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Status of Groundwater Aquifers, Water Quality, Sources of Contamination, and Future Challenges in Bangladesh: A Comprehensive Review

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ABSTRACT: The groundwater resource of Bangladesh is under increasing threat from population growth, over-water mining, quick urbanization, and pollution from industrial events with domestic and agricultural activities. The objective of this paper is to review over a hundred well-recognized national and international journals, conference proceedings, reports, and other related documents on the status of groundwater aquifers, water quality, sources of contamination, and future challenges in Bangladesh to develop sustainable groundwater resource management. The study observed that groundwater in several zones in the country has been contaminated with elevated levels of dissolved elements. Temporary hardness in countrywide groundwater was found in higher ranges for all purposes while except for bicarbonate, all anions did not cross the guideline value. Among the metal contaminants, arsenic found in the shallow aquifer at an alarming level throughout the country threatened public health, and millions of consumers are suffering from severe and chronic poisoning from arsenic riches water. Additionally, climate change and sea-level rise are likely with increasing salinity and various nutrient concentrations in the coastal aquifer systems of the country, and that water is not fit for domestic and agricultural uses.

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Bangladesh, the most densely populated and developing country, recently faced severe water pollution, crisis, and security (BBS, 2021). In this country, 75% of people who do not have access to piped water systems depend on hand tube-wells and 96% of rural individuals completely rely on raw groundwater for household uses (Islam and Mostafa, 2021a). Although 96% of the total inhabitants have access to fresh water, the cleanliness of water is always doubtful in this country (MICS-B, 2018). The groundwater quality has become a thoughtful concern in Bangladesh, over the last 2/3 decades (UNICEF, 2010). Nearly all rural peoples in Bangladesh consumed raw and untreated shallow layer groundwater through privately owned hand tube wells (depth 20-40 m) (BBS, 2021). Drinkable water has been the main consideration of regard since the early 1990s when widespread pollution of groundwater by arsenic exposure in shallow aquifers (15-40 m) water of Bangladesh (Ahmad *et al.*, 2001). At that moment, OXFUM, WHO, and UNICEF were setting an excess amount of shallow hand tube-well around the country. At present, arsenic infection of groundwater is increasing at an alarming rate in Bangladesh. An inclusive countrywide potable water quality investigation has conducted by BBS which was titled 'Bangladesh National Drinking Water Quality Survey' (BNDWQS) of 2009 with the assistance of UNICEF. The results of this survey presented that 13.3% of the samples carried a higher concentration of arsenic (BBS, 2009; Ahmad *et al.*, 2001). In addition, the Multiple Indicator Cluster Survey, Bangladesh was conducted in 2012-13 in all the 64 districts and the Underground Drinking Water Thematic Report

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exhibited, that 41.6% of the households used drinking water sources that were fecal polluted and arsenic concentrations exceeded the Bangladesh standard of 0.05 mg/L in 12.4% of samples (MICS-B, 2018). Groundwater is a substantial concealed resource in the context of quality and quantity and that vary across lithological and hydrological settings. Hydrogeochemical courses that are weathering of rocks, precipitated, recharge-discharge, redox, ion-exchange, hydrolysis of minerals, water mixing residence time, etc. possibly influence the compositional status of groundwater (Reghunath *et al.,* 2002). Too, human actives such as over-mining of groundwater, chemical spillages, chemical fertilizers and pesticides, industrial and transport wastes, leaching of sewage, landfill, etc. impact groundwater quality. Almost, not only that arsenic contamination, there are huge options to contaminate the groundwater concerning other heavy metals as well as some anions such as Cd, Cr, Co, Pb, Hg, Sb, F^-, NO_3^-, NO_2^-, SO_4^{2-}, PO_4^{3-} etc. by lithological or anthropogenic activities. Earlier numbers of research focused that Bangladesh's groundwater carries an excess of Ca, Mg, and Fe which are not toxic metals, but excessive amounts are very harmful to the human body (Islam and Majumder, 2020; Islam and Mostafa 2021a, 2021b, 2021c, 2021d). In the country, there are 37,258 million tone pesticides and 2.32 billion kg of chemical fertilizer used in the agricultural field annually (Faruq, 2018). Of these, the residual parts are leaching through the topsoil and ultimately reach into groundwater aquifers and make water pollution. The objective of this paper is to review critically reviewed to extract expressive information on over one hundred journal scientific articles, conference or workshop proceedings, national and international reports published by renowned organizations, books, online citations, and other materials on the status of groundwater aquifers, water quality, sources of contamination, and future challenges in Bangladesh to develop sustainable groundwater resource management strategies.

GROUNDWATER QUALITY OF BANGLADESH

Physicochemical water parameters: Physicochemical water variables (parameters), such as temperature (ºC), pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), salinity, and alkalinity of water are not water contamination indicators but those are very significant and vital properties and can affect the growth of biotic life in the water-body and afterward can cause an influence on the water. Various investigators have measured the above-mentioned parameters of groundwater in different zones of Bangladesh (Mahmud *et al.,* 2007; Islam and Shamsad, 2009; Ahmed *et al.,* 2010; Bhuiyan *et al.,* 2010; Rasul and Jahan, 2010; Bhuiyan *et al.,* 2015; Aminur *et al.,* 2016; Dider-Ul *et al.,* 2017; Mostafa *et al.,* 2017; Rahman *et al.,* 2017a; Islam *et al.,* 2017a; Islam *et al.,* 2017b; Tanvir *et al.,* 2017; Alam *et al.,* 2019; Islam and Mostafa, 2022a). Table 1 and Fig. 1 includes the division-wise result of different investigations on physicochemical parameters in groundwater, which were conducted in various zone of Bangladesh during different period. Though water pH has no conventional impact on the consumer, it is one of the most vital and crucial functioning water quality properties (WHO, 2011). The BDWS and WHO has suggested a maximum satisfactory limit of pH for potable from 7.5 to 8.5. Drinking water with a pH higher than 8.5 or less than 6.5 can generate staining etching or scaling. The general countrywide pH result demonstrates that the groundwater source is within a suitable or desirable range from every perspective. The average pH values of 4 divisions (old) are obtained: Dhaka (7.37), Chittagong (7.12), Rajshahi (7.22), and Khulna (7.58). Thus, the countrywide groundwater is almost neutral or slightly alkaline. One more physical parameter, TDS constitutes inorganic minerals or salts and negligible quantities of organic substances that are dissolved in water. The water with a high range of TDS designates that water is enormously mineralized. The required value for TDS is 600 mg/L but the maximum boundary is 1000 mg/L which is set for portable uses (WHO, 2011). In coastal zones of Bangladesh, some researchers have found that TDS and electrical conductivity (EC) levels surpass the wanted borderline. A high value of TDS in consumption water may affect individuals who are suffering from kidney functioning, constipation, and cardiovascular disease (Sasikaran *et al.,* 2012).

Table 1: Physicochemical characteristics including pH, EC (μS/cm), TDS (mg/L), salinity (mg/L), alkalinity (mg/L), and total hardness (TH, mg/L) (mean value) of groundwater in Bangladesh (Division wise)

Sampling area	pH	EC	TDS	Salinity	Alkalinity	TH
Dhaka Division	7.37	464.5	281.7	321.6	180.0	179.3
Chittagong Division	7.12	1378.9	827.9	2245.0	289.1	291.8
Rajshahi Division	7.22	372.5	237.0	302.5	165.9	267.7
Khulna Division	7.58	2021.6	1267.7	1978.0	156.8	423.9

Owing to weathering of rocks and minerals in the aquifers system, the total dissolved solids, as well as the electrical conductance value of groundwater, is slightly higher than surface water. The division-wise average TDS and EC values of groundwater are given in Table 1 and Fig. 1. The TDS in water regulates the EC, which measures the ionic concentration in water that permits it to transmit current. No typical value was projected by WHO or Bangladesh standard but Zuane (1996) proposed that portable water generally registers conductivity from 50 to 500 µs/cm and mineralized water records values over 500 µs/cm. Numerous investigations have shown that the groundwater in shallow aquifers contains an elevated value of EC in the Southern coastal part of Bangladesh (Islam *et al.*, 2017a; Islam *et al.*, 2017b). Water with high EC may have an offensive taste, cause discoloration, and precipitate scale in containers and pipes. Salinity in elevated groundwater is common at shallow aquifers in the coastal part of southern Bangladesh and is typically defined as TDS or EC or chemical components such as sodium (Na^+) and chloride (Cl^-) ions (Zahid *et al.*, 2015). Several studies showed that salinization is the main environmental adversity affecting soil and water resources, agriculture, and generating trouble in the natural ecosystem in the southern portion of Bangladesh. But there is no national-scale steady monitoring of groundwater salinity in Bangladesh (Dider-Ul *et al.*, 2017).

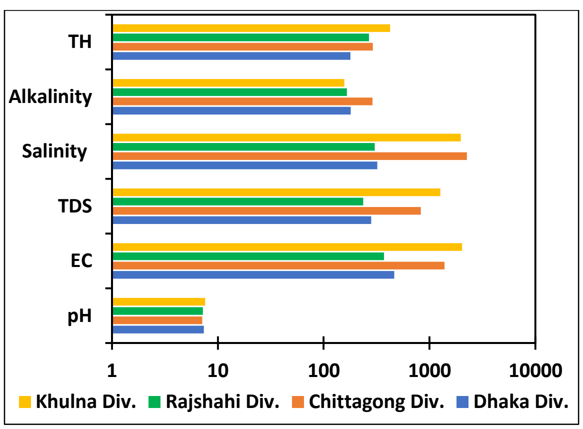

Fig. 1: The values of pH, EC (µS/cm), TDS (mg/L), salinity (mg/L), alkalinity (mg/L), and total hardness (TH, mg/L) in groundwater of Bangladesh

Alkalinity, one more physical parameter, is the power of water to protect against changes in water pH that would make the water more acidic and it is typically a measure of dissolved CO_3^{2-} and HCO_3. As far, not sufficient data in this regard have been found here. Amongst the physical parameters of groundwater, TH is very important and substantial for consumption, irrigation, and industrial purposes. TH is not caused by a single component but by a dissimilar type of dissolved multivalent metal ions, that dominate Ca^{2+} and Mg^{2+} cations, while other cations such as Fe, Ba, Al, Zn, Mn, and Sr also contribute and connected anions are non-carbonate and bicarbonate (WHO, 2011). Water containing the equivalent value of calcium carbonate ($CaCO_3$) at a concentration below 60 mg/L is generally considered soft; 61-120 mg/L: moderately hard; 121-180 mg/L: hard; and more than 180 mg/L: very much hard (McGowan, 2000). The investigations have shown that the total hardness value of groundwater samples of maximum areas of Bangladesh is higher than that of the satisfactory range and the waters become hard to very hard (Tables 1 and 4).

Chemical parameters: Most important cations and anions in groundwater comprise sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), ammonium (NH_4^+), chloride (Cl^-), nitrate (NO_3^-), nitrite (NO_2^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), phosphate (PO_4^{3-}), sulfate (SO_4^{2}), etc. are not serious contaminants; also, these are vital for the human body functions in inadequate quantity. Nevertheless, an additional amount of these ions can make the water insecure for any living biotic and non-biotic (Hasan *et al.*, 2019). Tables 2 & 3 and Figs. 2 & 3 denote the concise data of different ions in groundwater sources, which are taken out from frequent studies all over the country (e.g., Mahmud *et al.*, 2007; Islam and Shamsad, 2009; Ahmed *et al.*, 2010; Bhuiyan *et al.*, 2010; Rasul and Jahan, 2010; Bhuiyan *et al.*, 2015; Aminur *et al.*, 2016; Dider-Ul *et al.*, 2017; Mostafa *et al.*, 2017; Rahman *et al.*, 2017a; Islam *et al.*, 2017a; Islam *et al.*, 2017b; Islam *et al.*, 2017c; Islam *et al.*, 2017d; Tanvir *et al.*, 2017; Alam *et al.*, 2019; Islam and Mostafa, 2022a).

Cations: The most common inorganic constituent in groundwater is sodium (Na^+) and it is typically found as chloride, sulfate, phosphate, and bicarbonate salt (Caldwell *et al.*, 2010). Sodium (Na^+) is a vital electrolyte that helps keep the balance of water fluid in cells in the human body. It also helps proper muscle and nerve fractioning, keeps the osmotic pressure of the plasma, maintains a stable blood pressure range, acid-base balance in the blood, etc. (Whelton *et al.*, 2007). Though, the additional sodium increases blood pressure because it holds extra fluid in the body and upsurges the risk of stroke, kidney disease, heart failure, osteoporosis, and stomach cancer (WHO, 2006). As stated by BDWS and WHO, the standard concentration of Na^+ in drinking water is 8.7 mEq/L or 200 mg/L; and for irrigational use (FAO standard) is up to 40 mEq/L (Table 4). Division-wise sodium (Na^+) concentration in groundwater is included in Table 2 and Fig. 2.

Table 2: Average concentration (mg/L) of major cations in groundwater of 4 Divisions in Bangladesh.

Sampling area	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**
Dhaka Division	56.7	4.8	103.1	32.5	0.95
Chittagong Division	227.3	7.3	56.8	24.6	4.23
Rajshahi Division	27.6	3.2	116.4	23.0	0.54
Khulna Division	432.7	11.9	98.3	44.8	1.13

The groundwater of southern districts (coastal area) such as Satkhira, Bagerhat, Gopalganj, Barisal, Chandpur, Khulna, Borguna, etc. is not appropriate for drinking purposes without any proper desalinization (Islam and Mostafa, 2021a). Potassium (K^+) is normally found as halides, sulfate, and bicarbonate in groundwater, and its concentration is found less than other major cations in water. Along with sodium, it keeps the normal osmotic pressure in the body cell. In addition, it is a co-factor for several enzymes and is vital for the secretion of insulin, creatinine phosphorylation, protein dissolution, carbohydrate digestion, muscle contraction, and nerve stimulation (WHO, 2009). But then the excess level of potassium in the human body may direct to muscle weakness, heartbeat disorder, depression, etc. (He and MacGregor, 2008). The blood plasma K^+ level is typically 115 mg/L to 166 mg/L and if blood holds 190 mg/L can be risky, called hyperkalemia, and generally requires instant treatment (Gosselin *et al.*, 1984). Countrywide divisional potassium (K^+) levels in groundwater are included in Table 2 and Fig. 2. and overall data designate that, excluding Khulna, Satkhira, Thakurgaon, and Rajshahi districts, the rest of the district's groundwater contains potassium normal in range.

Alike Na^+ and K^+, magnesium (Mg^{2+}) are also abundant as a cation in groundwater. It is an essential metal for the human body, which controls 300 biochemical reactions and, assists in the production of protein and energy (WHO, 2011). It aids to maintain normal nerve and muscle systems, keeps the heartbeat steady, and helps bones remain strong. Besides that, it also helps adjust blood glucose levels (Gommers *et al.*, 2016). Normal Mg levels in blood plasma are between 11.4 to 20.6 mg/L with levels less than 11.4 mg/L defining hypomagnesemia (Soara *et al.*, 2010). As stated by BDWS and WHO, the normal values for Mg^{2+} in drinking water should be 18 and 30 mg/L, respectively. Numerous investigations exhibited that the maximum groundwater samples in Bangladesh contain an excess level of Mg^{2+} with a range from 32.9 to 155 mg/L; mainly in Chandpur, Monshiganj, Faridpur, Comilla, Pabna, Manikganj, Lakhimpur, Chuadanga, Barisal, Gopalgang, Borguna, Khulna, and Rajshahi district (Islam and Mostafa, 2021a).

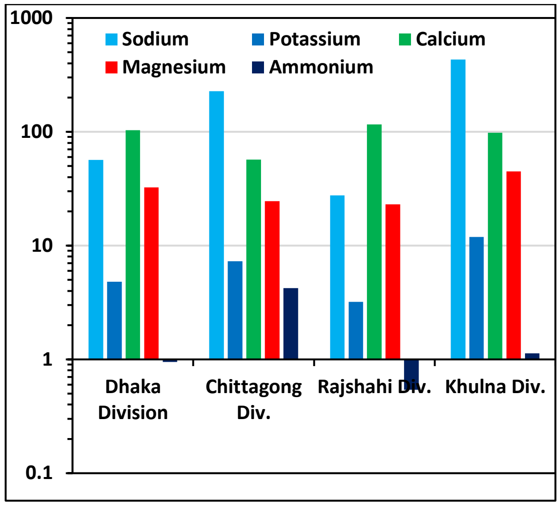

Fig. 2: The concentration (mg/L) of Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Ammonium (NH_4^+) in groundwater of Bangladesh

Another constituent Ca^{2+} is an abundant mineral in the human body and earth's crust, and this metal ion plays an important role in human cell functioning, heart disease, hormones, fluid balance, cancer, muscle contraction, neurodegenerative disease, etc., along with the descent of the testis (Pravina *et al.*, 2012). Although Ca^{2+} is good for bones and prevents osteoporosis, but bad for the brain, and excessive consumption leads to hypercalciuria, urinary tract concretion (UTI), kidney and arterial disease, and compression of bone restoration (Heaney *et al.*, 1982). Although the national and international normal values for a Ca^{2+} in potable water are 75 to 100 mg/L the maximum groundwater sample holds an excess of Ca^{2+}. Calcium loaded along with Mg^{2+} is mainly responsible for hardness, which is the main threat in the domestic and industrial water of Bangladesh. Table 2 and Fig. 2 show that the groundwater of shallow aquifers in the Rajshahi and Chittagong divisions contain an average of 114.4 and 56.8 mg/L of Ca, respectively. Ammonium (NH_4^+) is an important nutrient in primary production, nevertheless, high ammonium loads can disturb the metabolism by changing acid-base balance, troubling glucose tolerance, and reducing the tissue vulnerability to insulin. A few studies investigate the NH_4^+ concentration in groundwater and among those the average highest loads (1.13 mg/L) were found in the Khulna division (Table 2 and Fig. 2).

Anions: Chloride (Cl^-) is the most common and essential anion in groundwater for the human body, which acts as a comparatively minor contaminant in drinking water. An adult human body holds roughly 81 gm of chloride (Cl^-) ions and it preserves the fluid balance in the body, cellular activities, and metabolic actions in the human body and plants (Fadeeva, 1971). Even though Cl^- is not a pollutant, because of the unpleasant taste and odor of water WHO, US-EPA, and BDWS have set the secondary maximum ranges of 150 to 250 mg/L (Table 4). Several studies exhibited that the groundwater (shallow) of southern coastal areas in Bangladesh carries an extreme amount of Cl^- which are very much greater than standard levels. The highest concentration of Cl^- (3513 mg/L) was testified from the Borguna district (Islam *et al.*, 2017a). Also, the groundwater samples of Borgona (632 mg/L), Chittagong (463 mg/L), Satkhira (409.6 mg/L), Chandpur (602.2 mg/L), Khulna (1776 mg/L), and Noakhali (875.61 mg/L) hold an excess of Cl^- ion (Islam and Mostafa, 2021a). Fluoride (F^-) is a micro component in natural drinking groundwater and its shortage in water causes dental caries, predominantly in children, and high concentration, on the potable water body, perhaps causing weakness of the bones and cavities and blackening of the teeth (Ali *et al.*, 2016). Each year, the US spends about 1.08 Doller per person on fluoridated drinking water (Islam and Mostafa, 2021e). The acceptable level of F^- is from 0.5 to 1.5 mg/L in drinking water, dependent on the local environment, climate, and other sources of fluoride (WHO, 2011). Up to now, there is no national-wide monitoring and assessment for F^- levels in the drinking water of Bangladesh, and has inadequate data for those surveys.

Table 3: Average concentration (mg/L) of major anions in groundwater of 4 Divisions in Bangladesh

Sampling area	**Cl^-**	**F^-**	**NO_3^-**	**HCO_3^-**	**SO_4^{2-}**	**PO_4^{3-}**
Dhaka Division	35.9	0.25	3.03	317.8	7.7	2.6
Chittagong Div.	318.4	0.21	5.98	384.2	4.2	1.9
Rajshahi Division	41.1	0.12	2.65	493.8	11.6	4.9
Khulna Division	623.9	0.09	4.9	417.9	13.5	3.1

Bicarbonate (HCO_3^-) remains as Na, K, Mg, and Ca-bicarbonate and those are the most common and naturally occurring sufficient minerals in the aquifer's water. It plays remarkably vital roles in numerous biological activities (Casey, 2006). There are no national or international standard values for HCO_3^- and it is related to the total hardness (TH) of the water. A different countrywide investigation found the HCO_3^- concentration in groundwater generally varied from 2.6 to 700.2 mg/L (Islam and Mostafa, 2021a). Nitrite (NO_2^-) and Nitrate (NO_3^-) is the overall form of nitrogen in groundwater and a high concentration in drinking water may cause methemoglobinemia, also called 'blue baby syndrome, in which the aptitude of blood hemoglobin to transport oxygen (O_2) is reduced (Winton *et al.*, 1971). The main sources of both NO_3^- and NO_2^- in water include inorganic nitrogen fertilizers, septic tanks, and wastewater treatment. The division-wise concentration levels of NO_3^- have presented in Table 3.

Except for Sathkhira Sadar (14.80 mg/L), the groundwater of all regions of Bangladesh is safe level (Islam and Mostafa, 2021a). Another abundant and common anion of groundwater is Sulfate (SO_4^{2-}) which comes from the weathering and dissolution of Na, K, Ca, and Mg-sulfate rocks/minerals and some types of surfactants (de Araújo *et al.*, 2018). There is no primary human health-based standard value for SO_4^{2-} in domestic water projected. But US-EPA set a secondary recommendation value for SO_4^{2-} of 250 mg/L because water holding higher concentrations may produce an offensive taste that makes it unsuitable for household uses and it makes a high risk of dehydration from diarrhea (US-EPA, 2003). If the level of sulfate (SO_4^{2-}) in consumption water is over 600 mg/L the laxative effects are reported (Chien *et al.*, 1968). Table 3 shows that the levels of SO_4^{2-} in all the groundwater samples of Bangladesh are far below the threshold values (Table 4).

Phosphate (PO_4^{3-}) ion comes from detergents and phosphorus baring fertilizers into the water body. Like sulfate, PO_4^{3-} has no consumption water guideline concentration. However, too much PO_4^{3-} can cause health problems, such as osteoporosis and kidney damage and it can speed up eutrophication in the water body (Zhang *et al.*, 2011). The division-wise concentrations of phosphate in the groundwater of Bangladesh have included in Table 3. *Trace metals:* Trace metals and metalloids, among a wide-ranging limit of contaminations, are steady a health concern due to their toxicity capacities at a very little concentration and can show an opposite effect on living existences, and tendency to bio-accumulate and bio-magnification in lipids/fats and tissues of biotics over periods (Malik *et al.*, 2019).

Table 4: Drinking water quality standards of BDWS, WHO, US-EPA, and India

Parameters	Drinking water quality standard			
	WHO[1]	*BDWS*[2]	*US-EPA*[3]	*INDIA*[4]
pH	7.5-8.5	6.5-8.5	6.5-8.5	7-8.5
TDS (mg/L)	600	1000	500	500
Total hardness (mg/L)	500	200-500	-	300
Na (mEq/L)	8.6	8.7	1.3-2.6	8.0
K (mEq/L)	-	0.3	-	-
Ca (mEq/L)	5.0	3.75	-	3.75
Mg (mEq/L)	12.5	2.5	-	2.5
Cl^- (mEq/L)	7.0	4.2-17	7.0	7.0
NO_3^- (mg/L)	50 (as N)	10	10(as N)	45
SO_4^{2-} (mg/L)	500	400	250	200
PO_4^{3-} (mg/L)	-	6.0	-	-
NH_4^+ (mg/L)	-	0.2	-	-
F^- (mg/L)	1.5	1.0	2.0	1.9
Mn (mg/L)	0.5	0.1	-	0.1
Fe (mg/L)	0.3	0.3-1.0	0.3	0.3
Co (mg/L)	-	0.05	-	-
Ni (mg/L)	0.02	0.1	-	-
Cu (mg/L)	2.0	1.0	1.3	0.05
Zn (mg/L)	3.0	5.0	-	-
Cr(+6) (mg/L)	0.05	0.05	0.1	0.05
Cd (mg/L)	0.03	0.005	0.005	0.01
Pb (mg/L)	0.01	0.05	0.015	0.05
As (mg/L)	0.01	0.05	0.01	0.05

Note: [1]HWO-Drinking water standard (2011); [2]Department of Public Health and Engineering, Bangladesh (2019); [3]US-EPA-Drinking water standard (2018); and [4]Drinking water standard for India (2012).

Table 5: Trace metal mean concentrations (mg/L) in groundwater of Bangladesh

Sampling location	Cr	Mn	Fe	Cu	Zn	Pb	Cd	Ni	References
Dhaka Division									
Dhaka Metro		0.224	4.03	0.09	-	-	-	-	Nahar *et al*. (2014)
Gopalganj District	-	0.201	5.13	BDL	BDL	-	BDL		Atikul *et al*. (2018)
Manikganj District	-	0.455	0.81	-	-	-	-	-	Rahman *et al.* (2016)
Narayangonj City	0.06	2.71	-	-	-	-		0.057	BGS, (2001)
Narayangonj District	0.02	2.00	-	-	0.190	0.450	0.01	0.081	Seddique *et al*. (2004)
Faridpur District	-	BDL	5.93	-	0.011	0.006		0.003	Bodrud-Doza *et al*. (2016)
Rajarampur, N'ganj	-	-	-	.0002	0.030	0.0002	0.053	BDL	Islam *et al.* (2001)
Singair, M'ganj Dist.	0.093	2.08	7.11	.022	0.0643	0.019		0.043	Halim *et al*. (2014)
Dhaka District	0.011	-	-	0.056	0.034	-		0.037	Alam *et al.* (2019)
Chittagong Division									
Chittagong District	0.005	0.54	2.88	0.011	0.010	0.049	0.011	0.020	Ahmed *et. al.* (2010)
Brahmanbaria Dist.	-	0.27	0.67	0.003	0.037				Mahmud *et al.* (2007)
Lakshipur District	-	0.65	3.23	-	0.216	0.004		0.002	Bhuiyan *et. al.* (2015)
Cox'sBazar sea beach	-	1.87	1.81	-	-	BDL	-	0.0002	Seddique *et al.* (2016)
Moinamoti, Comilla	0.003	-	-	.0006	-	0.001		0.001	Islam *et al.* (2000)
Lakshimpur District	-	0.65	3.24	-	-				Bhuiyan *et al.* (2015)
Sylhet District	-	0.28	6.83	-	BDL	-	BDL	-	Islam *et al.* (2017c)
Khulna Division								-	
Kushtia District (1)	-	0.97	0.53	-	BDL	-		-	Hossain *et al.* (2013)
Andulia, Jhenaidah	-	-	-	0.078	-	0.0007		BDL	Islam *et al.* (2000)
Barishal Metro	-	-	4.42	-	-	-		-	Sukhen *et al.* (2017)
Samta, Jessore Dist.	BDL	-	-	0.027	-	0.0005	0.031	BDL	Islam *et al.* (2000)
Chuadanga Dist.		0.29	28.9	--	-	-		-	Nahar *et al.* (2014)
Kushtia District (2)	0.05	3.11	8.11	0.88	2.01	0.07	0.012	-	Islam and Mostafa (2022b)
Rajshahi Division						-		-	
Rajshahi City	-	1.84	2.82	0.281	0.185	1.15	0.015	-	Mostafa *et al.* (2017)
Pabna District	-	-	0.74	-	-	-		BDL	Sarkar *et al.* (2006)
Rangpur District	-	0.68	7.73	-	0.033	-		-	Islam *et al.* (2017b)
C' Nawabganj Dist.	0.001	1.44	-	BDL	-	0.096	0.010	-	Saha and Zaman(2011)

Note: BDL-Bellow detection limit

Those metals such as Cr, Cd, Pb, As, Hg, and Co have no convenient effects in the human body system, furthermore, long time exposure may cause more acute interruptions in the normal operations of the human organ systems where the metals are deposited (Mominul, 2018). The countrywide trace metals level in groundwater are comprised in Table 5. Chromium [Cr (+3) and Cr (+6)] is a naturally occurring toxic trace metal that is typically found in very small concentrations in groundwater and is not affected by point-source contamination. The main sources of chromium discharge in Bangladesh are the tannery industry and landfills or other solid waste. In the human body system, the maximum concentrations of chromium accumulated in lymph nodes, lungs, kidneys, liver, and spleen, and enduring exposure can injure the kidneys and liver (Shrivastava *et al.*, 2002). BDWS, WHO, and US-EPS suggested the acceptable highest value of Cr in drinking water of 0.05 mg/L (Table 4). Several studies in different areas of Bangladesh focused on the Cr content in groundwater (Table 5). Results revealed that the average concentration of Cr falls within the recommended limits. Iron (Fe) load is a challenging issue for rural drinking water in Bangladesh. It is the 3rd most abundant metal in the earth's crust and it remains as ferrous (Fe^{2+}) and ferric (Fe^{3+}) oxides, hydroxides, carbonates, nitrate, and sulfides (Knepper, 1981). While a low concentration of iron is vital in the human diet and plant metabolism and cannot do much harm, it encourages offensive bacterial growth (*iron bacteria*) inside waterworks and water supply systems, resulting in the deposition of a mushy coating on the piping operation (CanDNHW, 1990). In addition, a high iron load (>0.3 mg/L) leads to an excess which can cause stomach problems, hemochromatosis, nausea, vomiting, and diabetes (Toyokuni, 2009). Numerous studies showed that the Fe levels in the groundwater of Bangladesh are quite high (Table 5). The groundwater samples of the maximum area hold over allowable concentration and reach near about 8 mg/L of Fe. Bangladesh's national standard also informed that 40% of groundwater bears excess amounts of iron and the survey also presented the high average level of Fe present in the deep tube-well (1.37 mg/L) and shallow (2.65 mg/L) water all over the country. Table 5 showed that the Fe concentration in the aquifer water of the maximum region of the country is over the 3 mg/L which is much greater than the drinking water standard.

Manganese (Mn) is an element vital to the proper work of humans, animals, and plant metabolism, as it is mandatory for the functioning of numerous cellular enzymes and can help to activate hydrolases, decarboxylases, kinases, transferases, etc. (IPCS, 2002). But excess ingesting (over 0.5 mg/L) of Mn-rich water, then exhibited neural symptoms which are similar to Parkinson's disease (Kondakis *et al.*, 1989). Impulsive instability, memory damage, hallucinations, and disorientation are also concerns of manganese overdo (Dorman, 2000). There is no WHO and USEPA primary recommendation for Mn in water supplies because they have no recognized thoughtful health threats posed by it. Though, a secondary extreme contaminant level of 0.1 mg/L for Mn because higher levels yield aggressive taste, color, odor, staining, and corrosion (WHO, 2011). Table 5 shows that the maximum concentration of Mn is 2.71 mg/L in Kushtia; and maximum samples of, Narayonganj, Mnikganj, Rajshahi, and Rangpur District contained moderately high levels of Mn.

Nickel (Ni) occurs mostly as the hydrated form $[Ni(H_2O)_6^{2+}]$ in groundwater at pH 5–9 (IPCS, 1991). The initial cause of Ni in drinking water is the dissolution of metals in contact with supply water, such as pipes and fittings (WHO, 2005). The serious injurious health effects of ingesting nickel, such as cancer of the lung and nasal sinus, lung function disorder, and chronic bronchitis have occurred in those who have respired fine particles containing certain Ni species whiles employed in Ni melting plants (Sunderman *et al.*, 1988). As stated by WHO and US-EPA guidelines, the concentration of Ni should not exceed 0.02 mg/L in drinking water. Studies stated the average concentration range between <0.00006 to 0.055 mg/L in water, which is an almost safe range. Various investigations showed that the average Ni concentration of groundwater in the selected part of the country is within the standard limit (Table 5).

Copper (Cu) is a crucial element in animals and plants which shows a substantial role in body metabolism (Bremmer and Beattie, 1990). Extensively it is used in plumbing pipes and fittings and may dissolve from water pipes if the pH of acidic ranges (<7). Momentary exposure to copper in drinking water can lead to gastrointestinal suffering, long-time exposure can lead to copper toxicosis, which results in liver and kidney damage, hepatic cirrhosis, anemia, and deterioration of the basal ganglia (Harris and Gitlin, 1996). An extra copper in aquatic environments is extremely harmful to fish and other aquatic lives (Ali and Khan, 2018). Countrywide various investigations showed that the Cu levels, with the ranges of 0.0002 to 0.88 mg/L, in groundwater (Table 5) are almost in safe positions.

Zinc (Zn) is a naturally occurring trace element and an essential nutrient for body metabolism and development, predominantly for newborns and young children (Askary *et al.*, 2011). Water with a Zn concentration of more than 3 mg/L tends to be opalescent, grows an oily film when boiled, and has an unwanted loathful taste (WHO, 1996). All the collected groundwater samples from various regions of Bangladesh showed that the levels of Zn (0.01 to o.941 mg/L) are much below the maximum acceptable ranges. But in Kushtia District, groundwater carries over 2 mg/L Zn which is much higher than the guideline value.

Cadmium (Cd) is a very toxic trace element with a very long half-life and it occurs naturally with zinc rocks/minerals (Jihen *et al.,* 2008). This element can release into groundwater from buried wastes containing metal refinery byproducts and electronic wastes, and by coal-burning. Acute exposure can cause diarrhea, nausea, cancer, anemia, bone marrow disorders, liver injury, muscle cramps, and kidney failure (Krajnc *et al.,* 1987). In Bangladesh, the mean concentrations of 0.011-0.053 mg/L Cd were found in groundwater samples, which are 5 to 10 times higher than the unobjectionable level (Table 5).

Lead (Pb) is another ubiquitous toxic trace metal and a significant public health concern in the environment (Flora et al., 2012). It can cause different biochemical effects when exposed to it for a comparatively short time duration (Elom *et al.,* 2014). These effects may comprise interfering with red-blood-cell chemistry, delays in usual physical and mental growth in an infant, hearing and learning capacities of children, kidney disease, cancer, scarcity in attention span, stroke, and rises in the blood pressure of adults (Moore, 1988). The highest allowable concentration of Pb in drinking water set by Bangladesh and WHO is 0.05 and 0.01 mg/L, respectively. Kushtia, C' Nawabganj, Narayanganj, and Rajshahi city's groundwater samples contain 0.07 to 1.15 mg/L of Pb which are almost 7 to 115 times higher than the WHO standard (Table 5)

Arsenic (As), a first-category carcinogenic metalloid (Driscoll *et al.,* 2004), occurs naturally in groundwater supplies all over regions of Southeast Asia. In the Ganges delta plain of Bangladesh and northern India, severe contamination in groundwater by naturally occurring arsenic affects 25% of hand tube well in the shallow two provincial aquifers (Ravenscroft, 2007). Over 75 million people, from 59 out of 64 districts (Fig. 3), were carried to be at risk of drinking water contaminated by arsenic in Bangladesh (Safiuddin, 2001). Every year, a measured 43,000 people are attacked by arsenic poisoning in the country (Jahan, 2016). In the year 1992-93, the groundwater samples of some shallow tube wells placed in the northern area of Bangladesh, were examined for arsenic contamination and found to contain in the range of 59–388 µgm/L of arsenic, which was higher than the WHO and Bangladesh standard of 10 µgm/L (0.01 ppm) and 50 µgm/L (0.05 ppm), respectively in groundwater (DPHE, 2009).

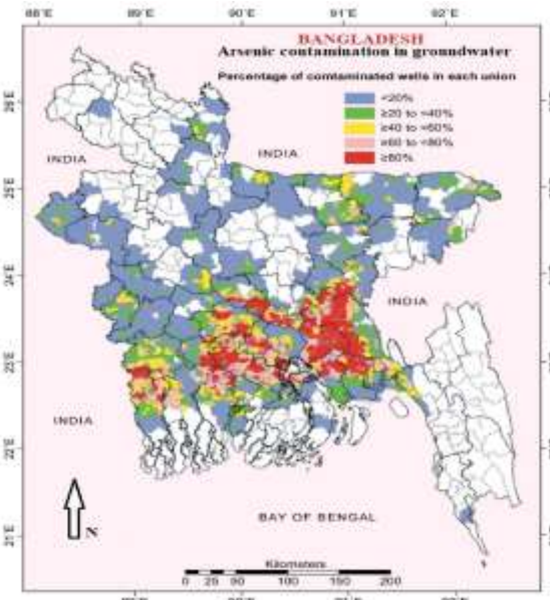

Fig. 3: Distribution of arsenic in groundwater of Bangladesh

In 1998, the British Geological Survey (BGS) collected 2,022 water samples from 41 arsenic-predominant districts (Smith, 2000). Lab tests discovered that 35% of these samples were found to have an arsenic level above 50 µgm/L. The preliminary screening that was guided in 1999 verified 51,000 tube wells, which quantified that arsenic toxicity was present in 211 out of 460 Upazillas (sub-districts), which are nearly one-third of the tested tube wells. Then, in 2003, a countrywide comprehensive study directed by Arsenic Mitigation Water Supply Project (AMWSP), cover 57,482 villages in 271 Upazillas, where it displayed 1.44 million tube-wells, out of a total of 4.95 million tube-wells, contaminated with arsenic. The As levels in the water of the maximum affected tube wells were found to be at the limit of 100–300 µgm/L (0.1-0.3 ppm). The highest concentration of arsenic detected in the shallow tube-well water was 470 µgm/L and a previous study conducted by the experts of the Bangladesh Council for Scientific and Industrial Research (BCSIR) have found also the highest concentration of 1400 µgm/L in the same types of tube-well water of Pabna district (New Nation Report, 1996). In Bangladesh, two predominant hypotheses stating the mobilization of arsenic in groundwater are pyrite oxidation and the reduction of metal oxy-hydroxide (Islam and Mostafa, 2021f).

Drinking Water Quality Evaluation

From the viewpoint of the earlier discussion in the text, the concentration of some parameters in groundwater such as total hardness with bicarbonate of Ca and Mg almost all over the zone; Fe, Mn, and Pb in some regions; salinity with NaCl in the coastal area, SO_4^{2-}, NO_3^-, and PO_4^{3-} in the north-east zone; and As in 80% area of the country are intolerable to drinking and another household purpose. Without any treatment and suitable filtration, particularly, the aquifer water of 11 coastal Districts in the country is unfit for drinking use. Though groundwater is well protected from microbial contamination, various studies confirm that water in some regions is contaminated with faecal coliform (Islam *et al.*, 2001; Rahman, 2009; MICS-B, 2018). With the help of well recognized several drinking water quality indices, it can evaluate the water quality for this purpose. The water quality index (WQI) is to abridge big quantities of water quality data into simple terms (e.g. good, fair, or poor) for reportage on the suitability of water use. It can assess based on various physical, chemical, and microbial parameters (Sahu and Sikdar, 2008). Some water quality directories have been formulated all over the world which can easily judge the overall water quality inside areas efficiently and promptly (Tyagi *et al.*, 2013). Water quality index (WQI), heavy metal evaluation index (HMEI), heavy metal pollution index (HMPI), the degree of contamination (C_d), etc. are the major evaluation indices for drinking water, and some results of these indices of various groundwater samples in different places of the country included in Table 6. The WQI range and type of water can classify as excellent (0-25), good (26-50), poor (51-75), fair (76-100), and rejection (>100); in which WQI values placed within the bracket (Bhuiyan *et al.*, 2010). Table 6 informed that concerning those indices an average of 40 to 60% of water is not completely fit for potable or other household uses. In Kushtia and Lakshimpur District, almost 50% of water samples are of very poor quality, 15% are highly metal-polluted, and the degree of contamination is almost high.

Table 6: Water quality assessment and health risk indices of groundwater in Bangladesh

Sampling location	Drinking-Water Quality Assessment Index				Reference
	WQI	*HMPI*	*HMEI*	C_d	
Faridpur District No. of samples: 62 Water depth: 14-204 m	**110.70 (Average)** EQ – 28.50% GQ –13.50% PQ – 38.00% FQ –15.00% RQ – 5.00%	**46.05 (Average)** LP – 66.67% MP – 25.0% HP – 8.33%	**8.54 (Average)** LP – 65.0% MP – 31.67% HP – 3.33%	**7.51 (Average)** LP – 71.7% MP – 26.67% HP – 1.67%	Bodrud-Doza *et al.* (2016)
Kushtia District No. of samples: 40 Water depth: 22-110 m	**88.1 to 551.6** EQ – 0% GQ – 0% PQ – 5% FQ – 20% RQ – 75%	**654.0 (Average)** LP – 20.0% MP – 2.5% HP – 77.5%	**38.3 (Average)** LP – 5.0% MP – 12.5% HP – 82.5%	**34.27 (Average)** LP – 17.5% MP – 20.0% HP – 62.5%	Islam and Mostafa (2021c, 2021d)
Lakshmipur District No. of samples: 70 Water depth: 10-318 m	**114.5 (Average)** EQ – 8.50% GQ – 20.00% PQ – 30.00% FQ – 45.50% RQ – 7.00%	**26.13 (Average)** LP – 67.14% MP – 18.57% HP – 14.29%	**7.45 (Average)** LP – 75.71% MP – 22.86% HP – 1.43%	**11.21 (Average)** LP – 60.0% MP – 24.29% HP – 15.71%	Bhuiyan *et al.* (2010)
Moddopara, Dinajpur District No. of samples: 12 Water depth: 25-35 m	**19.21 to 44.19** EQ – 40% GQ – 60% PQ – 0% RQ – 0%	**19.92 (Average)** LH – 81.0% MP – 9.67% HP – 9.33% *(Calculated)*	**6.88 (Average)** LH – 78.34% MP – 11.00% HP – 10.66% *(Calculated)*	**10.32 (Average)** LH – 73.09% MP – 23.71% HP – 2.39% *(Calculated)*	Howladar *et al.* (2018)
Rajshahi City No. of samples: 190 Water depth: 45-90 m	**23.51 to 89.99** EQ – 10.00% GQ – 20.00% PQ – 50.00% FQ – 20.00% RQ – 0%	**38.34 (Average)** LP – 66.67% MP – 25.0% HP – 8.33% *(Calculated)*	**7.51 (Average)** LP – 67.80% MP – 30.65% HP – 1.55% *(Calculated)*	**7.53 (Average)** LP – 62.92% MP – 28.67% HP – 8.32% *(Calculated)*	Rahman *et al.* (2017b)
Gopalganj District No. of samples: 23 Water depth: 20-35 m	**11.33 to 90.51** EQ – 56.52% GQ – 13.04% PQ – 13.04% FQ – 17.40% RQ – 0%	**46.38 (Average)** LH – 59.98% MP – 23.56% HP – 16.46% *(Calculated)*	**10.11 (Average)** LH – 78.37% MP – 10.67% HP – 11.96% *(Calculated)*	**12.90 (Average)** LH – 67.00% MP – 19.98% HP – 13.02% *(Calculated)*	Atikul *et al.* (2018)

Note: EQ – Excellent quality; GQ – Good quality; PQ – Poor quality; FQ – Fair quality; RQ – Rejected quality; LP – Low polluted; MP – Medium polluted; HP – Highly polluted

Sources of groundwater pollution: The geogenic course is the major cause of As contamination of groundwater in Bangladesh, which is a serious threat to countrywide public health. This process denotes naturally happens because of lithological and geological processes. Arsenic and fluoride pollution happens because aquifer sediments hold an excess of organic matter that makes anaerobic conditions in the aquifer basement, and those condition results in the bacterial dissolution of iron-oxides in the sediment and, later, the release of the arsenic, usually tightly bonded to iron-oxides, into the water phase. So, As-baring water is mostly Fe-rich, while secondary procedures often obscure the amalgamation of dissolved both As and Fe (Ahmed *et al.*, 2011). A suggestively high level of fluoride in groundwater is naturally caused by a deficiency of Ca in the aquifer systems (WHO, 2006). Excessive concentrations of other parameters like salinity, Fe, Cr, Mn, Pb, and radioactive metals in groundwater may also be the geogenic source (Leeuwen, 2000). Bangladesh is the ninth most populous and twelfth most densely populated country in the world. Along with population growth, there is a collective problem with waste management all around the country. Solid waste generation in Bangladesh is around 22.4 million tons (MT) per year, 60,000 m^3/day of effluents from 7000 big industries without any treatment just in and around Dhaka city, and 30,000 m^3/day of household liquid sewage generated by Dhaka Metropolitan (Abedin and Jahiruddin, 2015). The tannery industries in Bangladesh produced large amounts of effluents containing toxic chemicals and discharged them into nearby water bodies without any treatment that threatened the aquatic environment. Globally, it was estimated that discharged tannery waste effluent holds 300–400 MT of heavy metals, solvents, toxic sludge, liquor, and other solid waste materials, which are dumped into water bodies every year (Manjushree *et al.,* 2015). Bangladesh has insufficient wastewater treatment infrastructure and no modern waste disposal management or there are organized failures of the on-site sewage dumping system (Alamgir and Ahsan, 2007). Along with nutrients and pathogens, untreated sewage can also have a significant load of heavy toxic metals and other inorganic and organic pollutants that may seep and leach into the groundwater layer. The harmless effluent from Effluent Treatment Plants (ETP) may also reach into the aquifers by leaching if the effluent is discharged to local surface water bodies. So, those components that are not removed in simple sewage treatment plants (STP) may reach the aquifer system as well (Philips *et al.,* 2012). This is because, in local STP, micro-pollutants such as medicinal residues, hospital wastes, and other micro-contaminants contained in feces and urine are only partly removed and the remaining dumping into surface water bodies, from it, may also accumulate in the groundwater. In agriculture, sewage sludge and spreading wastewater may also comprise causes of fecal pollution in groundwater.

Agriculture is an influential factor in Bangladesh's gross economy. On a national scale, around 300 kg of chemical manures are consumed per hectare of cultivable land (FAO, 2018), and yearly 37,255 tons of pesticides are used in farmlands (Faruk, 2018). Sulfate, nitrate, phosphate, and some semi-toxic metals can also permit into the groundwater via the overuse of agrochemicals, as well as manure spreading. High application rates of phosphorous and nitrogen-containing fertilizers in the country combined with the rich water-solubility of phosphate and nitrate leads to increase runoff into surface water as well as leakage into groundwater, consequently producing groundwater contamination (Alam, 2006; Jackson *et al.,* 2008). Defective management practices in all types of fertilizer dispersal can introduce both pathogens and nutrients (nitrate/phosphate) into the groundwater system. The excess use of animal fertilizer or compost may also result in groundwater contamination with medicinal residues derived from veterinary drugs (UN-water, 2015). The Government of Bangladesh (GoB), USEPA, and European Commission (EC) also are dealing with the nitrate and phosphate hazard related to agricultural expansion, as a main water supply problem that requires suitable management and governance (DoFE, 2018). Runoff of pesticides, another thoughtful hazard of Bangladesh, may be leaching into groundwater, causing public health problems from contaminated water wells.

Very limited separate studies have been conducted on pesticide accumulation in the groundwater of Bangladesh. After using the pesticides, rain washes the residues to the adjacent water bodies and they become polluted (Kreuger, 1998). Matin *et al.* (1998) collected 144 groundwater samples from around the country and found most of the samples carried 10 to 1000 times higher concentrations of residual pesticide than WHO guideline values. In this study, Dichlorodiphenyltrichloroethane (DDT) values were found ranging from 0.27 to 1.204 mg/L which was very much higher than standard values. They also found Heptachlor residues ranging from 0.025 to 0.789 mg/L. Another investigator (Islam, 2007) collected 48 cultivated field water samples from various areas in the country and found water samples from 10 spots contaminated by DDT, lindane, and heptachlor. Instead, in Dhamrai and Savar Upazila, among the 27 well water samples, Diazinon and Carbofuran were found from Savar at 0.9 mg/L and

198.7 mg/L, respectively. In Dhamrai Upazila, Carbofuran Carbaryl, Malathion, and were found at 105.8 mg/L and 105.2 mg/L, 14.1–18.1 mg/L, separately (Chowdhury, 2012). Chowdhury *et al.* (2012) collected water samples from well, paddy fields, and lakes in Rangpur city and found Chlorpyrifos ranging from 0.554 to 0.895 mg/L, Carbofuran levels from 0.949 to 1.671 mg/L, and Carbaryl was 0.195 mg/L in the lake water. Similarly, they found Carbofuran in 7 samples ranging from 0.934 to 3.395 mg/L, Carbaryl in 2 samples at 0.055 and 0.163 mg/L, Chlorpyrifos in 7 samples ranging from 0.477 to 1.189 mg/L, and in the paddy field water samples.

CONCLUSION

In a densely populated and developing country like Bangladesh, groundwater is the most valued unlimited natural resource for livelihood, and food security; and plays a dynamic role in the development process. The review observed that the water hardness and some trace metal levels of underground drinking water is a key problem in Bangladesh. Among the trace heavy metals, As found in groundwater at an alarming level in the country and now that is a great threat to public health. In some cases, a high level of Ca, Mg, Fe, Cr, Pb, and salinity, especially in the coastal zone, is also worrying. Other metals like Cu, Zn, Co, Cd, and Ni were found below the standard limit in most of the samples. The review demonstrated that groundwater of some areas was found highly polluted with heavy metals and unsafe for domestic and drinking purposes. Besides, except for bicarbonate and chloride in the coastal zone, the anions found in water sources are below the permissible level. In seaside areas, climate change and rising sea levels result in saline water intrusions into shallow aquifers, and in those areas, groundwater is unfit for household uses. The study found that the lack of modern water treatment and supply facilities, quality monitoring, as well as the reluctance of law implementation are the main challenges to safe water supply in the country. Additionally, public awareness and publicity programs towards groundwater contamination are seriously needed to ensure safe water for all.

REFERENCES

Abedin, MA; Jahiruddin, M (2015). Waste generation and management in Bangladesh: An overview. *Asian J. Med. Biol. Res.* 1(1): 114-120.

Afful, SA-A (2010). Spectrum of organochlorine pesticide residues in fish samples from the Densu Basin. *Res. J. Environ. Earth Sci.* 2(3): 133–138.

Ahmed, KM; Imam, MB; Akhter SH; Hasan MA; Khan AA (2001a). Sedimentology and mineralogy of arsenic contaminated aquifers in the Bengal Delta of Bangladesh. Groundwater arsenic contamination in the Bengal Delta Plain of Bangladesh. In: Jacks G, Bhattacharya P, Khan AA, editors Proc. KTH-Dhaka University Seminar, KTHSpecial Publication, TRITA-AMI Report 3084, pp. 97–108.

Ahmed, MJ; Haque, MR; Ahsan, A; Siraj, S; Bhuiyan, MHR; Bhattacharjee, SC; Islam, S (2010). Physicochemical Assessment of Surface and Groundwater Quality of the Greater Chittagong Region of Bangladesh, *Pak. J. Anal. Environ. Chem.* 11(2); 1–11.

Ahmed, ZU; Panaullah, GM; Gauch Jr, H; McCouch, MR; Tyagi, W; Kabir, MS; Duxbury, JM (2011). Genotype and environment effects on rice (Oryza sativa L.) grain arsenic concentration in Bangladesh. *Plant Soil.* 338: 367-382.

Alam, MS; Han, B; Al-Mizan, Pichtel, J (2019). Assessment of soil and groundwater contamination at a former Tannery district in Dhaka, Bangladesh. *Environ. Geochem. Health*. 42: 1905-1920.

Alamgir, M; Ahsan, A (2007). Municipal solid waste and recovery potential: Bangladesh perspective. *Iran j. environ. Health sci. eng.* 4(2): 67-76.

Ali, S; Thakur, SK; Sarkar, A. *et al.* (2016). Worldwide contamination of water by fluoride. *Environ. Chem. Lett*, 14: 291–315.

Aminur, MR; Nahar, K; Al-Reza, SM (2016). Chemical Analysis of Drinking Water Samples of Some Primary Schools from Magura District, Bangladesh. *J. Water Res. & Ocean Scie.* 5(5): 73-77.

Anwar, AHMF; Bari, MF (2004). Prioritizing areas for groundwater monitoring based on pesticide leaching. *J. Appl. Hydro.* 17(1): 43-52.

Askary, VR; Jahan, NA; Sabbagh, A; Jahani, FS; Dourandish, N; Kamachali, AR (2011). A potential medicinal importance of zinc in human health and chronic diseases. *Clin. Biochem.* 44(13): 1-11.

Atikul, MI; Rahman, MR; Bodrud-Doza, M; Muhib, MI (2018). A study of groundwater irrigation water quality in south-central Bangladesh: a geo-statistical model approach using GIS and multivariate statistics. *Acta Geochimica.* 1-22.

BBS (Bangladesh Bureau of Statistics), 2009. Agricultural Statistical Yearbook. Ministry of Planning. Dhaka.

BBS (Bangladesh Bureau of Statistics), 2021. Annual report. Ministry of Planning. Dhaka.

BGS-DPHE (2001). Arsenic contamination of groundwater in Bangladesh. British Geological Survey (BGS) and Department of Public Health Engineering (DPHE), Bangladesh. Rapid Investigation Phase, Vol.1, Final Report.

Bhuiyan, MAH; Bodrud-Doza, M; Islam, ARMT; Rakib, MA; Rahman, MS; Ramanathan, AL (2010). Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods, and multivariate analysis. *Environ. Earth Sci.* 75(1020): 1-23.

Bhuiyan, MAH; Ganyaglo, S; Suzuki, S (2015). Reconnaissance on the suitability of the available water resources for irrigation in Thakurgaon District of northwestern Bangladesh. *Appl. Water Sci.* 5: 229–239.

Bodrud-Doza, M; Islam, ARMT; Ahmed, F; Das, S; Saha, N; Rahman. MS (2016). Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh. *Water Sci.* 30: 19–40.

Bremner, I; Beattie, JH (1990). Metallothionein and the trace minerals. *Annu. Rev. Nutr.* 10(1): 63–83.

Caldwell, DJ; Mastrocco, F; Nowak, E; *et al.* (2010). An assessment of potential exposure and risk from estrogens in drinking water. Environ. *Health Perspect.* 118(3): 343.

CanDNHW (1990). Nutrition recommendations. The report of the Scientific Review Committee, Department of National Health and Welfare (Canada), DSS Cat. no. H49-42/1990E, Ottawa.

Casey, JR (2006). Why bicarbonate? *Biochem Cell Biol.* 84(6): 930–939.

Chien, L; Robertson, H; Gerrard, JW (1968). Infantile gastroenteritis due to water with high sulfate content. *Cana. Medical Assoc. J.* 99: 102–104.

Chowdhury, MA (2012). Organophosphorus and carbamate pesticide residues detected in water samples collected from paddy and vegetable fields of the Savar and Dhamrai Upazilas in Bangladesh. *Int. J. Environ. Res. Public Health.* 9(9): 3318–3329.

de Araújo, KCF; de Barreto, JP; Cardozo, JC; *et al.* (2018). Sulfate pollution: evidence for electrochemical production of persulfate by oxidizing sulfate released by the surfactant sodium dodecyl sulfate. *Environ. Chem. Lett.* 16: 647–652.

DGHS (2016). Health Bulletin-2016. Dhaka: Directorate General of Health Services, Bangladesh.

Dider-Ul, SMI; Bhuiyan, MAH; Rume, T (2017). Hydrogeochemical investigation of groundwater in shallow coastal aquifer of Khulna District, Bangladesh. *Appl. Water Sci.* 7: 4219-4236.

DoFE (2018). Department of Forest and Environment. Ministry of Environment, Bangladesh. Annual Report, 2018.

Dorman, DC (2000). Neurotoxicity of manganese chloride in neonatal and adult CD rats following sub chronic (21- day) high-dose oral exposure. *J. App. Toxicol.* 20: 179–187.

DPHE (2009). Bangladesh national drinking water quality survey. Department of Public Health and Engineering, Govt. of Bangladesh.

Driscoll, T; Steenland, K; Prüss-Üstün, A; Nelson, DI; Leigh, J. In: Annette Prüss-Üstün DC-L (2004). Occupational Carcinogens: Assessing the Environmental Burden of Disease at National and Local Levels. Vol. 6. World Health Organization, Geneva.

Elom, NI; Entwistle, J; Dean, JR (2014). Human health risk from Pb in urban street dust in northern UK cities. *Environ. Chem. Lett*. 12: 209–218.

Fadeeva, VK (1971). Effect of drinking water with different content of chlorides on the organism of experimental animals. *Gigiena i sanitariia.* 36(6): 11-5.

FAO (2018). Fertilizer consumption in Bangladesh, A report.

Faruq, AN (2018). Agriculture and pesticide consumption in Bangladesh (conference paper). Conference on Effluent Control and Waste Disposal in Pesticide Industry – with Especial Agenda on – Integrated Pest Management with Special Emphasis on Bio-pesticide Component," at Bogor, Indonesia.

Flora, G; Gupta, D; Tiwari, A (2012). Toxicity of lead: A review with recent updates. Interdiscip. *Toxicol.* 5(2): 47-58.

Gommers, LM; Hoenderop, JG; Bindels, RJ; de Baaij, JH (2016). Hypomagnesemia in Type 2 Diabetes: A Vicious Circle. *Diadates.* 65(1): 1-13.

Gosselin, RE; Smith, RP; Hodge, HC (1984). Clinical toxicology of commercial products, 5th ed. Baltimore, MD: Williams & Wilkins.

Halim, MA; Majumder, RK; Rasul, G; Hirosiro, Y; Sasaki, K; Shimada, J; Jinno, K (2014). Geochemical evaluation of arsenic and manganese in shallow groundwater and core sediment in Singair Upazila, Central Bangladesh. *Arabian J. Sci. Eng.* 39(7): 5585-5601.

Hasan, MK; Shabbir, A; Jim, KU (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon.* 5: 1-23.

Harris, ZL; Gitlin, JD (1996). Genetic and molecular basis for copper toxicity. *Am. J. Clin. Nutr.* 63: 836–841.

He, FJ; MacGregor, GA (2008). Beneficial effects of potassium on human health. *Physiol. Plant.* 133(4): 725–735.

Heaney, RP; Gallagher, JC; Johnston, CC; Neer, R; Parfitt, AM; Whedon, GD 1982. Calcium nutrition and bone health in the elderly. *Am. J. Clin. Nutr.* 36: 986–1013.

Hossain, MG; Selim. RAHM; Lutfun-Nessa, M; Ahmed, S (2013). Factor and cluster analysis of water quality data of the groundwater wells of Kushtia, Bangladesh: Implication for arsenic enrichment and mobilization. *J. Geologic. Soci. India*. 81: 377-384.

Howladar, MF; Al-Numan, MA; Faruque, MO (2017). An application of Water Quality Index (WQI) and multivariate statistics to evaluate the water quality around Maddhapara Granite Mining Industrial Area Dinajpur, Bangladesh. *Environ. Syst. Res.* 6: 1-13.

IPCS (2002). Principles and methods for the assessment of risk from essential trace elements. World Health Organization, Geneva, International Programme on Chemical Safety (Environmental Health Criteria 228).

Islam, MS; Siddika, A; Khan, MN; Goldar, MM; Sadique, MA; Kabir, AN (2001). Microbiological analysis of tube well water in a rural area of Bangladesh. *Appl. Environ. Microbiol.* 67(7): 3328–3330.

Islam, MN (2007). Monitoring of organochlorine pesticide residues in surface water samples of the agricultural field of Bangladesh. *J. Subtrop. Agric. Res. Dev*. 5(5): 357–360.

Islam, M; Shamsad, S (2009). Assessment of irrigation water quality of Bogra district in Bangladesh. *Bangladesh J. Agri. Res.* 34(4): 507-608.

Islam,SM-U; Majumder, RK; Uddin, MJ; Khalil, MI; Alam, MF (2017a). Hydrochemical characteristics and quality assessment of groundwater in Patuakhali district, southern coastal region of Bangladesh. *Exposure Health* 9(1): 43-60.

Islam, ARM; Shuanghe, S; Bodrud-Doza, M; Atiqur, MR; Samiran, D (2017b). Assessment of trace elements of groundwater and their spatial distribution in Rangpur district, Bangladesh. *Arabian J. Geosciences*. 10(95): 1-14.

Islam, ARM; Nasir, A; Bodrud-Doza, M; Ronghao, C (2017c). Characterizing groundwater quality ranks for drinking purposes in Sylhet district, Bangladesh, using entropy method, spatial autocorrelation index, and geostatistics. *Environ, Sci. Pollut. Res.* 24: 1-25.

Islam, ARM; Shuanghe, S; Muhammed, H; Bodrud-Doza, M; Khin, M; Habib, M (2017d). Assessing groundwater quality and its sustainability in Joypurhat district of Bangladesh using GIS and multivariate statistical approaches. *Environ. Dev. Sustain.* 19: 1-25.

Islam, MS; Majumder SMMH (2020). Alkalinity and Hardness of Natural Waters in Chittagong City of Bangladesh. *Int. J. Sci. Bus.* 4(1): 137-150.

Islam, MS; Mostafa MG (2021a). Groundwater Status and Challenges in Bangladesh. Eric Lichtfouse (Eds.), *Sustainable Agriculture Reviews*, Springer Nature, Switzerland AG. Chapter 4, Volume 52, pp. 79-146.

Islam, MS; Mostafa MG (2021b) Groundwater suitability for irrigated agriculture in Alluvial Bengal delta plain: A review. *Int. J. Adv. App. Sci.* 10(2): 156-170.

Islam, MS; Mostafa MG (2021c). Groundwater Quality and Risk Assessment of Heavy Metal Pollution in Middle-West Part of Bangladesh. *J. Earth & Environ. Sci. Res.* 3(2): 1-9.

Islam, MS; Mostafa MG (2021d). Health risk assessment of trace metals from groundwater in the deltaic plain_of Bangladesh. *Int. J. Water Res. & Environ. Sci*. 10(1): 1-13.

Islam, MS; Mostafa MG (2021e). Meta-analysis and risk assessment of fluoride contamination in groundwater. *Water Environ. Res.* 93(8): 1194–1216.

Islam, MS; Mostafa MG (2021f). Influence of chemical fertilizers on arsenic mobilization in the alluvial Bengal delta plain: a critical review. *Journal of Water Supply: Research and Technology-Aqua.* 70(7): 948–970.

Islam, MS; Mostafa MG (2022a). Evaluation of hydrogeochemical processes in groundwater using geochemical approaches and geostatistical models in the upper Bengal basin. *Geofluid*. 2022: 1-21.

Islam, MS; Mostafa M. G. (2022b). Selection of water quality index models for the evaluation of groundwater quality: A case study in river basin, Kushtia, Bangladesh. *H_2Open.* 5(2): 198-220.

Jackson, LE; Burger, M; Cavagnaro, TR (2008). Roots, Nitrogen Transformations, and Ecosystem Services. *Annual Rev. Plant Bio.* 59(1): 341–363.

Jahan, H. (2016). Arsenic in Bangladesh: How to Protect 20 Million from the World's Largest Poisoning.

Jihen , ElH; Imed, M; Fatima, H; Abdelhamid, K (2008). Protective effects of selenium (Se) and zinc (Zn) on cadmium (Cd) toxicity in the liver and kidney of the rat: Histology and Cd accumulation. *Food Chem. Toxicol.* 46(11): 352.

Knepper, WA (1981). Iron. In: Kirk-Othmer encyclopedia of chemical technology. Vol. 13. New York: Wiley Interscience, pp. 735-753.

Kondakis, XG (1989). Possible health effects of high manganese concentration in drinking water. Archives of Environ. *Health.* 44: 175–178.

Krajnc, EI (1987). Cadmium - Effects. Integrated criteria document, National Institute of Public Health and Environmental Protection, Bilthoven, Report No. 758476004.

Kreuger, J. 1998. Pesticides in stream water within an agricultural catchment in southern Sweden. *Sci. Total Environ.* 216(3): 227–251.

Leeuwen, FX (2000). Safe drinking water: the toxicologist's approach. *Food Chem. Toxicol.* 38: 51–58.

Mahmud, R; Inoue, N; Sen, R (2007). Assessment of irrigation water quality by using principal component analysis in arsenic affected area of Bangladesh. *J. Soil. Nature.* 1(2): 8-17.

Malik, LA; Bashir, A; Qureashi, A; *et al.* (2019). Detection and removal of heavy metal ions: a review. *Environ. Chem. Lett.* 17: 1495–1521.

Manjushree, C; Mostafa, MG; Biswas, TK; Mandal, A; Saha, AK (2015). Characterization of the Effluents from Leather Processing Industries. *Env. Processes*. 2(1): 173-187.

Marcus, AH; Most, BM; Creason, J (1990). Nickel absorption and kinetics in human volunteers. *Proc Soc Exp Bio. Med.* 191(1): 5-11.

Matin, MA; Malek, MA; Amin, MR; Rahman, S; Khatoon, J; Rahman, M; Aminuddin, M; Mian, A (1998). Organochlorine insecticide residues in surface and underground water from different regions of Bangladesh. *Agri. Ecosys. & Environ.* 69(1): 11-15.

McGowan, W (2000). Water processing: residential, commercial, light-industrial. 3rd ed. Lisle, IL, Water Quality Association.

MICS-B (2018). Water quality thematic report: 2012-2013, Multiple Indicator Cluster Survey, UNICEF and BBS, Bangladesh.

Mominul, MI; Karim, MR Zheng, X; Li, X (2018). Heavy Metal and Metalloid Pollution of Soil, Water and Foods in Bangladesh: A Critical Review. *Int. J. Environ. Res. Public Health.* 15(2825): 1-16.

Mondal, NC; Singh, VP; Singh, VS; Saxena, VK (2010). Determining the interaction between groundwater and saline water through groundwater major ions chemistry. *J. Hydrol.* 388: 100-111.

Mostafa, MG; Helal. SMU; Haque, ABMH (2017). Assessment of hydro-geochemistry and groundwater quality of Rajshahi City in Bangladesh. *Appl Water Sci*. 7: 4663–4671.

Moore, MR (1988). Hematological effects of lead. *Sci. Total Environ*. 71: 419-431.

Nahar, MS; Zhang J; Ueda A; Yoshihisa, F (2014). Investigation of severe water problem in urban areas of a developing country: the case of Dhaka, Bangladesh. *Environ. Geochem. & Health*, 36: 1079–1094.

New Nation Report, 11 November, 1996. Immediate Government Steps Needed, Millions Affected by Arsenic Contamination. The New Nation, A daily newspaper of Bangladesh.

Philips, PJ; Chalmers, AT; Gray, JL; Kolphin, DW; Foreman, WT; Wall, GR (2012). Combined sewer overflows: An environmental source of hormones and wastewater micropollutants. *Environ. Sci. Tech.* 46(10): 5336-5343.

Pravina, P; Sayaji, D; Avinash, M (2012). Calcium and its Role in Human Body. *Int. J. Res. Pharma. .Biomed. Sci.* 58: 144.

Rahman, SH (2009). Investigation of Shallow Tube-Well Water Quality Considering the Influence of Nearby Latrines in a Rural Village of Bangladesh. *IAHS pub.* 299–304.

Rahman, MM; Sultana, R., Shammi, M., Bikash, J., Ahmed, T., Maruo, M., Kurasaki, M., Uddin, M.K. 2016. Assessment of the status of groundwater arsenic at Singair Upazilla, Manikganj, Bangladesh; exploring the correlation with other metals and ions. *Expo health*, 8: 217-225.

Rahman, MS; Saha, N; Islam, ARMT; Shen, S; Bodrud-Doza, M (2017a). Evaluation of Water Quality for Sustainable Agriculture in Bangladesh. *Water Air Soil Pollut.* 228(10): 385.

Rahman, MATMT; Saadat, AHM; Islam, MS; Al-Mansur, MA; Ahmed, S (2017b). Groundwater characterization and selection of suitable water type for irrigation in the western region of Bangladesh. *Appl. Water Sci.* **7**: 233–243.

Rasul, T; Jahan, MS (2010). Quality of Ground and Surface Water of Rajshahi City Area for Sustainable Drinking Water Source. *J. Sci. Res*. 2(3): 577-584.

Ravenscroft, P (2007). Predicting the global distribution of natural arsenic contamination of groundwater. Symposium on Arsenic: the geography of a global problem, Royal Geographical Society, London.

Reghunath, R; SreedharaMurthy, TR; Reghavan, BR 92002). The utility of multivariate statistical techniques in hydrogeochemical studies: An example from Karnataka, India. *Water Res.* 36: 2437-2442.

Safiuddin, M (2011). Arsenic contamination of groundwater in Bangladesh: A review. *Int. j. Physic. sci.* 6(30).

Sahu, P; Sikdar, PK (2008). Hadrochemical Framework of the Aquifer in and around East Kolkata Wetlands, West Bengal, India. *Environ. Geo.* 55: 823-835.

Sasikaran S; *et al.* (2012). Physical, chemical and microbial analysis of bottled drinking water. *J. Ceylon Medical* 57(3): 111–116.

Seddique, AA; Ahmed, KM; Shamsudduha, M; Aziz, Z; Hoque, MA (2004). Heavy Metal Pollution in Groundwater in and around Narayanganj Town. Bangladesh. *Bangladesh J. Geo.* 23: 1–12.

Shrivastava, R; Upreti, R; Seth, P; Chaturvedi, U (2002). Effects of chromium on the immune system. *Immunol. Med. Microbiol.* 34(1): 1–7.

Smith, AH; Lingas, EO; Rahman, M (2000) Contamination of drinking-water by arsenic in Bangladesh: A public health emergency. *Bull. World Health Organ.*78 (9): 1093–110.

Soara, A; Perkinsb, GD; Abbasc, G; *et al.* (2010). European Resuscitation Council Guidelines for Resuscitation 2010. Section 8. Cardiac arrest in special circumstances: Electrolyte abnormalities, oisoning, drowning, accidental hypothermia, hyperthermia, asthma, naphylaxis, cardiac surgery, trauma, pregnancy, electrocution. Medicine.

Sunderman, FW Jr; Hopfer SM; Sweeney, KR; Sumon, KA; Rashid, H; Edwin, TH; Peeters, M; Bosma, R (2018). Environmental monitoring and risk assessment of organophosphate pesticides in aquatic ecosystems of north-west Bangladesh. *Chemosphere*, 206: 92-100.

Tanvir, MATBR; Tirkey. P; Bhattacharya, T; Chakraborty, S; Baraik, S (2017). Assessment of groundwater quality and associated health risk: a case study of Ranchi City, Jharkhand, India. *Groundwater Sustain. Dev*. 5: 85-100.

Toyokuni, S (2009). Role of iron in carcinogenesis: cancer as a ferrotoxic disease. *Cancer Sci.* 100(1): 9–16.

Tyagi, S; Sharma, B; Singh, P; Dobhal, R (2013). Water Quality Assessment in Terms of Water Quality Index. *American J. Water Res.* 1(3): 34-38.

UNICEF (2010). Towards an Arsenic Safe Environment in Bangladesh. Executive Summary: World Water Day, 22 March, 2010.

UN-water (2015). Wastewater Management - A UN-Water Analytical Brief.

US-EPA (2003). Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Sulfate.

U.S. Environmental Protection Agency, Office of Water (4304T) Health and Ecological Criteria Division, Washington, DC 20460.

US-EPA (2019). Getting up to Speed: Ground Water Contamination. United State Environmental Protection Agency.

Valenzuela, EF; Menezes, HC; Cardeal, ZL (2020). Passive and grab sampling methods to assess pesticide residues in water. A review. *Environ Chem Lett.* 18: 1019–1048.

WB Group (2019). Multi-Hazard Groundwater Risks to the Drinking Water Supply in Bangladesh. *Water Global Practice.* 8922.

Whelton, A; Dietrich, A; Burlingame, G; Schechs, M; Duncan, S (2007). Minerals in drinking water: impacts on taste and importance to consumer health. *Water Sci. Technol*. 55(5): 283-291.

WHO (1996). Zinc in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality, 2nd ed. Vol. 2. World Health Organization, Geneva (WHO/SDE/WSH/03.04/17).

WHO (2005). Nickel in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality, World Health Organization, WHO/SDE/WSH/05.08/55.

WHO (2006). Section 4: approaches to drinking water source protection management. Protecting groundwater for health: Managing the quality of drinking-water sources. IWA publishing for WHO.

WHO (2009). Potassium in drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality, WHO/HSE/WSH/09.01/7, Geneva, Switzerland.

WHO (2011). Guidelines for Drinking-Water Quality. 4th ed. Geneva: World Health Organization. Winton, EF; Tardiff, RG; McCabe, LJ (1971). Nitrate in drinking water. *Journal AWWA.* 63(2): 95-98.

Zahid, A (2015). Groundwater management aspects in Bangladesh. Technical Report, Center for Water and Environment, Bangladesh Water Development Board.

Zhang, L; Wan, L; Chang, N; Liu, J; Duan, C; Zhou, Q (2011). Removal of phosphate from water by activated carbon fiber loaded with lanthanum oxide. *J. Hazard Mater*. 190(1-3): 848–855.

Zuane, JD (1996). Handbook of Drinking Water Quality. 2nd ed. John Wiley & Sons, New York.