrina, 2013)
Tube-well water, Sinduria, Dhaka	21	8.44×10^3	5.16×10^2	(Rahman, 2013)

samples from different districts of the country and found that 81.2% of them were contaminated with coliforms (Parvez, 2016).

In Bangladesh, pond water also is not free from fecal coliforms and other pathogenic bacteria (Albert, 2000; Alam, 2006). A study collected 120 samples from 5 ponds around Dhaka city, and among the five, four ponds were highly polluted by fecal coliforms ranging from 1.63×10^4 to 6.48×10^5 cfu/100mL (Islam, 1994). Similarly, a recent study tested 12 pond water samples across the country and found all of the ponds were contaminated with coliforms (Parvez, 2016). People from coastal areas of Bangladesh drink pond water in the dry season (Frisbie, 2002) and the alarming fact is those pond waters contain fecal coliforms. In coastal regions of Dacope and Mongla sub-district of the Khulna and Bagerhat districts, a study collected 39 samples of pond water and found fecal coliforms ranging from 12 to 10^4 cfu/100mL (Islam, 2011).

Though one study found no bacterial contamination in the WASA treated water (Acharjee, 2011), several other studies found bacterial contamination not only in the WASA treated water but also in other government and non-government water treating agency including in the bottled mineral water. A study found high numbers of pathogenic bacteria both in the WASA supply points and in the consumer points. They found high amount of *Salmonella spp.*, *Shigella spp.*, *Aeromonas spp.*, *Vibrio spp.*, *Listeria spp.*, *Pseudomonas spp.* and *Staphylococcus spp.* bacteria's in those supply points (Acharjee et al., 2014). Similarly, another study tested ten municipal tap water samples, eight filtered water samples, eight mineral water samples and found total coliform ranging from 150 to 1100 cfu/100mL in the municipal tap water, 63 to 1100 cfu/100mL in the filtered water and 2 to 47 cfu/100mL in the mineral water samples. They also found *Escherichia coli* (60%), Klebsiella (40%), Enterobacter (20%), Pseudomonas (70%), Proteus (10%), Staphylococcus (40%) and Salmonella (0%) in the municipal tap water samples (Islam, 2010). Moreover, another study found that the water supplied by WASA in Dhaka city is highly contaminated with fecal coliforms such as fecal coliforms found in Basabo (2.8×10^3 c.f.u/100mL), in Sobujbag (5.2×10^6 c.f.u/100mL), in Shagun Bagichaa and Mohammadpur (5.0×10^3 c.f.u/100mL) (Sabrina, 2013). In Chittagong city, water supplied by CWASA was also contaminated by fecal coliforms (Zuthi, 2009). Similarly, another study reported that 75% of water samples collected from tube-wells of Rajshahi city is polluted by total coliforms, of which 59% polluted by fecal coliforms (Rasul, 2010).

Escherichia coli is also a detector of fecal contamination (Ferguson, 2012; Talukdar, 2013). A study collected samples from rural shallow tube-wells of the country and found that *Escherichia coli* concentrations were within ranges of 1–10, 10–100 and 100–2000 MPN/100mL on 30%, 9%, 4% samples respectively (van Geen et al., 2011). In Dhaka city, out of 175 tap water samples 80% of their water samples were contaminated with fecal coliforms, 38% samples had fecal coliforms more than 10^4 cfu/100 mL, and also 63% of total water samples contained *E. coli* (Talukdar, 2013). In Mymenshing district, among the tube-well water samples, in 14% of the samples, *E. coli* were average ten cfu/100mL, and in 3% of the samples, *E. coli* were 100cfu/100mL (Ercumen, 2015).

There are several causes for contamination of drinking water. Groundwater might be polluted by various kinds of human activities. Residential, metropolitan, business activities would all be able to affect groundwater quality. Contamination of tube well water seems identified with various components, including nearness of toilets or channels to the tube wells, depth of the tube-wells. Distribution pipes might pollute supplied water because of spillage (Parvez, 2016).

2.2.4. Pesticides

Pesticides are lethal to living beings which are used for controlling plant bugs (Chowdhury et al., 2013). In 1951, pesticide was first used in Bangladesh for treating pest during cultivation and for improving production (Rahman, 1997). The use of pesticide in Bangladesh is increasing day by day (Matin et al., 1998). Rahman et al. (1995) reported that the consumption of pesticide in Bangladesh was double within six years. Moreover, Rahman (1997) reported that in 1956–57, around 2 tons of pesticide imported in Bangladesh and the consumption of pesticide increased per year such a high rate that eight metric ton pesticide was imported in Bangladesh in 1993. A few data is available regarding pesticide pollution of drinking water in Bangladesh. Lack of funds and laboratory facilities are the main obstacles in the availability of data in the country. The results of different examinations detailing pesticide deposits in ground and surface water of Bangladesh are abridged in Table 7, and WHO standards for different pesticide residues are in Table 8.

Rice, wheat, jute, potato, sugarcane, vegetables, and tea are the main crops cultivated in the country (Chowdhury et al., 2013). The paddy fields consume 70% of the total pesticides (Bhattacharjee, 2013). In Bangladesh, insecticides are largely used than herbicides, fungicides, acaricides, and rodenticides. Miah (2014) also found that 20 types of insecticides, 18 types of fungicides and two types of rodenticides are applied in Bangladesh. Similarly, Rahman et al. (1995) reported that 95% of total pesticides, used in Bangladesh, are insecticides and the remaining 5% are fungicides, weedicides, and rodenticides. They also reported that among the pesticides, 60.4% are organophosphorus, 28.6% are carbamates, 7.6% are organochlorines and 3.4% are other compounds. Another study found that in Bnagladesh, carbamates are used in 64% of the area used for crop production and organophosphates are used in 35% of that area (Chowdhury et al., 2012).

After applying pesticide, rain runoff, the residues to the nearest water bodies and they become contaminated (Kreuger, 1998). (Islam, 2007) collected 48 agricultural field water samples from different regions in the country and found water samples from 10 locations were polluted by P, P-DDT, heptachlor, and lindane. P, P-DDT was found at Rajbari and Bogra districts, heptacholor was found at Dhaka, Magura, and Chittagong districts, lindane was found at Dhaka, Sylhet, Shariatpur and Noakhali districts, also the highest concentration of P, P-DDT residue was found Bogura, and it was 0.5401 ppm. In Savar and Dhamrai Upazila, out of 27 water samples, Diazinon and carbofuran were found in water samples from Savar Upazila at 0.9 ppm and 198.7 ppm, respectively. Malathion was found from Dhamrai Upazila at 105.2ppm. Carbaryl was also found ranging from 14.1 ppm to 18.1 ppm and carbofuran at 105.2 ppm in the Dhamrai Upazila (Chowdhury, 2012). In Savar Upazila, out of 12 water samples beside the agricultural fields, carbaryl residues were found ranging from 4.6 ppm to 6.3 ppm, carbofuran residues at 43.2 ppm, cypermethrin in three water samples ranged from 54.36 ppm to 80.5 ppm (Hossain et al., 2015). Similarly, Chowdhury et al. (2012) collected 16 water samples from paddy fields and lakes in Rangpur city and found chlopyrifos ranging from 0.554 ppm to 0.895 ppm, carbofuran ranging from 0.949 ppm to 1.671 ppm and carbaryl in one sample at 0.195 ppm in the lake water samples. In the paddy field water samples, they found, cholrpyrifos in seven samples ranging from 0.477 ppm to 1.189 ppm, carbofuran in seven samples ranging from 0.934 ppm to 3.395 ppm and carbaryl in two samples at 0.055 ppm and 0.163 ppm. Moreover, Chowdhury et al. (2013) collected irrigated water samples from 22 districts in Bangladesh. They found DDT residue in Feni, Rajshahi and Nawabganj districts. The highest DDT concentration was 8.29 ppm. They also found heptachlor residues in Natore, Sunamganj, and Madaripur districts and the highest concentration was 5.24 ppm. They also found both DDT and heptachlor residues in water samples from Chhatak at Sunamganj district.

Pond water can be contaminated by the pesticides used in crops field situated around the pond (Chowdhury et al., 2013). Several studies found pesticide residues in pond water samples. Bagchi (2009) collected 20 pond water samples and found DDE and heptachlor in one water sample and DDT, DDE, DDD in another sample but their concentration level was within the WHO guideline value of the water quality. They also found carbofuran residues in 10 water samples but that also within the WHO guideline value. Similarly, another study collected 25 pond water samples from Nabinagar Upazila (Brahmanbaria district) and found Malathaion in three samples ranging from 0.0241 ppm to 0.0463 ppm and that also within the WHO guideline value of water quality (Uddin, 2012). Another study done in the Rangpur district collected seven pond water samples, but they found no water samples contaminated with pesticide residues (Chowdhury et al., 2012). In Meherpur district, out of 20 pond water samples, diazoin was found in three samples ranging from 0.0328 ppm to 0.0790 ppm, and chlorpyriphos was found in two samples ranging from 0.0107 ppm to 0.0143 ppm (Uddin, 2013). In Dhamrai Upazila, Hasanuzzaman et al. (2016) collected six pond water samples for the analysis of Malathion residue and found Malathion residue ranging from 261.06 ppm to 922.8 ppm.

Groundwater levels in Bangladesh are high, and soil is mainly coarse, so there is a chance that groundwater can have polluted by pesticide residues. Matin et al. (1998) collected 144 groundwater samples from underground sources and found most of the samples were free from pesticide residues. All DDT values they found were ranging from 0.051 ppm to 1.653 ppm that were below the WHO recommended values. Also, they found heptachlor residues ranging from 0.025 ppm to 0.789 ppm.

Over the years it has been seen that the consumption and use of pesticide in the agricultural sector have increased and this is expected to continue for the next decades due to socio-economic and technological progress (Bempah, 2011). Most farmers in Bangladesh use pesticides excessively and purposelessly as they have little consciousness and knowledge about the use (Miah, 2014). Overuse of pesticides can cause genuine public health insecurity particularly as residues in food (Chowdhury, 2013). Several studies found pesticide residues in different vegetable samples like in tomato, Lady's finger, eggplant, long yard bean (Fatema, 2013; Miah, 2014; Rahman, 2015). Pesticide residues were also detected in meat, milk and dry fish samples (Rahman, 1997; BHUIYAN, 2009; Shoeb, 2016).

Most farmers used mainly organochlorine, organophosphorous and carbamate pesticides in Bangladesh (Dasgupta, 2007). Organochlorine pesticides like DDT, lindane, heptachlor, dieldrin were used in agricultural fields and to treat diseases like malaria in Bangladesh from the early fifties (Rahman, 2000). Organochlorine (DDT) was banned in 1993 in Bangladesh but there were reports that it is consumed illegally (Shoeb, 2016). Several studies found residues of DDT and its metabolites in fresh fish, dry fish and poultry feeds (Nahar, 2008; Shoeb, 2009). All the pesticides have negative effects on human. Organochlorine pesticide

Table 7
Pesticide concentrations (ppm) in surface and groundwater sample of Bangladesh. Data are extracted from different studies and values given represent the mean values or the range from minimum to maximum.

Sampling Location	Water Type	Pesticide detected	Concentration	Reference
BIT, Khulna	Surface Water	DDT	0.0195	(Rahman, 1997)
		DDE	0	
		Endrin	0	
		Heptachlor	0.0002	
Kittonkhola, Barisal	Surface water	DDT	0.035	(Rahman, 1997)
		DDE	0	
		Endrin	0	
		Heptachlor	0.0002	
Anowara, Chittagong	Surface water	DDT	0	(Rahman, 1997)
		DDE	0	
		Endrin	0.075	
		Heptachlor	0	
Amin Bazar, Dhaka	Surface water	DDT	0	(Rahman, 1997)
		DDE	0.01	
		Endrin	0.014	
		Heptachlor	0.00023	
Baman Danga Beel	Surface water	p,p'-DDE	0	(Rahman, 1997)
		Dieldrin	0.00064	
		p,p'-DDT	0.0015	
Hand Tubewel (Nayerhat, Dhaka)	Groundwater	p,p'-DDE	0	(Rahman, 1997)
		Dieldrin	Traces	
		p,p'-DDT	Traces	
Niger bell (Comilla)	Surface water	p,p'-DDE	0.0001	(Rahman, 1997)
		Dieldrin	0	
		p,p'-DDT	6×10^{-6}	
Begumgonj, Sylhet	Surface water	p,p'-DDE	0.00046	(Rahman, 1997)
		Dieldrin	0	
		p,p'-DDT	0.019	
Water samples collected from different regions of Bangladesh	Surface water	p,p'-DDE	0.013–0.060	(Matin et al., 1998)
		p,p'-DDD	0.014–0.038	
		p,p'-DDT	0.015–0.068	
		Heptachlor	0.150–1.020	
samples collected from different regions of Bangladesh	Groundwater	p,p'-DDE	0.010–0.084	(Matin et al., 1998)
		p,p'-DDD	0.014–0.365	
		p,p'-DDT	0.027–1.204	
		Heptachlor	0.025–0.789	
Samples collected at 48 different locations in Bangladesh	Surface water	Aldrin	ND	(Islam, 2007)
		Dieldrin	ND	
		Endrin	ND	
		p,p'-DDT	ND-0.5401	
		Heptachlor	ND-1.479	
		Lindane	ND-1.826	
Pond Water samples collected from different regions of Bangladesh	Surface water	Aldrin	ND	(Bagchi, 2009)
		Dieldrin	ND	
		Endrin	ND	
		DDT	ND-0.316	
		DDD	ND-0.052	
		DDE	ND-0.014	
		Lindane	ND	
		Heptachlor	ND-0.048	
		Carbaryl	ND-0.609	
		Carbofuran	ND-1.760	
Pond water collected from Nabinagar Upazila under Brahmanbaria district	Surface water	Malathion	ND-0.0463	(Uddin, 2012)
		Carbofuran	ND-0.0629	
		Cypermethrin	ND-0.09	
Samples collected from Savar and Dhamrai Upazila	Surface water	Malathion	ND-105.2	(Chowdhury, 2012)
		Diazinon	ND-0.9	
		Carbaryl	ND-18.1	
		Carbofuran	ND-198.7	
Samples collected from the paddy fields, Rangpur district	Surface water	Chlorpyrifos	ND-1.189	(Chowdhury et al., 2012)
		Carbofuran	ND-3.395	
		Carbaryl	ND-0.163	
Samples collected from pond water in Meherpur zilla	Surface water	Diazinon	ND-0.0775	(Uddin, 2012)
		Chlorpyriphos	ND-0.0143	
		Carbofuran	ND-0.0387	
		Carbaryl	ND	
Water samples collected from Jessore region	Surface water	Quinaphos	ND-0.241	(Fatema, 2013)
Water samples from the lakes, Rangpur district	Surface water	Chlorpyrifos	0.544–0.895	(Chowdhury et al., 2012)
		Carbofuran	0.949–1.671	
		Carbaryl	ND-0.195	
Samples collected from different spots in Bangladesh	Surface water	Aldrin	ND	(Chowdhury et al., 2013)
		Dieldrin	ND	
		DDE	ND-4.06	

(continued on next page)

Table 7 (*continued*)

Sampling Location	Water Type	Pesticide detected	Concentration	Reference
		DDD	ND	
		DDT	ND-8.29	
		Endrin	ND	
		Lindane	ND	
		Heptachlor	ND-5.24	
Water samples collected from near the vegetable fields of Savar Upazila	Surface water	DDT	BDL	(Hossain et al., 2015)
		Chlorpyrifos	BDL-9.31	
		Diazinon	BDL-7.86	
		Ethion	BDL	
		Fenthion	BDL-56.3	
		Fenitrothion	BDL-33.41	
		Malathion	BDL-59.9	
		Parathion	BDL-6.23	
		Carbaryls	BDL-6.3	
		Carbofuran	BDL-43.2	
		Cypermethrin	BDL-80.5	
		Methoxychlor	BDL	
Samples collected at different spots from Dhamrai Upazila	Both surface and groundwater	Malathion	ND-922.8	(Hasanuzzaman et al., 2016)
		Diazinon	ND-31.5	

ND, not detected; BDL, below detection Limit.

residues having low polarity, low aqueous solubility, high lipophilicity and a very stable half-life in the environment make it a potential threat to human health and environment as it can bioaccumulation in the food chain (El-Mekkawi, 2009; Afful, 2010). As organophosphorous pesticides are cheap and their effectiveness is very good, farmers are encouraged to use it. But these pesticides are harmful to farmer's health, and those pesticides are also genotoxic and carcinogenic (Chowdhury, 2012; Hayat, 2010). Chlorpyrifos can cause attention deficit hyperactivity disorder and development disorder both in fetuses and children (Rauh, 2006). Carbamate pesticides such as carbofuran cause major problems in the reproductive system (Goad, 2004) and carbaryl can cause nausea, vomiting, blurred vision and breathing difficulties (Kamrin, 1997).

2.3. *Sources of water pollution*

Water can be polluted by both natural and anthropogenic sources (Harrison, 2001). Majority of the water sources, chiefly surface water bodies, however, are polluted because of the industrial growth; urbanization and man-made problems (Pandey, 2006) (see Table 9). In Bangladesh, sewage and solid waste & industrial waste & effluents are the main cause of surface water pollution. Arsenic contamination in groundwater is devastating in case of Bangladesh, and an estimated 35 to 77 million people of this particular country have been chronically exposed to arsenic in their drinking water (Flanagan et al., 2012).

Industrial pollutants are the major cause of surface water pollution in the urban region in Bangladesh. According to an industrial survey conducted by Bangladesh Center for Advanced Studies (BCAS) in 2009, only about 40% of industries had ETPs. In 10% of industries, ETPs were under construction at that time, and about 50% of industries have no ETP establishment (Amin, 2015). In terms of overall emission (indicated as BOD and TSS) into water, pulp and paper industry is the major contributor (47%), followed by pharmaceuticals (16%), metal (14%) and food industries (12%), fertilizers/pesticides (7%), industrial chemicals (1%) and other industries (3%) which includes the cumulative contribution of cement and clay, textile, wood and furniture, tanneries and leather and petroleum industries (Rasul et al., 2006). Dhaka and it's adjacent districts like Gazipur, Narayanganj are the worst victim of unplanned industrialization; hence, exhibit drastic pollution in water sources. Although Dhaka City is surrounded by some peripheral rivers, the water of these rivers is too contaminated to use as potable water. There are 19 primary and at least 41 secondary discharge points to the rivers within the city (IWM, 2007). Improper discharge of untreated wastewater from various industries neighboring these rivers adulterates the water quality

Table 8
WHO standards of pesticide residues for drinking water quality (WHO, 2008).

Quality Parameter	WHO Standard (in ppm)
2,4-DDD	0.001
2,4-DDT	0.001
4,4-DDT	0.001
Aldrin	0.00003
Carbofuran	0.007
Dieldrin	0.00003
Dimenthoate	0.006
Endosulfane	0.00025
Endrin	0.0006
Lindane	0.002
Chlorpyrifos	0.03
Heptachlor	0.00003

Table 9
Point and non-point sources of water pollution in Bangladesh.

Types of Pollutants	Point Sources	Non-point Sources
Pathogens	Raw sewage	Runoff from agricultural waste and chemicals
	Urban solid waste	Septic tank leachate, Animal waste
	Excrement of human and animal	
Heavy Metal	Discharge of industrial effluent	Pesticide runoff
	Effluent from mines	Smelting
	Thermal power plants	
	Hospital and Pharmaceutical waste	
Organic Chemical	Industrial effluent mostly from paper mills	Fertilizer, Pesticide, and Herbicide runoff
	Urban solid and liquid waste	Runoff from pasture and farms, household
Nutrients	Wastewater from treatment plants	Runoff agricultural waste and chemicals
Thermal	Electric Power Plants	
	Industrial effluents	
Sedimentation	Runoff from construction sites less than 20,000 m^2	Runoff from construction sites more than 20,000 m^2
		Agricultural runoff
Radioactivity*	Discharge from nuclear plants	Natural occurring radioactivity

* Country's first 2.4 GWe nuclear power plant –Rooppur Nuclear Power Plant—is under construction. Adopted from (Cunningham and Cunningham, 2011; Botkin and Keller, 2011; Miller and Spoolman, 2016).

(Rahman and Hossain, 2008; Subramanian, 2004; Karn and Harada, 2001; Kamal et al., 1999). A World Bank study reported that peripheral rivers of Dhaka took 1.5 million cubic meters of wastewater every day from 7,000 industrial units in surrounding areas and another 0.5 million cubic meters from other sources (Islam, 2010a). Before relocating to Savar Upazila, Dhaka (Roy, 2017), tanneries located in Hazaribagh and Rayer Bazar in Dhaka city were responsible for discharging 15,000 cubic meters of liquid wastes, 19,000 kilograms of solid wastes and 17,600 kilograms of BOD into Buriganga river daily (Rahman and Bakri, 2010). Kaliakoir Upazila of Gazipur is only 25 km northeast of the capital city where an unplanned industrial cluster has been developed in the past 20 years. These industries are discharging 30 billion liters of effluent water annually in the nearby waterbodies such as Mokosh Beel, Turag river and Ratanpur Khal (Chowdhury and Clemett, 2006). Large numbers of textile dyeing industries along with other industries situated surrounding D.N.D embankment discharge a large amount of effluents and solid wastes into different waterbodies which eventually enter into the Shitalakshya River. Almost 80% of the total industries does not have any treatment plant and hence discharge toxic untreated industrial effluent into those waterbodies (Sultana et al., 2009).

A vast amount of untreated effluents from industries such as spinning mills, dying, cotton, textile, steel mills, oil refineries, and others industries is discharged regularly into the Karnaphuli river, Chittagong (Ali et al., 2016). Ship Breaking industry is one of the fastest growing industries in Bangladesh which is a significant contributor of trace metal pollution in seawater and groundwater in the coastal region of Bangladesh (Hasan et al., 2013).

Pollution of closed water bodies caused by human waste is a major problem in Bangladesh (Chowdhury, 2010). According to previous statistics, it is estimated that 16,380 tons of waste were produced in Bangladesh every day (Sujauddin et al., 2008). Urban cities are the worst victim of this kind of water pollution. The wastewater discharge from Dhaka city dwellers is about 1.22 million m3/day, whereas the only sewage treatment plant in Dhaka, namely “Pagla Sewage Treatment Plant” can treat 0.12 million m3 wastewater per day (Akter et al., 2017). The surface water quality in the two river systems and other surface water bodies, e.g. khals (small waterbody) and ponds in Dhaka have very high BOD, COD, and E-coli content which indicates discharge of untreated industrial effluents and domestic sewage. Moreover, only 50% of the municipal solid waste being collected by the two city corporations of Dhaka results in most of the wastes dumped into water bodies, low lying areas and khals (Anonymous, 2010). Among the total habitat of Dhaka, 15% use pit latrines and 30% use open latrines; the sewage generated from these latrines are mostly released without any treatment into low-lying areas and river water (Alam, 2009).

The agriculture sector is the economic backbone of Bangladesh which represents 15.33% of the Gross Domestic Product (GDP) and contributes almost half of the country's economic output (Uddin, 2013). Different types of organophosphorus and carbamate pesticides are used extensively by the local farmers, but due to the lack of proper knowledge and instruction, they overuse these pesticides (Chowdhury, 2012; Bhattacharjee et al., 2012). Haphazard use of pesticides leads to both surface and groundwater pollution, chiefly caused by rain or runoff water from the agricultural land (Hasanuzzaman et al., 2016). A World Bank survey reported that 6% of the total pesticides applied to crops are extremely hazardous (Meisner, 2004). Nitrate, phosphate, potassium, aldrin, dieldrin, chlardane, indrin, cadmium, arsenic, chromium and other toxins extracted from different kinds of agrochemical eventually get mixed with the water of various waterbodies (Rahman and Debnath, 2015). Furthermore, pesticide leaching into groundwater can contaminate the water (Anwar and Saing, 2010).

Arsenic contamination in groundwater is a major threat to public health in Bangladesh (Smith et al., 2000). Groundwater pollution is very alarming for Bangladesh as 95% of drinking water is derived from groundwater sources (Chowdhury, 2010). Although the sources of higher concentration of arsenic present in the groundwater in Bangladesh is ambiguous, different theories have been developed (Islam et al., 2000; Das et al., 2004). Initially, various anthropogenic sources such as pesticides, industrial waste, tubewell filters, etc. were considered as the leading sources of arsenic in groundwater, but field observations reported that the source of this trace metal was in geological deposits (Fazal et al., 2001). Even though there is three arsenic ore in the world, Fazal et al. (2001) stated that Arsenopyrite or ferrous arsenic sulfide (FeAsS) is the main source of arsenic pollution in Bangladesh. Pyrite Oxidation and Oxy-hydroxide Reduction are the two hypotheses developed to explain the mobilization of arsenic.

Other minor sources also contribute to the contamination of water bodies. Bhuiyan et al. (2010) showed that Barapukuria coal mine is responsible for heavy metal and thermal pollution in nearby water systems. Accidental oil spill also can cause severe damage to the water quality and aquatic life forms of large water bodies. A recent ‘oil spill from a crashed tanker’ incident resulted in an estimated 350,000 liters of the oil spill; spreading over a 60 km-long area in the Shela and Passur rivers inside Sundarbans, the largest mangrove forest of the country (AFP, 2014).

2.4. Human health effects

Water pollution has increased in both developed and developing countries, threatening the physical and environmental health of billions of people (Javier et al., 2017). About 3.4 million people die worldwide each year from water-related diseases like cholera, typhoid, polio, ascariasis, cryptosporidiosis and diarrheal diseases (UNEP, 2016). Water tainted with defecation puts individuals in danger of contracting cholera, looseness of the bowels, typhoid, and polio (WHO, 2017a,b).

In Bangladesh, every year more than one hundred thousand children under five years old die due to diarrhea-related diseases (Rana, 2009). In 2004 Bangladesh Demographic and Health Survey (BDHS) also reported that 5.1% of deaths of children under five years and 1.2% neonatal deaths were related to diarrhea. Another study reported that 6.9% of deaths of children under five years and 0% neonatal deaths were related to diarrhea (Halder, 2009). Another study reported that 1% neonatal deaths, 15% post-neonatal deaths and 6% under five age children deaths were associated with diarrhea (WHO, 2016). (WHO, 2017a,b) also reported that more than 45,000 under-five youngsters die each year in Bangladesh from diarrhea brought about by sullied water.

Arsenic has been reported as a threat in many parts of the country. Every year, an expected 43,000 individuals die from arsenic harming in the nation. The legislature has made various strides and made strategies to attempt to address the issue. Be that as it may, regardless of a nationwide campaign and social assembly exercises by the legislature and NGOs, information and mindfulness levels among networks stay far beneath desires (Jahan, 2016). Overexposure to arsenic can cause skin lesions, diabetes mellitus, high blood pressure and chronic disease (Yunus et al., 2011). A study collected information from 52 districts of Bangladesh and found that about 40 million people are at risk due to arsenic. They also found that the most common diseases affected by people are melanosis, keratosis, hyperkeratosis, dorsum, gangrene, and skin cancer (Karim, 2000). Another study found that arsenic-related diseases were responsible for 9136 deaths per year in Bangladesh (Alam, 2003). Similarly, another study examined 811 patients with arsenic skin lesions from Pabna, Jessore, Kustia, Chuadanga, Narayanganj and Meherpur districts and found that about 16.6% of those patients had died due to cancer during the last 9–12 years (Chakraborti et al., 2010).

Drinking water polluted by microbial contamination increases the risk of some diseases like typhoid, dysentery, diarrhea, hepatitis A and hepatitis B (Shar et al., 2007). A study found that typhoid, bacillary dysentery, and diarrhea are very common among the bacterial origin waterborne diseases (Parveen, Microbial Contamination of water in around Dhaka city, 2008). Another study revealed that there is a significant correlation between the microbiological quality of water and gastrointestinal diseases (Oguntoke, 2009).

Pesticide contamination in surface water is another threat to public health in Bangladesh. Studies found that pesticide residues can cause nausea, vomiting, blurred vision, coma, difficulty in breathing, deficit hyperactivity disorder in the human body (Rauh et al., 2006). A study found that 26.3%, 24.4% and 18.8% farmers of their study reported excessive sweating, burning eyes and fatigue respectively due to occupational exposure of pesticides (Bhattacharjee, 2013). A daily newspaper published that 11 children were died by diseases which were provoked by pesticides at Dinajpur medical college hospital between May 30 to June 20 (Roy and Karmakar, 2015). Another study reported that many pesticide residues increase the possibility of some diseases like cancer and heart diseases. It also reported that pesticide residues could cause respiratory and neurological damages (Galloway and Handy, 2003). Another study reported that food products containing pesticide residues could cause cancer, teratogenesis and genetic damage (Chowdhury, 2011).

As heavy metals are non-biodegradable, it can show its toxic effect at points which are far from the source of pollution (Tilzer, 1993). Exposure to heavy metals can cause several diseases like kidney damage, cancer, abortion, effect on mind and behavior and sometimes even death in the cases of high exposure (Saha, 2011). Vegetables and fruits contained a high concentration of trace elements like copper, cadmium, and lead which increased the probability of upper gastrointestinal cancer (Türkdoğan et al., 2002). Several studies found different effects of different ions or compounds such as chromium compounds increases the risk of lung cancer (Ishikawa et al., 1994), high consumption of nickel increases the probability of lung and nasal cavity cancer (Ahmed et al., 2015), excessive consumption of zinc can cause electrolyte imbalance, nausea, anemia and lethargy (Prasad, 1984), long term consumption of cadmium increases the rate of kidney failure, softening of bones (Ahmed et al., 2015), and prostate cancer (Gray, 2005).

2.5. *Environmental legislation in Bangladesh and it's effectiveness*

Water Pollution Control Ordinance 1973 was the first legislation in Bangladesh about water pollution. Then in 1977, Environment Pollution Control Ordinance was declared. Department of Pollution Control Ordinance was organized in 1985 which was renamed as Department of Environment (DoE) afterward. In 1992 another Environmental Policy was declared and The Government of Bangladesh has additionally organized various supplementary arrangements such as the Forest Policy (1994), the Fisheries Policy (1998), the Water Policy (1998), the New Agriculture Extension Policy (1995), the Energy Policy (1995) (Aminuzzaman, 2010).

Bangladesh Environment Conservation Act (ECA), 1995 was passed for the protection of environment models and moderating environmental contamination but the main impediments of the Act are its hushes on the benchmarks, parameters, discharge levels and administration components in view of which the ecological clearance ought to have been connected and gotten (Aminuzzaman, 2010).

The Environmental Conservation Rules, 1997, were proclaimed in promotion of the destinations of the ECA, 1995. As to of poisonous and hazardous substances, the Principles have extensively characterized rules for transfer of waste from various classes of ventures, but it has not indicated the admissible degree of outflows or the commitments of restorative activities (Aminuzzaman, 2010).

Ministry of Water Resources formulated National Water Policy in 1999 to guarantee effective and impartial administration of water assets, appropriate outfitting, and advancement of surface and groundwater, accessibility of water to all concerned, and institutional limit working for water resource administration. The Bangladesh Water Act, 2013 is for the most part given the National Water Policy of 1999, and it is intended for coordinated improvement, administration, appropriation, utilization, security and preservation of water assets in Bangladesh. The demonstration proclaims all type of water inside the region of Bangladesh as the property of the government. Notwithstanding, the surface water in private property can be utilized by the proprietor for all the required reason. The demonstration requires permit for pulling back expansive size of surface or groundwater; notwithstanding, the most significant measure of water that can be pulled back isn't said in the law (BanDuDeltAS, 2015).

Ministry of Environment and Forest formulated the National Environmental Policy 2013 which depends on 17 essential issues and 12 goals pertinent to economic advancement, valuation of environment administrations, sustenance wellbeing, polluter's compensation standard, and adjustment and alleviation to combat environmental change. The activity designs incorporate some new instrument or activities like environmental auditing, agriculture, nearby and national contingency for keeping pollution from sea/water car crash, EIA for lodging and urban advancement ventures, squander heat Recovery activities and so on (BanDuDeltAS, 2015).

Though the defined environment policy genuinely rich in content, it isn't bolstered by essential activities of execution. Several studies reported that the execution of the environmental arrangement and the Environmental Protection Act had been hindered because of some institutional and utilitarian impediments (Khan, 1999; Hanchett, 1997). Different operational guidelines for successful execution of the policy and act would require corresponding and nitty-gritty operational guidelines, a considerable lot of which have not yet been figured. Besides, surges and typhoons are real worries for ecological administration in Bangladesh. However, the Environmental Protection Act still have restricted concern and intercession for such catastrophes. Other problems for a successful execution of environmental policy are insufficient funding, skilled human, lack of inter-agency relation, irregularity with different policies, absence of inter-sectoral arrangement, lack of administrative and institutional capacity, impediments of the environment laws, Outdated environmental laws as well as ignorance about these laws, non-punitive approach of laws, political corruption and so on (Aminuzzaman, 2010).

3. Conclusion

The present investigation demonstrates that most of the water bodies in Bangladesh are contaminated with several contaminants and not suitable for human consumption without proper treatment. Besides heavy metal contamination, pesticide contamination of surface water sources is the most prospective menace for the people of Bangladesh. Bacteriological contamination is also a great source of surface water which causes threats to both urban and rural people. Among the heavy metals, Arsenic found in groundwater at an alarming rate all over the country. High level of iron, chromium, nickel, and lead is also worrying. Copper, zinc, and manganese are found below the standards limit in most of the sources. In addition, most of the cations like Na^+, K^+, Ca^{2+}, Mg^{2+} found in water sources are mostly below the standards limit. Lack of proper monitoring, laws implementation, adequate human resources as well as lack of modern treatment plants and water supply systems, and poor awareness and education about water use and safety are the main prompt of water pollution in Bangladesh. There are little records mainly longitudinal data about water-borne diseases in the nation, so more surveys need to be done to get a better idea of water-related diseases.

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