Groundwater Pollution in Bangladesh: A Review

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Abstract

Bangladesh relies mainly on groundwater for irrigation and drinking purposes. Groundwater, however, continuously polluted, is a major obstacle. Now-a-days, Bangladesh is moving towards industrial revolution in a considerable speed. As part of the paper's attempt to illustrate the groundwater pollution scenario in Bangladesh, specifically in the past two decades, around 100 articles, conference papers, and reports published in national and international journals and books were reviewed, as well as issues regarding pollution sources, health impact assessment, and future perspectives were discussed. The groundwater is contaminated by different factors, such as physico-chemicals, trace metals, and microbes. Human health is at great risk from arsenic (As) contamination; it is one of the biggest threats. The cancer risk and non-carcinogenic risk of ingesting water were increased. On the other hand, a large number of peoples were affected due to waterborne diseases governed by microbial contamination. Geophysical and anthropogenic sources, the height of wells, and geographical factors may influence groundwater pollution. In this review, it is suggested that policy makers should address the issue immediately and precautions should be taken.

Keywords

Groundwater pollution; Physico-chemical; Trace Metals; Bacteriological contamination; Pesticides; Health risk; Bangladesh

Introduction

Human metabolic systems and other life sustaining activities require water (Dkhar *et al.* 2014). A natural and renewable asset that is essential to life, water experiences natural and continuous processes within the hydrological cycle (Iscen *et al.* 2008). Life on earth began with water (Moe and Rheingans 2006), however, groundwater is perhaps the most valuable resource, which has been misused (Arumugam and Elangovan 2009; Chaudhary and Satheeshkumar 2018). Globally, groundwater sources supply 43% and 40% of total water used for irrigation and drinking purposes respectively (Salman *et al.* 2018). Over the last few decades, water demand has increased rapidly with the development of energy, industry, urbanization, agriculture, improvements in living standards, and construction of environmentally friendly homes (Ravikumar and Somashekar 2017). Besides, lack of water is a major issue in many countries because of the disparity in rainfall caused by global warming (Mahaqi *et al.* 2018). Practically 1.8 billion individuals around the globe, may face absolute water shortages by 2025 (UNESCO 2012).

In Bangladesh, amount of withdrawal groundwater is approximately 32 km^3 per year where 90% of water is used for irrigation and rest 10% is utilized for industrial and domestic purposes which is equivalent to 4% of the world withdrawal groundwater (Shamsudduha *et al.* 2019). Bangladesh has between 6 and 11 million tube wells and 98% of its people use groundwater as their main source of drinking water (Islam *et al.* 2020a; Gaus *et al.* 2003). During 1970s, Department of Public Health Engineering (DPHE) of Bangladesh and the United Nations Children's Fund (UNICEF) worked together to establish hand-pumped tube wells for providing fresh drinking water among the rural population in Bangladesh to prevent waterborne diseases (Haque 2018), nevertheless, the number of deaths caused by waterborne diseases is still 8.5% (UN-Water 2013). Bangladesh's biggest challenge is to preserve its groundwater sustainably (Saha *et al.* 2020). Water quality and quantity in Bangladesh are affected by several factors, either directly or indirectly (Islam *et al.* 2020a). At 21^{st} century groundwater pollution by arsenic in Bangladesh has been associated with health issues (Mukherjee and Bhattacharya 2001). Arsenic contamination occurs in groundwater in 61 districts of Bangladesh, and 20 million people drink water with levels exceeding the national standard limit for arsenic (Ghosh *et al.* 2020). Pb, Cd, Cr, Cu, Fe and Zn are other common metals that contribute to groundwater contamination in Bangladesh (Zakir *et al.* 2020). Additionally, bacteria and pesticides play a significant role in groundwater pollution (Anwar and Yunus 2013; Sarker *et al.* 2020). According to BNDWQS (Bangladesh national drinking water survey), As concentrations exceeded Bangladesh standard in 8% of sampled water samples and WHO standards in 18% of cases (BNDWQS 2009).They reported that 97.8% of Bangladesh's population used safe drinking water. Nevertheless, many studies in recent decades have indicated the hazard of drinking groundwater over the long term, including cancer-causing and non-cancer risks which actually insisted us to review the groundwater pollution in Bangladesh.

To the best of our knowledge, very few review articles have been published on surface water and a review on surface plus groundwater in Bangladesh (Arefin and Mallik 2017; Hasan *et al.* 2019a; Sarkar *et al.* 2019). On the other hand, other has been reviewed on groundwater while emphasizing on arsenic only (Hossain 2006; Raessler 2018; Safiuddin *et al.* 2011). Therefore, for the first time, this review demonstrates a comprehensive report on groundwater pollution in Bangladesh.

Methodology

We have extracted the recent data on groundwater pollution in Bangladesh especially from the last two decades. Hundreds of journal articles, conference proceedings, reports published by renowned organizations, and books have been reviewed to extract significant findings about the present pollution status. Our next step was to organize and present the information in a systematic manner. Additionally, many details are provided regarding the sources of pollution, and the impact of this pollution on the health of Bangladeshis.

Figure 1: Map of Bangladesh (Map 2021)

Results and discussion

Physico-Chemical properties

This review examined temperature, total dissolved solids (TDS), electrical conductivity (EC), salinity, total hardness (TH), pH, and turbidity (Table 1). Different chemical reactions may be controlled by the water temperature under certain conditions (Patil *et al.* 2012). The recommended water temperature range is 20-30°C (Islam *et al.* 2017a) and all studies recorded groundwater temperatures in the appropriate range (Table 1). TDS represents the amount of inorganic and organic substances in water (Solangi *et al.* 2019). Water can be categorized as excellent and good if the TDS values of water are <300 mg/L and 300-600 mg/L respectively, but >1000 mg/L concentration makes the water unsuitable for drinking (WHO 2004). Multiple studies have reported high concentrations of TDS in Gopalganj, Noakhali, Khulna, Satkhira, Barisal, and Patuakhali, where Satkhira has the highest value (3691.0±1648.52 mg/L) (Table 1). In addition to measuring mineralization, EC determination can be used to tell if water quality is changing in natural and waste water quickly (Arulbalaji and Gurugnanam 2017). Permissible limit of EC value is 500 μS/cm based on WHO and BSTI standards. There have been 25 studies reporting above the acceptable limit. In Satkhira district, for example, EC levels were reported to be too high (7135.67 ± 3433.58 μS/cm) (Rakib *et al.* 2020). Besides, BSTI and WHO do not specify a range of salinity for drinking water. As a result of field sampling from 113 different locations in Bangladesh, Shahid *et al.* (2006) found that 8.31%

of the groundwater had high salinity levels (Shahid et al. 2006). According to a study, groundwater in Faridpur, Netrokona, Madaripur, Khulna, Shatkhira, Barguna, Patuakhali and Chittagong is highly salinized (Akter *et al.* 2016). Water hardness has no known adverse effects; but, some evidences denote its role in heart diseases, kidney problems, unpleasant taste and decreases the ability of soap to make lather (Ali and Ali 2018). For drinking, the WHO recommends a limit of 300 mg/L and only few study areas have exceeded the limit. Khustia has the highest concentration (432.85 mg/L), while Dinajpur has the lowest concentration (22.74 ± 20.44 mg/L). pH can indicate the acidity or alkalinity of the water and the strength of the H+ ions in that water (Tiwari *et al.* 2017). pH range 6.5-8.5 indicated the water as safe for drinking. Except for Khagrachari, Rangamati, and Satkhira, most studies reported pH values within the range that is suitable. Besides, less than 6.5 (6.26±0.11 and 6.36±0.33 during winter and summer) pH value is observed in Chittagong (Rifat *et al.* 2021). Acidic water may damage the mucous membrane cell and cause of irritation in eyes and skins as well as metal corrosion (WHO 1986, Popoola *et al.* 2019). The turbidity of water is measured by the presence of tiny-sized suspended particles, which tint and cloud the water (Solangi *et al.* 2019) and has potential health risk when it is consumed (WHO 1996). BSTI determines turbidity at 10 NTU, whereas WHO specifies 5 NTU. The standard limit for turbidity was exceeded only in Chittagong, Noakhali, and Dinajpur districts.

Ion characteristics

Table 2 summarizes the major cations and anions in the groundwater in different regions of Bangladesh. Despite its essential role in human function, excessive levels of Na may result in high blood pressure and kidney failure in the body (Ameen 2019). WHO and BSTI established 200 mg/L of Na in drinking water as the prescribed limit. Only Gopalganj, Satkhira, Jashore, and Barisal have exceeded the recommended level (Table 2). In human and animal tissues, potassium is essential to life; it is especially abundant in plants cells (Meride and Ayenew 2016). However, excess potassium may cause some health issues like nausea, vomiting, diarrhea, hyperkalaemia, shortness of breath, and heart failure (WHO 2009). In every study except Satkhira, Jashore, Barisal and Sunamgonj, potassium concentrations were less than 12 mg/L (WHO and BSTI) (Table 2). Humans need calcium for strong bones and for a healthy nervous system, but too much calcium causes kidney stones and digestive problems (WHO 2009, Verma *et al.* 2020), formed scale in pipeline (Saraswat *et al.* 2019). Two studies have found levels above the WHO standard for calcium concentrations in drinking water (200 mg/L), however many areas have exceeded the BSTI standard (75 mg/L) (Table 2). The body requires magnesium for over 300 biochemical reactions (Jamal *et al.* 2020) and also helps to maintain normal nerve and muscle function, and supports a healthy immune system (Solangi *et al.* 2019; Verma *et al.* 2020). Magnesium concentrations were predominantly below the permissible limit (30-35 mg/L) compared to BSTI standards in the majority of the study areas. On the other hand, Satkhira and Jessore districts reported excess magnesium based on WHO standards (150 mg/L) (Table 2). Chloride makes a salty taste in water and higher consumption may cause hypertension, stroke risk, renal stones, left ventricular hypertension and asthma in human body (McCarty 2004). Water should have a chloride concentration of no more than 250 mg/L and 150-600 mg/L according to WHO and BSTI, respectively. At Satkhira district, 2940.78±1563.53 mg/L chloride ion concentrations were recorded. Besides, excess content of chloride ion was reported in Gopalganj, Noakhali and Barisal (Table 2). Naturally, no more than 10 mg/L of nitrates are present in water, but anything greater indicates man-made pollution (Rao and Rao 2010) and may be associated with different diseases, such as methemoglobinemia or blue baby syndrome, thyroid disease, gastric cancer and diabetes specially in pregnant women and bottle-fed children (Asamoah and Amorin 2018; Kumar *et al.* 2015; Kumar and Puri 2012).

Table 1: Summary of physico-chemical parameters within Bangladesh. Mean values with standard deviations were displayed

SL No.	Sample Location	Temp (˚C)	TDS (mg/L)	EC (µS/cm)	Turbidity (NTU)	pH	TH (mg/L)	Salinity (mg/L)	References
	Dhaka Division								
01	Dhaka	-	72.22 ± 43.15	-	-	7.32 ± 0.43	-	-	(Bodrud-Doza *et al*. 2019a)
02	Faridpur	-	748.61±198.28	788.77 ± 242.83	-	7.53 ± 0.77	394.52	-	(Islam *et al.* 2017b)
03	Tangail	-	194.0 ± 15.77	0.496 ± 0.32	-	7.180 ± 0.19	-	-	(Sultana *et al.* 2015)
04	Gopalganj (pre-monsoon)	27.41 ± 0.37	1635.04 ± 1463.33	3206.95 ± 2870.97	-	7.53 ± 0.17	-	170.0 ± 161.0	(Rahman *et al.* 2018a)
	Gopalganj (post-monsoon)	27.16 ± 1.28	1643.49 ± 1455.83	3218.47 ± 2902.74	-	8.43 ± 1.59	-	169.0 ± 158.0	(Rahman *et al.* 2018a)
05	Manikganj	-	-	-	-		-	-	(Rahman *et al.* 2016a)
06	Munshiganj	26.29 ± 0.55	-	968.31 ± 388.67	-	7.05 ± 0.103	-	-	(Halim *et al.* 2009)
07	Narayanganj	-	554.5 ± 222.51	1350.0 ± 584.45	5.95 ± 7.46	8.06 ± 0.51	-	-	(Rahman *et al.* 2020a)
	Chittagong Division								
08	Chitagong	24.81± 0.94	218.7 ± 6.4	437.27 ± 3.0	18.2 ± 1.77	7.37 ± 0.53	84.13 ± 0.79	0.05	(Chowdhury and Ahmed 2019)
9	Lakshimpur	-	-	1135.09 ± 954.72	-	7.03 ± 0.24	-	-	(Bhuiyan *et al.* 2016)
10	Noakhali	-	1575.81	884.04	18.53	7.40	-	129.0	(Sarker *et al.* 2020)
11	Khagrachari	26.63	102.88	205.38	-	5.86	60.0	-	(Ahmed *et al.* 2010a)
12	Rangamati	25.72	53.80	107.60	-	6.26	39.50	-	(Ahmed *et al.* 2010a)
13	Cox's Bazar	-	844.0	1322.0	-	-	-	-	(Fatema *et al.* 2018)

14	Bandarban	26.85	266.93	534.50	-	6.55	60.0	-	(Ahmed *et al.* 2010a)
15	Chandpur	26.50	-	1341.0	-	6.94	-	-	(Bibi *et al.* 2008)
16	Brahmanbaria	-	233.0 ± 52.79	327.50 ± 69.11	-	7.18	-	-	(Mahmud *et al.* 2007)
17	Comilla	24.0	392.75	935.1	-	6.69	337.0	-	(Ahmed *et al.* 2010b)
	Rangpur Division								
18	Rangpur	26.53 ± 0.77	242.25 ± 192.91	361.58 ± 287.93	-	6.63 ± 0.33	62.63	-	(Saha *et al.* 2019a)
19	Dinajpur	-	103.9 ± 74.05	147.2 ± 113.65	10.74 ± 10.69	7.49 ± 0.71	22.74 ± 20.44	-	(Howladar *et al.* 2018)
20	Thakurgaon	-	166.0	203.5	-	7.53	67.82	-	(Bhuiyan *et al.* 2015)
21	Gaibandha	-	650.75	935.38	-	8.06	-	-	(Rahman *et al.* 2005)
22	Panchgarh	-	53.5	117.2	-	6.5	65.4	-	(Saha *et al.* 2017)
23	Kurigram	26.0	78.8	123.0	-	7.9	-	-	(Moni *et al.* 2019)
	Rajshahi Division								
24	Rajshahi (pre-monsoon)	-	477.39	-	-	6.96	163.47	-	(Rahaman *et al.* 2020a)
	Rajshahi (Post-monsoon)	-	516.26	-	-	6.89	163.71	-	(Rahaman *et al.* 2020a)
25	Joypurhat	-	270.48 ± 104.78	422.63 ± 163.73	-	7.94 ± 0.46	-	-	(Islam *et al.* 2018)
26	Bogra	20.0 ± 1.41	335. 70 ± 83.23	549.5 ± 164.40	-	7.22 ± 0.37	-	-	(Islam *et al.* 2009)
27	Chapai-Nawabganj	-	222.6 ± 54.76	348.2 ± 86.11	-	7.89 ± 0.46	-	-	(Islam *et al.* 2017c)
28	Pabna	20.7 ± 0.94	328.25 ± 61.95	522.8 ± 109.63	-	7 ± 0.622	-	-	(Haque 2017)
29	Naogaon	-	291.9	441.4	-	8.21	-	-	(Rahman *et al.* 2005)

30	Sirajganj	-	170.0 ± 0.468	402.95 ± 521.4	-	6.94 ± 0.342	-	-	(Uddin *et al.* 2019)
	Khulna Division								
31	Khulna	-	1188.70	1650.0	-	7.3	52.03	-	(Mahmud *et al.* 2020)
32	Jhenaidah	-	598.55	618.89	-	7.39	-	-	(Kundu *et al.* 2018)
33	Magura	-	601.2	873.9	-	8.4	284	-	(Rahman *et al.* 2015)
34	Chaudanga	-	-	686.10 ± 180.99	-	6.47 ± 0.15	-	-	(Bodrud-Doza *et al.* 2019b)
35	Satkhira	28.32 ± 28.32	3691.0 ± 1648.52	7135.67 ± 3433.58	-	6.03 ± 0.61	-	-	(Rakib *et al.* 2020)
36	Khustia	-	578.68	841.09	-	7.66	432.85	-	(Rahman and Rahaman 2018b)
37	Jessore	-	819.0 ± 1692.19	1170.0 ± 2417.4	-	7.34 ± 0.67	178.17 ± 137.24	-	(Ahmed *et al.* 2020a)
	Barisal Division								
38	Barisal	28.25	2190.38	4263.38	-	7.58	-	2.31	(Goswami *et al.* 2017)
39	Patuakhali	23.39	842.0	1165.67	-	7.89	-	81.0	(Islam *et al.* 2017a)
40	Barguna (Dry Season)	-	-	1068.57 ± 429.17	-	8.0 ± 0.26	-	-	(Akter *et al.* 2019)
	Barguna (Wet Season)	-	-	210.95 ± 75.13	-	7.32 ± 0.26	-	-	(Akter *et al.* 2019)
41	Pirojpur	-	542.0	-	-	6.97	-	-	(Amin and Hasan 2011)
	Mymeningh Division								
42	Mymensingh	-	-	369.62	-	7.08	-	-	(Ahmed *et al.* 2010c)
43	Sherpur	-	240.33	351.0	-	8.05	-	-	(Rahman *et al.* 2005)
44	Jamalpur	-	162.16 ± 54.42	270.50 ± 105.69	-	6.87 ± 0.25	-	-	(Zakir *et al.* 2018)

	Sylhet Division								
45	Sylhet	-	120.40 ± 50.25	200.65 ± 83.66	-	7.11 ± 0.43	-	-	(Hasan *et al.* 2020)
46	Sunamganj	-	-	-	-	7.13 ± 0.07	-	-	(Chowdhury *et al.* 2012)
	BSTI standard	20-30	1000	500	10	6.5-8.5	500	-	
	WHO standard	20-30	1000	500	5	6.5-8.5	300	-	

Table 2: Summary of major cations and anions within Bangladesh. Mean values with standard deviations were represented

SL No.	**Sample Location**	**Na^+ (mg/L)**	**K^+ (mg/L)**	**Ca^{2+} (mg/L)**	**Mg^{2+} (mg/L)**	**HCO_3^- (mg/L)**	**Cl^- (mg/L)**	**NO_3^- (mg/L)**	**SO_4^{2-} (mg/L)**	**References**
	Dhaka Division									
01	Dhaka	-	-	-	-	-	28.04 ± 2.24	-	-	(Hassan *et al.* 2016)
02	Faridpur	35.35 ± 38.00	5.01 ± 1.37	103.75 ± 36.23	32.92 ± 10.39	542.37 ± 130.71	23.96 ± 36.64	-	5.27 ± 2.40	(Islam *et al.* 2017b)
03	Tangail	21.0	6.0	12.8	15.0	-	30.0	-	1.2	(Islam *et al.* 2015)
04	Gopalganj (pre-monsoon)	547.26 ± 582.31	8.14 ± 6.30	106.45 ± 90.46	80.47 ± 71.61	263.48 ± 97.36	847.34 ± 979.69	9.95 ± 9.12	-	(Rahman *et al.* 2018a)
	Gopalganj (post-monsoon)	639.24 ± 555.16	8.53 ± 6.60	90.50 ± 69.78	76.56 ± 72.42	266.76 ± 148.70	874.75 ± 1049.29	9.42 ± 9.98	-	(Rahman *et al.* 2018a)
05	Manikganj	88.80	4.14	195.98	49.43	-	-	253.18	-	(Rahman *et al.* 2016a)
06	Munshiganj	64.75± 73.63	10.11 ± 5.22	87.49 ± 41.44	44.34 ± 24.64	478.23 ± 181.08	-	3.93 ± 6.93	5.23 ± 2.31	(Halim *et al.* 2009)
07	Narayanganj	22.74	3.58	67.99	16.0	272.55	35.46	0.08	1.54	(Bhattacharya *et al.* 2009)
	Chittagong Division									
08	Chittagong	-	-	-	-	-	10.88 ± 0.76	0.36 ± 0.03	18.6 ± 1.39	(Chowdhury and Ahmed

										2019)
09	Lakshimpur	159.78 ± 225.63	10.89 ± 7.75	55.76 ± 34.72	46.14 ± 31.55	430.18 ± 217.53	227.19 ± 364.67	-	16.14 ± 45.05	(Bhuiyan *et al.* 2016)
10	Noakhali	-	0.04	-	-	-	681.99		29.68	(Sarker *et al.* 2020)
11	Khagrachari	-	-	-	-	-	15.79	ND	3.63	(Ahmed *et al.* 2010b)
12	Rangamati	-	-	-	-	-	12.55	0.534	1.41	(Ahmed *et al.* 2010b)
13	Cox’s Bazar	167.0	-	-	-	-	227.0	-	-	(Fatema *et al.* 2018)
14	Bandarban	-	-	-		-	35.41	0.11	6.40	(Ahmed *et al.* 2010b)
15	Chandpur	79.71	6.04	32.36	17.41	-	146.07	7.9	31.88	(Reza *et al.* 2010)
16	Brahmanbaria	29.0 ± 11.0	8.0 ± 4.0	52.0 ± 19.0	53.0 ± 26.0	1.69 ± 0.51	1.60 ± 0.30	0.25 ± 0.08	0.21± 0.10	(Mahmud *et al.* 2007)
17	Comilla	77.5	7.8	31.0	33.7	291.0	98.8	0.55	4.7	(Saha and Rahman 2020)
	Rangpur Division									
18	Rangpur	39.1 ± 24.16	6.51 ± 6.26	12.63 ± 8.97	7.546 ± 4.122	95.5 ± 39.8	78.64 ± 54.94	-	7.93 ± 8.15	(Saha *et al.* 2019a)
19	Dinajpur	14.34 ± 10.58	3.1 ± 2.53	15.06 ± 14.01	10.56 ± 10.16	28.31 ± 20.94	9.79 ± 14.4	0.35 ± 0.16	0.86 ± 1.86	(Howladar *et al.* 2018)
20	Thakurgaon	1.9	0.5	21.0	1.9	93.0	4.6	1.49	6.8	(Bhuiyan *et al.* 2015)
21	Gaibandha	2.93	0.39	2.45	4.91	4.43	3.61	10.27	26.5	(Rahman *et al.* 2005)
22	Panchagarh	0.13	0.01	0.52	0.79	0.02	0.10	-	-	(Saha et al. 2017)
23	Kurigram	12.8	6.38	21.9	1.69	127.6	8.39	8.69	0.34	(Moni *et al.* 2019)
	Rajshahi Division									
24	Rajshahi (pre-monsoon)	30.57	1.89	127.85	37.45	319.89	74.99	1.24	31.77	(Rahaman *et al.* 2020a)

	Rajshahi (Post-monsoon)	25.23	1.72	135.84	27.62	333.33	72.32	2.18	36.59	(Rahaman *et al.* 2020a)
25	Joypurhat	12.17 ± 2.10	0.30 ± 0.09	54.71 ± 4.39	4.04 ± 1.28	136.97 ± 20.34	17.19 ± 7.35	-	1.51 ± 0.24	(Islam *et al.* 2018)
26	Bogra	41.3	5.2	47.5	10.0	-	19.0	-	1.0	(Islam *et al.* 2015)
27	Chapai-Nawabganj	21.6 ± 9.91	8.14 ± 3.18	108.2 ± 27.81	28.22 ± 8.05	378.5 ± 70.79	27.08 ± 14.01	3.02 ± 2.25	9.86 ± 12.1	(Islam *et al.* 2017c)
28	Pabna (dry season)	29.50	7.01	65.03	41.53	386.86	74.66	1.39	2.95	(Hossain et al. 2010)
	Pabna (Wet season)	29.94	7.24	70.15	42.64	396.86	75.85	1.97	3.19	(Hossain *et al.* 2010)
29	Pabna	-	-	-	-	151.6 ± 36.8	63.2 ± 31.6	-	-	(Haque 2017)
30	Naogaon	0.65	0.03	1.11	2.44	3.03	0.89	2.28	3.22	(Rahman *et al.* 2005)
31	Sirajganj	12.74 ± 0.62	3.12 ± 0.02	64.53 ± 1.43	18.25 ± 1.077	0.83 ± 0.01	0.58 ± 3.01	-	4.89 ± 0.74	(Uddin et al. 2019)
	Khulna Division									
32	Khulna	-	-	-	-	-	414.6	0.03	-	(Mahmud *et al.* 2020)
33	Jhenaidah	24.62	2.95	60.34	28.39	370.42	35.36	-	0.92	(Kundu *et al.* 2018)
34	Magura	-	-	-	-	-	111.6	-	-	(Rahman *et al.* 2015)
35	Satkhira	1569.51 ± 1728.42	28.54 ± 34.78	289.5 ± 221.22	340.51 ± 312.48	-	2940.78 ± 1563.53	54.44 ± 80.11	181.61 ± 392.8	(Rakib *et al.* 2020)
36	Kushtia	26.87 ± 6.60	4.73 ± 1.65	88.81 ± 21.56	33.54 ± 14.90	388.48 ± 68.34	64.09 ± 13.29	-	3.19 ± 1.52	(Hossain *et al.* 2013)
37	Jessore	342.84 ± 263.12	40.92 ± 25.64	302.72 ± 277.32	262.35±218.98	-	535.13± 797.49	2.76± 2.91	21.55 ± 40.69	(Ahmed *et al.* 2020a)
	Barisal Division									
38	Barisal	710.97	19.46	31.84	73.79	369.81	1313.75	4.23	46.85	(Goswami *et al.* 2017)
39	Patuakhali	78.99	3.80	12.47	9.34	391.02	298.13	11.57	12.5	(Islam *et al.* 2017a)

40	Barguna (Dry Season)	55.30 ± 6.49	7.45 ± 2.18	-	-	-	-	-	1.99 ± 0.525	(Akter *et al.* 2019)
	Barguna (Wet Season)	11.67 ± 2.68	9.68 ± 3.87	-	-	-	-	-	3.96 ± 1.55	(Akter *et al.* 2019)
41	Pirojpur		-	-	-	-	0	13.5	22.0	(Amin and Hasan 2011)
	Mymensingh Division									
42	Mymensingh	-	-	37.92	-	-	-	-	-	(Ahmed *et al.* 2010c)
43	Sherpur	0.72	0.05	1.32	1.33	2.43	0.72	0.19	ND	(Rahman *et al.* 2005)
44	Jamalpur	30.8 ± 12.0	2.4 ± 2.0	86.8 ± 29.6	43.6 ± 24.4	134.8 ± 67.6	18.0 ± 10.4	-	9.18± 16.97	(Zakir *et al.* 2018)
	Sylhet Division									
45	Sylhet	11.45 ± 6.37	1.36± 0.53	8.4 7± 2.60	28.43 ± 6.62	87.70 ± 33.34	37.20 ± 12.74	0.95 ± 0.69	1.80 ±2.73	(Hasan *et al.* 2020)
46	Sunamganj	90.4 ± 27.7	3.27 ± 1.82	26.66 ± 10.85	9.55 ± 3.9	-	-	-	-	(Chowdhury *et al.* 2012)
	BSTI standard	200	12	75	30-35	-	150-600	10	400	
	WHO standard	200	12	200	150	-	250	45	250	

In Manikganj, the nitrate concentration was 253.18 mg/L, 25 times the permissible limit (Rahman *et al.* 2016a), however, nitrate concentration was below the standard limit in most of the areas (Table 2). Sulfate is formed by the oxidation of the ore and H_2S by a variety of bacteria including Rhodothiobacteria, Chlorothiobacteria, etc. (Mkadmi et al. 2018) whereas extra sulphate may cause diarrhea and gastro-intestinal irritation (Bashir *et al.* 2012; Marghade *et al.* 2012). All studies have recorded sulphate concentrations below WHO (250 mg/L) and BSTI (400 mg/L) standards. Another dominant ion is bi-carbonate, however, no recommended intake level for it has been established (Hasan *et al.* 2019a). There is lowest bicarbonate concentration in Panchagarh district (0.02 mg/L), highest in Faridpur district (542.37±130.71 mg/L).

Trace metals

Table 3 summarizes the trace metals in different parts of Bangladesh. Arsenic (As) is the 20th most abundant element in the earth's crust (Huq *et al.* 2020). For As, there are generally 4 oxidation forms: −3, 0, +3, and +5. As (III) and As (V) is the most durable form among those (Zhao *et al.* 2010). Groundwater may become contaminated by arsenic through industrial and natural processes (Safiuddin and Karim 2001). Tolerable limit of As in Bangladesh is 0.05 mg/L and WHO established the value as 0.01 mg/L. Many study areas exceeded the BSTI standard, and at almost all study sites the As value exceeded the WHO standard. Das and his team collected groundwater samples from 50,515 tube-wells in 64 districts of Bangladesh. According to his report, As was found above 0.01 mg/L in 60 districts and above 0.05 mg/L in 50 districts (Das *et al.* 2009). Furthermore, Chakraborti and his group published a report on As after their 14 year survey in 338 Upazilla (Sub-district) where 52,202 groundwater samples were analyzed. In 197 Upazilla, concentrations were greater than 0.05 mg/L. 15.8% samples were crossed the WHO standard and 7.1, 12.4, 4.3, 1.8, 1.0 and 0.6 percent samples were fall in 0.05-0.1, 0.1-0.29, 0.3-0.49, 0.5-0.69, 0.7-1.0 and >1.0 mg/L ranges (Chakraborti *et al.* 2010). In another study Chakraborti and his group survey As concentration in four major geomorphological regions (Tableland, Flood Plain, Deltaic Region including Coastal region and Hill Tract) of Bangladesh (Chakraborti *et al.* 2015). In Flood Plain and Deltaic (including Coastal) regions As value was crossed at 10085 and 6932 samples out of 19845; and 12128 and 7,255 samples out of 22,113 based on WHO and BSTI standard respectively where in Tableland region maximum samples and hill tract region all the samples were below tolerable limit (Chakraborti *et al.* 2015). As affects the circulatory system, gastrointestinal tract, liver, kidneys, skin, nervous system and heart and results even death. Moreover, inorganic arsenic increases the cancer risk in human body (Ahmad *et al.* 2018; Smith *et al.* 2000; Tchounwou *et al.* 1999). Inhalation of hexavalent Chromium (Cr-VI) can cause lung cancer and stomach in human body (Smith and Steinmaus 2009). Only one study reported excess chromium (>0.05 mg/L) in Narayanganj district (0.071 ± 0.03 mg/L) (Table 3). Iron (Fe) is an essential element in human nutrition, and is also important to good health because it transports oxygen in the blood (Kumar *et al.* 2010). Safe limit of Fe in drinking water is prescribed as 0.3 mg/L and 1.0 mg/L according to WHO and BSTI respectively. It was reported that Fe concentrations were above the permissible limit in most study areas in the country, where Kurigram observed the highest concentration (16.6 mg/L) (Table 3). Of note, Fe can make oxidized taste in water and lead to stain clothes, discolor plumbing fixtures. In human body, excess Fe may lead to heart disease, liver problems, diabetes and organ dysfunction (Kohgo *et al.* 2008).

Manganese (Mn) occurs naturally in ores and rocks (Popoola *et al.* 2019). Maximum allowable limit of Mn in drinking water is 0.1 mg/L. Except for Dhaka, Panchagarh, Kushtia, and Patuakhali, all other locations (30 study sites) had Mn concentrations above the standard limit (Table 3). Excess amount of Mn affects on nervous system, heart, liver and may cause cancer and pancreatic damage (Mukanyandwi *et al.* 2019). Humans require copper (Cu) and zinc (Zn) as essential nutrients like iron and manganese. But excess amount of these elements can also cause adverse health effects (Akoto and Adiyah 2007; Javaid *et al.* 2008; Zahra *et al.* 2015). Permissible range of Cu and Zn are 1 mg/L and 5 mg/L respectively, however, unfortunately content of Cu and Zn were observed in all places below acceptable limit (Table 3). Excess lead (Pb) can damage the brain, nerves, and kidneys of children. Pregnant women, infants and children are more susceptible to the toxic effect of Pb (Barua *et al.* 2016; Javaid *et al.* 2008). Tolerable limit of Pb in drinking water is 0.05 and 0.01 mg/L based on BSTI and WHO respectively. Maximum Pb concentration was observed in Tangail (0.307± 0.15 mg/L). In terms of long-term environmental effects, cadmium (Cd) is another concern (Fernández-Luqueño *et al.* 2013). Cd can cause headaches, nausea, cough and vomiting even in a little dose intake (Burke *et al.* 2016). In addition, Cd may cause of cardiovascular diseases, cancer, liver and kidney failure. Fortunately, most of the study sites in Bangladesh have recorded below the permissible limit of Cd value based on WHO (0.001 mg/L) and BSTI (0.005 mg/L) standards. Surprisingly, only one report in Chaudanga district contains the highest Cd concentration (0.33 ± 0.14 mg/L) (Table 3).

Bacteriological contamination

Waterborne diseases are primarily caused by microbial contamination. In Bangladesh, it is undoubtedly shocking to see a high percentage of pathogenic microorganisms in groundwater that can lead to disease (Datta *et al.* 2014). Total coliform bacteria are very common in nature and a large group of bacteria. Without some exceptions most of them are harmless (USEPA 2013). Bacteria known as faecal coliforms (FC) reside in the feces, while Escherichia coli (E. coli) belong to FC (Karim *et al.* 2016). Escherichia coli (E. coli) and Fecal coliforms (FC) bacteria are important indicators for detecting the level of health risk and water borne diseases in drinking water (Saha *et al.* 2019b). Presence of these microorganisms in water may cause of several diseases like diarrhea, cholera, dysentery, gastroenteritis, typhoid fever, nausea, vomiting, headaches and fatigue (Okullo *et al.* 2017). Most study areas contained coliform bacteria and E. coli was detected in Khulna, Barguna, Jessore and Narayangonj (Table 4). Islam and his group (2001) found the existence of microbial contamination in the deep way back at Chandpur (Table 4). Also noteworthy, other groups also reported bacterial presence in Jamalpur, Tangail, Netrokona, and Kishoreganj in 2018 as well as Rajshahi in 2020 and Narayunganj, Chittagong, Noakhali and Patuakhali in 2021 (Table 4).

Pesticides pollution

Throughout the world, pesticides are needed for irrigation purposes to control undesirable organisms like weeds, fungi, insects as well as to increase the yield of crops (Shammi *et al.* 2020). Due to the indiscriminate application of pesticides on land, groundwater can easily become contaminated by rain or runoff (Hasanuzzaman *et al.* 2017).The availability of data on pesticide contamination of groundwater in Bangladesh is very limited. This could be attributed to a lack of facilities (funding and laboratory) in the country (Hasan *et al.* 2019a). Malathion was detected at extreme concentration which was seventy eight times greater than permissible limit in Rangpur. Fortunately, other pesticides such as DDT, DDE, DDD, Diazinon and Chloropyrifos were not detected at all (Ara *et al.* 2014). Like Rangpur, malathion was detected in Dhaka but below the acceptable range (Hasanuzzaman *et al.* 2017). However in 1997, 0.0015 mg/L DDT was observed in Nayarhat, Dhaka and that was the breakthrough in the groundwater of Bangladesh and the value is slightly higher than tolerable limit (0.001 mg/L) (Rahman 1997). Next year (1998), trace amounts of DDT were found at the same location (Matin *et al.* 1998). Matin *et al.* (1998) collected 144 groundwater samples and found DDT concentrations ranging from 0.051 to 1.653 g/L and heptachlor concentrations between 0.025 and 0.789 g/L. As for DDT, all samples were lower than the permissible limit, and as for heptachlor except only one sample were above the limit (Matin *et al.* 1998). Matin and his group concluded that the groundwater was not contaminated by pesticides (Matin *et al.* 1998).

Table 3: Summary of trace metals within Bangladesh. Mean values with standard deviations were represented

SL No.	Sample Location	As (mg/L)	Cr (mg/L)	Cu (mg/L)	Pb (mg/L)	Fe (mg/L)	Mn (mg/L)	Cd (mg/L)	Zn (mg/L)	References
	Dhaka Division									
01	Dhaka	-	-	-	-	0.21 ± 0.21	0.06 ± 0.05	-	0.02 ± 0.04	(Bodrud-*Doza et al.* 2019a)
02	Faridpur	0.088	-	-	-	3.29	-	-	-	(Saha and Ali 2007)
03	Tangail	0.0071 ± 0.005	-	-	0.307± 0.15	0.255 ± 0.09		-	-	(Sultana *et al.* 2015)
04	Gopalganj (pre-monsoon)	0.05 ± 0.04	-	-	-	5.12 ± 5.27	0.20 ± 0.10	-	-	(Rahman *et al.* 2018a)
	Gopalganj (post-monsoon)	0.04 ± 0.03	-	-	-	3.31 ± 3.31	0.19 ± 0.18	-	-	(Rahman *et al.* 2018a)
05	Manikganj	0.02	-	-	-	0.81	0.46	0.002	-	(Rahman et al. 2016a)
06	Munshiganj	0.106 ± 0.119	-	-	-	2.122 ± 1.358	0.421 ± 0.357	-	-	(Halim *et al.* 2009)
07	Narayanganj	-	0.071 ± 0.03	-	0.182 ± 0.10	-	-	0.007	-	(Rahman *et al.* 2020a)
	Chittagong Division									
08	Chittagong	0.037 ± 0.01	0.006 ± 0.001	0.003 ± 0.001	0.002 ± 0.001	0.325 ± 0.01	0.232 ± 0.04	0.001± 0.0	0.016 ± 0.001	(Chowdhury and Ahmed 2019)
09	Lakshimpur	0.09 ± 0.09	-	-	0.004 ± 0.001	3.23 ± 3.89	0.65 ± 0.58	-	0.02 ± 0.01	(Bhuiyan *et al.* 2016)
10	Noakhali	<.05	<0.005	-	<0.01	-	-	<0.001	-	(Miah *et al.* 2017)
11	Khagrachari	0.100	BDL	BDL	0.050	4.28	0.61	BDL	BDL	(Ahmed *et al.* 2010a)
12	Rangamati	BDL	BDL	BDL	0.053	0.41	0.11	BDL	BDL	(Ahmed *et al.* 2010a)
13	Cox's Bazar	BDL	BDL	BDL	0.045	2.80	0.52	BDL	BDL	(Ahmed *et al.* 2010a)

14	Bandarban	BDL	BDL	BDL	0.047	5.21	1.27	BDL	BDL	(Ahmed *et al.* 2010a)
15	Chandpur	0.347	-	-	-	7.8	-	-	-	(Bibi *et al.* 2008)
16	Brahmanbaria	0.160 ± 0.142	-	0	-	0.665± 0.75	0.270± 0.513	-	0.037 ± 0.026	(Mahmud *et al.* 2007)
17	Comilla	0.26	0.008	0.010	0.05	3.94	1.97	<0	0.01	(Ahmed *et al.* 2010b)
	Rangpur Division									
18	Rangpur	0.9 ± 0.01	-	-	-	7.73 ± 6.56	0.68 ± 0.75	-	0.03 ± 0.04	(Islam *et al.* 2017d)
19	Dinajpur	0.001± 0.001	0.002 ± 0.003		-	0.34 ± 0.23		0.002 ± 0.001	0.15 ± 0.06	(Howladar *et al.* 2018)
20	Thakurgaon	-	-	-	-	0.49	0.2	-	-	Bhuiyan *et al.* 2015)
21	Gaibandha	-	-	-	-	0.51	0.15	-	-	(Rahman *et al.* 2005)
22	Panchagarh	-	-	0.026	-	0.017	0.008	-	0.003	(Saha *et al.* 2017)
23	Kurigram	0.077	-	-	-	16.6	1.69	-	-	(Moni *et al.* 2019)
	Rajshahi Division									
24	Rajshahi (pre-monsoon)	-	-	-	-	0.59	0.43	-	-	(Rahaman *et al.* 2020a)
	Rajshahi (Post-monsoon)	-	-	-	-	0.54	0.34	-	-	(Rahaman *et al.* 2020a)
25	Joypurhat	-	-	-	-	0.793 ± 0.445		-	-	(Islam *et al.* 2018)
26	Bogra	<1	-	-	-	0.045	-	-	-	(Saha and Ali 2007)
27	Chapai-Nawabganj	0.07 ± 0.04	-	-	-	0.18 ± 0.09	0.17 ± 0.11	-	-	(Islam *et al.* 2017c)
28	Pabna	0.071	-	-	-	0.2	0.67	0.021	-	(Islam *et al.* 2013)
29	Naogaon	-	-	-	-	0.28	0.17	-	-	(Rahman *et al.* 2005)

30	Sirajganj	-	-	-	-	5.29 ± 0.01	1.58 ± 0.02	-	-	(Uddin *et al.* 2019)
	Khulna Division									
31	Khulna	-	-	-	-	1.21± 0.72		-	-	(Adhikary *et al.* 2012)
32	Magura	0.004	-	-	-	1.25	0.144	-	-	(Rahman *et al.* 2015)
33	Chuadanga	-	-	0.334 ± 0.35	-	1.3 ± 0.64	0.28 ± 0.18	0.33 ± 0.14	0.08 ± 0.067	(Bodrud-Doza *et al.* 2019b)
34	Satkhira	0.02 ± 0.030	-	-	0.034± 0.040	4.9 ± 4.76	-	-	0.42 ± 0.26	(Rakib *et al.* 2020)
35	Kushtia	0.37 ± 0.43	-	-	-	0.97 ± 0.63	0.53 ± 0.33	-	-	(Hossain *et al.* 2013)
36	Jessore	-	-	-	-	0.56 ± 2.07	-	-	0.024 ± 0.11	(Ahmed *et al.* 2020a)
	Barisal Division									
37	Barisal	0.009	-	-	-	4.42	-	-	-	(Goswami *et al.* 2017)
38	Patuakhali	0.007	-	-	ND	-	0.004	ND	-	(Islam *et al.* 2017a)
39	Barguna and Patuakhali (pre-monsoon)	-	-	-	-	5.57 ± 5.95	0.50 ± 0.65	-	-	(Islam *et al.* 2017e)
	Barguna and Patuakhali (post-monsoon)	-	-	-	-	5.84 ± 5.26	0.66 ± 0.94	-	-	(Islam *et al.* 2017e)
40	Pirojpur	-	0.003	-	0.001	-	-	0	-	(Amin and Hasan 2011)
	Mymensingh Division									
41	Sherpur	-	-	-	-	0.29	0.29	-	-	(Rahman *et al.* 2005)
42	Jamalpur	-	0.006 ± 0.003	0.008 ± 0.006	0.016 ± 0.011	0.363 ± 1.486	1.075 ± 1.221	0.008 ± 0.005	0.020 ± 0.032	(Zakir *et al.* 2018)
43	Netrokona	0.031 ± 0.053	-	-	-	1.1 ± 1.7	0.3 ± 0.3	-	-	(Akter *et al.* 2016)
	Sylhet Division									

44	Sylhet	-	-	-	-	0.64 ± 0.21	-	-	-	(Begum *et al.* 2019)
45	Sunamganj	0.56 ± 0.21	-	-	-	0.0043 ± 0.007	0.14 ± 0.08	-	-	(Chowdhury *et al.* 2012)
46	Moulovibazar	-	-	-	-	5.0 ± 6.2	0.4 ± 0.3	-	-	(Akter *et al.* 2016)
	BSTI standard	0.05	0.05	1.0	0.05	0.3-1.0	0.1	0.005	5.0	
	WHO standard	0.01	0.05	1.0	0.01	0.3	0.1	0.001	3.0	

Table 4: Summary of microbiological data within Bangladesh. Mean values with standard deviations were represented

SL No.	Sample Location	TVC (cfu/ml)	TFC (MPN/100 ml)	TCC(MPN/100 ml)	*E. coli*(MPN/100 ml)	References
	Dhaka Division					
01	Tangail	2.7×10^7	-	6.4	-	(Champa and Kabir 2018)
02	Kishoreganj	2.4×10^7	-	7.2	-	(Champa and Kabir 2018)
03	Narayanganj	2.68×10^6	Nil	-	58.0	(Islam *et al.* 2020b)
	Chittagong Division					
04	Chittagong		1×10^2	3.73×10^2		(Datta *et al.* 2014)
05	Chittagong (Winter)	7.68×10^1	0	0		(Rifat *et al.* 2021)
	Chittagong (Summer)	2.56×10^2	5.4	8.6	-	(Rifat *et al.* 2021)
06	Chandpur	3.86×10^2	4.0	6.0	-	(Islam *et al.* 2001)
07	Noakhali	2.25×10^2	6.25	120.0	-	(Sarker *et al.* 2020)
	Rajshahi Division					
08	Rajshahi	-	5.0 ± 11.0	57.0 ± 101.0	-	(Basak 2021)

09	Pabna	-	24.74±59.42	-	-	(Uddin *et al.* 2017)
	Khulna Division					
10	Khulna	-	1058.0 ± 2015.0	3495.0 ± 6814.0	40.0 ± 95.0	(Ahmed *et al.* 2020b)
11	Jessore	-	-	59.0	19.0	(Karim *et al.* 2016)
12	Kushtia	-	4.09	16.88	-	(Rahman *et al.* 2017)
13	Kushtia		4.0	14.0		(Rahman and Rahaman 2018b)
14	Magura	-	2.25	15.32	-	(Rahman *et al.* 2015)
	Barisal Division					
15	Barguna	-	-	142.33	39.22	(Kormoker *et al.* 2017)
16	Patuakhali	-	2.29 ± 3.33	9.71 ± 14.52	-	(Kormoker *et al.* 2020)
	Mymensingh Division					
17	Jamalpur	$4.2x10^7$	-	6.4	-	(Champa and Kabir 2018)
18	Netrokona	$4.4x10^7$	-	9.8	-	(Champa and Kabir 2018)
	BSTI standard	0	0	0	0	
	WHO standard	$1x10^3$	0	0	0	

Human Health Risk Assessment of Trace Metals in Groundwater

When significant amounts of metals containing water are ingested, it may cause health effects ranging from cancer to non-cancer (Karim 2011; Kavcar *et al.* 2009). Several villages in Pabna, Kushtia, Chuadanga, Meherpur, and Jessore districts were surveyed by Chakraborti et al. (2015) presented in Table 6. During 1996-1999, some people with arsenical skin lesions and drinking highly arsenic contaminated water from local hand tube wells were selected. In 2009, they observed that 15.66, 15.0, 27.40, 17.51 and 15.77 percent of their registered patients died in respective districts. In another study, 70 spontaneous abortions, 48 stillbirths, and 67 neonatal deaths per 1000 live births were observed (Milton *et al.* 2005). Yunus and his team published a review on the impact of As on health in Bangladesh that reported cancer-causing and non-carcinogenic effects (Yunus *et al.* 2016). Both carcinogenic and non-carcinogenic effects of As were observed in Satkhira (Rahman *et al.* 2019). Rangpur and Gopalganj districts have carcinogenic effects for As and non-carcinogenic effects for Mn, As, Fe, Ba, Zn, and Al; and for As, Fe, Mn, and B, respectively (Rahman *et al.* 2018a; Islam *et al.* 2019). The Haripur gas blowout area of Sylhet district presents a cancer risk for Pb, Cd, and Ni (Howladar *et al.* 2021). In addition, another study was conducted in Sylhet district, where 11 Upazilla were considered under Surma basin, and carcinogenic health risk was determined for As. Non-carcinogenic effect also observed due to As, Mn, Fe and NO_3^- (Bodrud-Doza *et al.* 2019b). The presence of cadmium and manganese in the groundwater did not lead to cancer risk in Chuadanga District, where Pb was the only carcinogen (Bodrud-Doza *et al.* 2019b). Furthermore, in Dhaka city, non-carcinogenic health effects were found for metals (Fe, Mn and Zn) and anions (F and NO_3^-) (Bodrud-Doza *et al.* 2020). In Khulna and Jessore district, Fe and Mn played a key role in non-carcinogenic health risks (Ghosh *et al.* 2020; Hossain and Hassan 2020).

Effect of different factors on groundwater pollution

Geogenic and Anthropogenic Factors

Groundwater contamination sources are represented in a scheme (Figure 2). There are typically two factors that contribute to groundwater contamination: geological and anthropogenic (Islam *et al.* 2020a). Various natural or geogenic processes such as evaporation, mineral dissolution, precipitation of secondary minerals, cation and anion exchange, redox reactions, microbial processes, erosion, ore formation, weathering of rocks and mixing of waters influence groundwater quality (Bodrud-Doza *et al.* 2019a; Bodrud-Doza *et al.* 2019b; Wu *et al.* 2016). The contamination of groundwater is exacerbated by anthropogenic sources, including raw sewage, urban waste, medical waste, mining, smelting, wastewater treatment, industrial effluent, and agricultural activity (Bodrud-Doza *et al.* 2020; Bodrud-Doza *et al.* 2019b; Hasan *et al.* 2019b; Saha and Rahman 2020). In terms of bacterial contamination, nearby latrines and septic tanks may be responsible for infiltrating waste water into the tube well. Also, seepage of polluted surface water through leaky tube well seals is a risk factor. Drinking water also becomes contaminated by secondary microbial organisms at the time of collection, handling, and storage in households (Dey *et al.* 2017; Rahman *et al.* 2019b). Several researchers used principal component analysis (PCA) and cluster analysis (CA) to identify pollution sources in Bangladesh that are both geogenic and anthropogenic in origin (Bhuiyan *et al.* 2016; Bodrud-Doza *et al.* 2016; Bodrud-Doza *et al. 2019b*; Bodrud-Doza *et al.* 2020; Rahman *et al.* 2018a; Rifat *et al.* 2021; Islam *et al.* 2017b).

Geographical Factors

Geographically, Bangladesh is located between 20º34'N and 26º38'N; and 88º01'E and 92º41'E (Shahid *et al.* 2006). The Bengal Delta Plain (BDP) is one of the largest deltas in the world, formed by sediment deposition carried by the Ganges, Meghna and Brahmaputra (GMB) rivers (Mukherjee and Bhattacharya 2001). There are two different mechanisms of contamination in the Ganges delta plain of arsenic (As): (i) The lowering of the water table allows arsenic-rich pyrite to oxidize and enter the groundwater (ii) Sedimentary geology reduces iron oxyhydroxide by organic matter (Anawar *et al.* 2003). Arsenic was also detected in Bangladesh due to its fluvial-sedimentary history (Tareq *et al.* 2003). Fe and Mn are also naturally generating metals found in minerals and rocks in an insoluble form. The occurrence of Fe in water is due to the weathering of iron-rich rocks or the interaction of rock with water (Islam *et al.* 2017d).

Moreover, southern part of the Bangladesh is located in bank of the Bay of Bengal (Mukherjee and Bhattacharya 2001). Due to the infiltration of seawater into the coastal area, it has a high potential of contaminating groundwater (Rahman *et al.* 2011) which was observed in different individuals study. (Naus *et al.* 2019). Furthermore, as the ship breaking industries were located close to the sea, wastes release from ship breaking industries are severely threatens for water contamination in southern part of Bangladesh (Kutub *et al.* 2017; Patwary and Bartlett 2019). Polluted groundwater has been observed in Chittagong's ship breaking industrial area (Hasan *et al.* 2013).

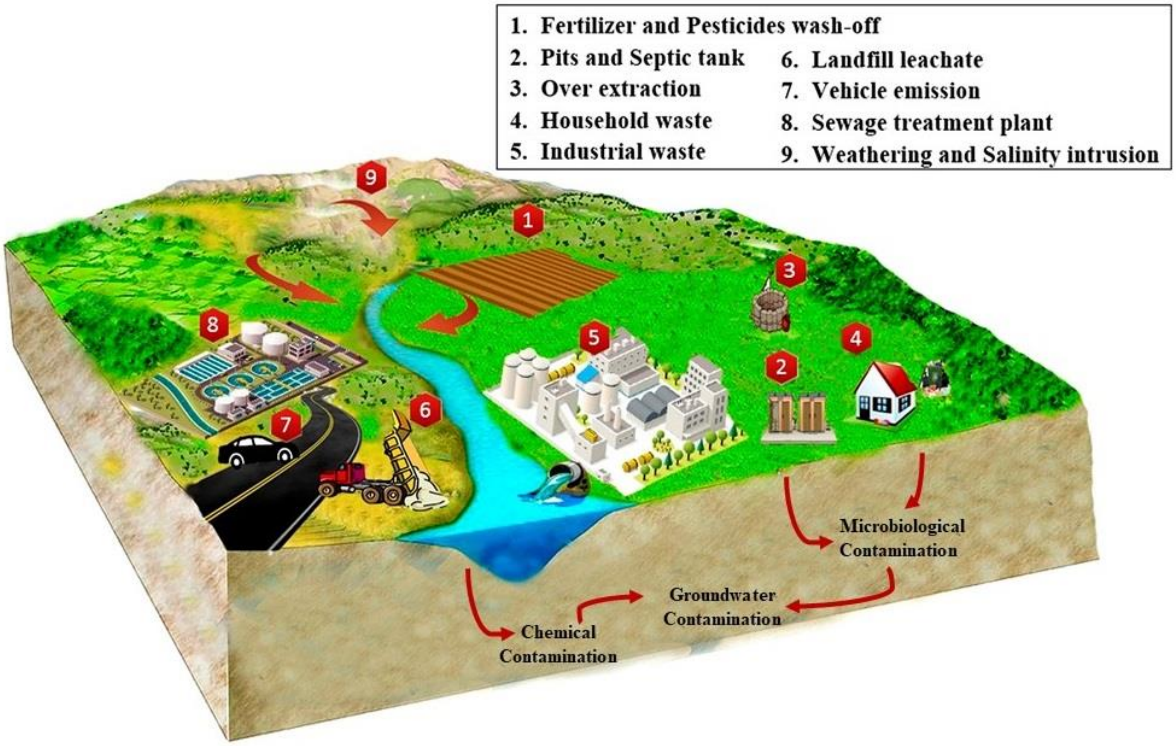

Figure 2: Sources of groundwater contamination (Adapted from Bodrud-Doza *et al.* 2016)

Industrialization

Industrialization can also affect groundwater quality by discharging toxic effluents (Hossain *et al.* 2020). Dhaka, Chittagong, Gazipur, Khulna, Sylhet and Narsingdi are the main industrial city of Bangladesh. Bear in mind that, industries are normally established on the bank of river or sea therefore, industrial effluents are easily released into the river or sea. For instance, a survey showed that river water around Dhaka is highly contaminated and 60% of that contamination occurred due to industrial effluent (Ahsan 2019). Polluted seawater and river water can infiltrate into the groundwater of industrial areas (Arefin and Mallik 2017).

Water Height Factors

The BNDWQS 2009 survey covered both shallow (<150 m) and deep (>150 m) tubes wells, and it found that metal concentrations of deep tubes wells were lower than shallow tubes wells. According to BGS and DPHE (2001), shallow wells had higher Mn concentrations than deep wells. Deep wells are also relatively free of arsenic pollution (Hasan and Ali 2010).

Table 5: Summarized data of pesticides content within Bangladesh. Mean values were represented

SL No.	Location	DDT (mg/L)	DDE(mg/L)	DDD(mg/L)	Malathion(mg/L)	Diazinon(mg/L)	Chloropyrifos(mg/L)	References
01	Taragang, Rangpur	ND	ND	ND	15.0	ND	ND	(Ara *et al.* 2014)
02	Dyamrai, Dhaka	-	-	-	0.043	ND	-	(Hasanuzzaman *et al.* 2017)
03	Nayarhat, Dhaka	0.0015	0	-	-	-	-	(Rahman 1997)
04	Nayarhat, Dhaka	Trace	ND	-	-	-	-	(Matin *et al.* 1998)
	WHO standard	0.001	0.001	0.001	0.19	0.02	0.03	

Table 6: As contamination effect in different districts (Chakraborti *et al.* 2015)

SL No.	Location	Registration year	Number of patient registered	Died before 2009	% of death
01	Pabna	1996	83	13	15.66
02	Kushtia	1999	160	24	15.0
03	Chuadanga	1997	73	20	27.40
04	Meherpur	1996-1999	177	31	17.51
05	Jessore	1997	298	47	15.77

According to Mukherjee and Bhattacharya (2001), the concentration of arsenic decreases with depth (Mukherjee and Bhattacharya 2001, Tareq *et al.* 2003). A low amount of arsenic was detected in shallow wells, while a high amount of arsenic (>450 m, 0.25 mg/L, and >375 m, 0.37 mg/L) was detected in deep wells (Tareq *et al.* 2003). Fluvial-sedimentary history may have caused it (Tareq *et al.* 2003). To add, a study by Parvez and his co-authors found coliform bacteria in 81.2% of tube well samples (<140 feet) and 0% of deep tube well samples (>300 feet) from 37 Bangladeshi districts (Parvez *et al.* 2016).

Synthesis of the existing scenario and future recommendation

There are several physical, chemical, and even trace-metal pollutants in groundwater in coastal areas. High salinity is observed in coastal districts (Akter *et al.* 2016; Islam *et al.* 2017a; Rahman *et al.* 2018a; Sarker *et al.* 2020). TDS and EC were found to be proportional to salinity (Mahmud *et al.* 2020). Moreover, the groundwater surrounding ship dismantling and industrial areas was found to be contaminated by trace metals (Chowdhury and Ahmed 2019; Hasan *et al.* 2013; Hiroshiro *et al.* 2009; Rahman *et al.* 2020b; Islam *et al.* 2017d). As a result, this review suggests policy makers and the proper authorities should focus on the coastal zone and industrial zone for sustainable management. The most common trace metal contamination problem in Bangladesh is arsenic (As). Iron has a correlation with arsenic, where iron concentrations increase with an increase in arsenic levels (Ahmed *et al.* 2010a; Bhuiyan *et al.* 2016; Bibi *et al.* 2008; Halim *et al.* 2009; Islam *et al.* 2017d). Most of the study areas had excessive concentrations of Fe and Mn. Conversely, vital nutrients such as Cu and Zn remained below the prescribed levels throughout the country. Several studies found bacterial contamination in very few locations and found it to be alarming. However, extensive investigations on microbial contamination were missing. Because the investigations of pesticides in groundwater are very limited, concluding remarks are impossible. There have been no reports of residues of pesticides in groundwater in the past few years except for Rangpur (Ara *et al.* 2014) and Dhaka (Hasanuzzaman *et al.* 2017). Despite being banned, DDT is still available illegally on the market in Bangladesh (Rahman *et al.* 2019a; Shammi *et al.* 2017). The health risks were also assessed, but only in a few places.

On the whole, the quality of groundwater has been assessed in 55 districts out of 64. Major concern is that most studies looked at the contents of physico-chemicals parameters or trace metals only or both of them. There would be a need for background investigations at Gazipur, Madaripur, Narshingdi, Kishoreganj, Feni, Lalmonirhat, Meherpur, Jhalokati, Habiganj districts. Importantly, future studies should analyze the detection of microorganisms and pesticides against the water height. An assessment of health risks from groundwater is warranted, especially in the untouched area. This review suggests comprehensive research on another untouched area: exposure to mixed metals/loids in residents (urine/blood) living in an industrial zone in Bangladesh. Further, the regions in which ingestion of water caused cancer risk such as (Satkhira, Sylhet, Gopalganj, Rangpur and Chuadanga) to residents should be re-evaluated by comparing the metal content in the groundwater to the bio-fluids. Finally, contaminants of emerging concern (CESs) such as bisphenol A (BPA), nonylphenol (NP), benzophenones (BPs), and benzotriazole (BT); disinfectant by products (DBP), pharmaceuticals, pe-and polyfluoroalkyl substances (PFAS) need to be addressed in future study for sustainable management of groundwater.

Conclusion

Our report on Bangladeshi groundwater pollution is the first ever to focus on this topic. There are various contaminants polluting the groundwater in most parts of Bangladesh. Coastal as well as industrial zone of Bangladesh is worrying. Among the trace metals, As content shows alarming situation throughout the country. Besides, Fe and Mn also observed in most of the areas. Moreover, Pb, Cd and Cr were found in few studies only and Cu, Mn and Zn were detected below the acceptable limit. Major cations and anions were found below permissible limit throughout the country. Carcinogenic and non-carcinogenic effects were observed at Dhaka, Gopalganj, Rangpur, Sylhet, Chuadanga, Jessore, Satkhira and Khulna districts. Geogenesis, anthropogenic activities, changes in water height, unplanned industrialization, and geography all influence groundwater pollution. By monitoring groundwater pollution, implementing laws, using adequate human resources and installing modern treatment and supply systems, groundwater pollution can be managed. Educating the public about water usage and safety could be a solution to water pollution in

Bangladesh. We recommend that policy makers and appropriate authorities take proper measures to protect groundwater.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5
Conceived and designed the research or analysis	Yes	Yes	No	No	No
Collected the data	Yes	Yes	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes	Yes
Supervision	Yes	No	No	No	Yes
Project Administration	Yes	Yes	No	No	No
Funding Acquisition	No	No	No	No	No
Overall Contribution Proportion (%)	35	35	10	10	10

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