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Iron, manganese, and lead contamination in groundwater of Bangladesh: a review

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ABSTRACT

Groundwater is a vital source of safe drinking water in Bangladesh and most South Asian countries. The study aimed to identify the sources and assess the contamination of Fe, Mn, and Pb in groundwater. The study considered published articles, reports, and data repositories of concerned departments over the past two decades using various search engines, including Web of Science, Scopus, Science Direct, Google Scholar, etc. The study results showed the concentrations of Fe, Mn, and Pb in groundwater exceeded 55.93, 75.44, and 37.50%, respectively, of different standards, including the World Health Organization and United Nations Environmental Protection Agency. The concentrations of Fe, Mn, and Pb ranged from 0.003 to 16.6, 0.00063 to 3.11, and 0.0006 to 5.01 mg/L, respectively, and followed the order Fe > Mn > Pb in the groundwater of Bangladesh. Sources of Fe and Mn in groundwater are mostly geogenic in origin, while Pb contamination in groundwater is anthropogenic and derives from industry dust piles, vehicle exhaust discharge, lead pipes, faucets, fixtures, and batteries. The higher levels of heavy metals in groundwater cause health and environmental hazards. The study recommended that the higher concentrations of Fe, Mn, and Pb in groundwater make it unsuitable for drinking purposes and should be treated before consumption.

Key words: contamination, geogenic, groundwater, iron (Fe), lead (Pb), manganese (Mn)

HIGHLIGHTS

- Higher concentrations of Fe, Mn, and Pb were in groundwater.
- The sources of Fe and Mn in groundwater are mostly geogenic.
- Pb contamination in groundwater was anthropogenic.
- The higher levels of these heavy metals in groundwater concern human health.

INTRODUCTION

Groundwater is the single largest source of drinking water in most of the developing countries, including Bangladesh. It is considered a safer source of drinking water for its excellent microbial and chemical quality, which requires minimal treatment (Helal Uddin *et al.* 2011). A substantial portion of the rural population relies largely on groundwater for domestic and agricultural uses due to its cleanliness. Groundwater ensured 20% of the fresh water (Khanam & Singh 2014) and played a vital role in strengthening the economic growth of developing countries like Bangladesh (Kumar *et al.* 2017a, 2017b). Globally, groundwater sources provide 43 and 40%, respectively, of the total amount of water utilized for drinking and irrigation (Salman *et al.* 2018). It can be noted that metal poisoning (such as Fe, Mn, and Pb) in groundwater frequently goes undetected and stays out of sight of the general public. If their levels are within the defined range as advised by the World Health Organization (WHO 2004), some metals (such as Fe, Mn, and Pb) found in groundwater play significant roles in water pollution (Buragohain *et al.* 2010; Hossen & Mostafa 2023).

Iron (Fe) and manganese (Mn) are essential nutrients for humans, but lead (Pb) is a poisonous element (heavy metal) that is classified as a priority pollutant by the United Nations Environmental Protection Agency (USEPA). Pb has no essential function for the human body. The main sources of Fe and Mn are soils, clay layers near the aquifer, and human activity (Islam & Mostafa 2023). Fe and Mn are found naturally in groundwater, rocks, minerals, and soil. They are released into groundwater through various dissolution processes and are present in several oxidation states, including Fe-II and III and Mn-II and IV (Zhang *et al.* 2018; Islam & Mostafa 2022a). Fe and Mn coexist in groundwater naturally due to their common chemical characteristics, including similar valence charges in physiological conditions, ionic radius, and absorption mechanisms for individuals (Hem 1972; Davidson 1993). According to the national hydro-chemical survey (BGS and DPHE 2001), about 42% of tube wells have Mn concentrations exceeding permissible limits. The groundwater of central, northern, and western Bangladesh is highly Mn-contaminated, but eastern Bangladesh is comparatively less Mn-contaminated (Hasan & Ali 2010). Pb is addressed as a normal constituent of the earth's crust, and it is found in two oxidation states, 2 and 4. It exists in water as Pb^{2+}, $PbOH^{+}$, and $PbHCO_3^{+}$ at a normal pH (Raviraja *et al.* 2008). The lead-acid battery industry and vehicle exhaust discharge lead to metal contamination in groundwater. Lead pipes, faucets, and fixtures are the most frequent causes of lead contamination in drinking water (USEPA 2022).

Excessive levels of Fe cause diabetes, anemia, hemochromatosis, lung embolism, and heart disease, while Mn creates Parkinson's disease, hallucinations, memory impairment, disorientation, and emotional instability (Butterworth 2010; Bouchard *et al.* 2011). A trace amount of Pb exposed to humans is more poisonous than other heavy metal contamination, and exposure to high levels of lead may cause anemia, weakness, and damage to the kidney, DNA, brain, and a developing baby's nervous system (Hashim *et al.* 2011; Islam & Mostafa 2021a). The consumption of Pb over the permissible limit is carcinogenic for humans. Children are more vulnerable than adults to exposure to Pb impacts for the long-term and even the short-term (Agrawal *et al.* 2021). Lead also causes long-term harm in adults, including an increased risk of high blood pressure (Saha 2011; Majumder *et al.* 2021).

To the best of our knowledge, only a small number of review articles have been published on surface water and surface plus groundwater in Bangladesh (Arefin & Mallik 2018; Hasan *et al.* 2019; Sarkar *et al.* 2019). Others, however, have studied groundwater while focusing solely on arsenic (Hossain 2006; Safiuddin *et al.* 2011; Raessler 2018) and groundwater pollution in Bangladesh (Ganguli *et al.* 2021). Thus, this review presents the scenario of Fe, Mn, and Pb contamination in groundwater in Bangladesh for the first time. The study aimed to understand the scenario of Fe, Mn, and Pb contamination in groundwater and their impacts on human health. This review explored the sources of Fe, Mn, and Pb contamination in the groundwater of Bangladesh and evaluated the deleterious effects of these metals on humans.

METHODS AND MATERIALS

The review collected data from different published articles and reports for the last 22 years (2000 to date) using different search engines, including Google Scholar, Scopus, Web of Science, PubMed, and other databases. To search for relevant research articles, the study used the following terms via the Boolean operators 'and' and 'or': (a) groundwater status of Bangladesh; (b) heavy metal contamination in groundwater; (c) health effect of heavy metal contamination in groundwater; (d) Fe, Mn, and Pb contamination of groundwater; (e) source of heavy metals in groundwater; (f) groundwater status in different countries. At first, over 300 published papers, articles, book chapters, and reports were selected. Then, 150 papers on heavy metals in groundwater were sorted out. Finally, 36 papers were selected for their relevance. Data on Fe, Mn, and Pb concentrations in groundwater from different areas of Bangladesh and other countries were collected and assessed for pollution levels in groundwater.

Drinking water standards

The national and international organizations Bangladesh Drinking Water Standard (BDWS), World Health Organization (WHO), United Nations Environmental Protection Agency (USEPA), European Union (EU), Indian, New Zealand, Australian, and Iranian standards fixed permissible limits of Fe, Mn, and Pb concentrations in groundwater for drinking purposes (Table 1).

Table 1 | Permissible standard of Fe, Mn, and Pb concentrations in groundwater

	Drinking water quality standard (mg/L)							
Metals	**BDWS (2019)**	**WHO (2011)**	**USEPA (2019)**	**EU (1998)**	**IS10500 (2012)**	**New Zealand (2008)**	**Australia (1996)**	**Iran (1997)**
Fe	0.3–1.0	0.3	0.3	0.2	0.3	0.2	0.3	1.0
Mn	0.1	0.1	0.05	0.05	0.1	0.4	0.5	0.5
Pb	0.05	0.01	0.015	0.01	0.05	0.01	0.01	0.01

Notes: BDWS, Bangladesh drinking water standard; Department of Public Health and Engineering, Bangladesh (2019); WHO, World Health Organization Drinking water standard, 4th ed. (2011); USEPA Drinking water standard 2018 and amendment 2019; ISI, Indian Standard Institution, Drinking water standard for India (IS10500 2012).

Table 1 shows that permissible limits of Fe, Mn, and Pb are not the same. Different organizations fix the different concentrations for the same element as standard permissible limits, for example, the concentration of Fe is set lower in the EU (1998) and New Zealand (2008) standards (0.2 mg/L), but the others show permissible limits between 0.3 and 1 mg/L. In the case of Mn, the concentration was set lower in the USEPA (2019) (0.05 mg/L) than that of the other permissible limits. The higher permissible limit for Mn is provided by the Australian (1996) and Iranian (1997) standards. From the perspective of Pb, most of the standard limits showed 0.01 mg/L, except for the USEPA (0.015 mg/L), BDWS (0.05 mg/L), and IS1-0500.

Concentration of Fe, Mg, and Pb in groundwater of Bangladesh

Bangladesh lies in the Ganges–Brahmaputra–Megna delta and is mainly divided into four regions (Figure 1), which are eastern (Chittagong and Sylhet division), southern (southern part of Dhaka, Barisal, and Khulna division), central (Dhaka and Mymensingh division), and northern (Rajshahi and Rangpur division) Bangladesh (Khan 1999). This study showed Fe, Mn, and Pb concentrations in groundwater in Bangladesh in Tables 2–5.

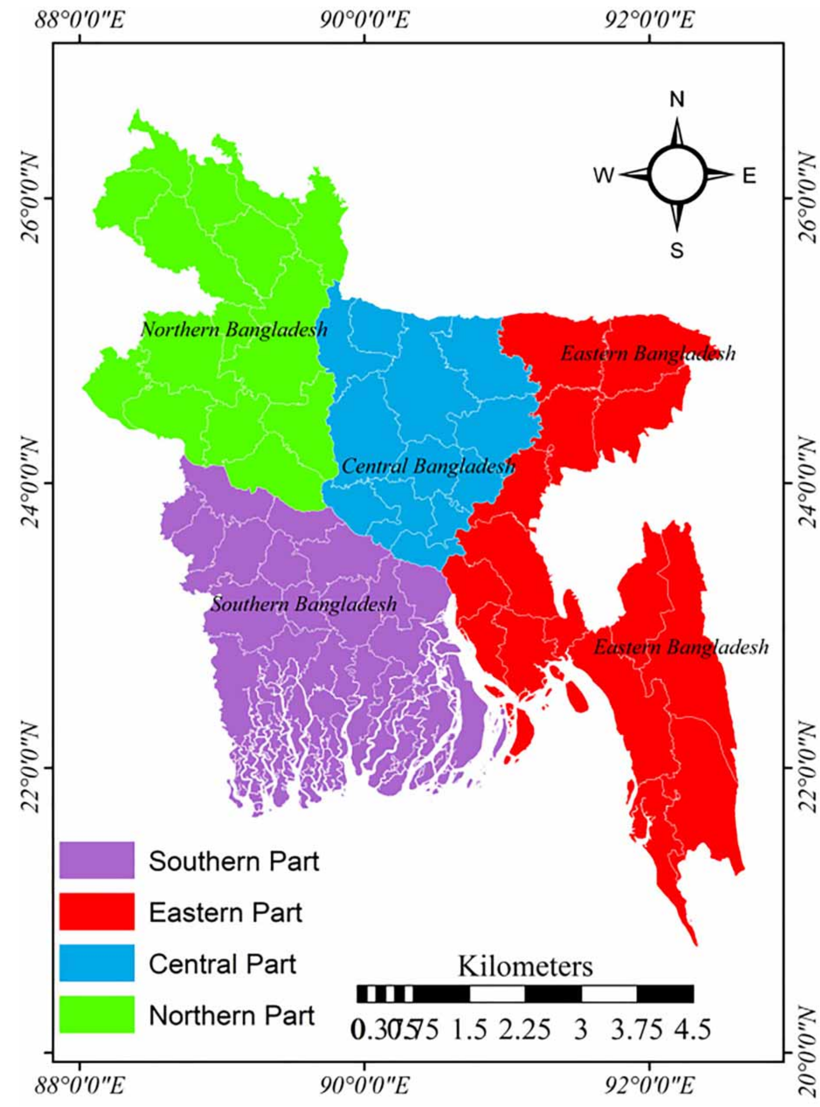

Figure 1 | Bangladesh map shows four regions.

The study showed the highest Fe concentration was in Sylhet (6.832 mg/L) in eastern Bangladesh (Table 2). The Fe concentrations of Bandarban, Moulvibazar, Khagrachhari, Lahshmipur, and Cox's Bazar were 5.21, 5.0, 4.28, 3.235, and 2.80 mg/L, which were considerably higher than the other parts of the region. All the concentrations of Fe in groundwater exceeded (12 out of 16) all permissible limits stated in Table 1, except Noakhali

Table 2 | Average concentrations of Fe, Mn, and Pb in groundwater in eastern Bangladesh

	Metals' concentration (mg/L)			
Area/district	**Fe**	**Mn**	**Pb**	**Reference**
Malnicherra Tea Garden, Sylhet	0.075	0.007	–	Islam *et al.* (2018a)
Sylhet	6.832	0.281	–	Islam *et al.* (2017a)
Sylhet	5.91	0.30	Nd	Ahmed *et al.* (2019)
Sunamganj	0.0043	0.14	–	Chowdhury *et al.* (2012)
Moulvibazar	5.0	0.4	–	Akter *et al.* (2016)
Cox's Bazar	2.80	0.52	0.045	Ahmed *et al.* (2010a)
Chottogram	1.67	0.19	0.049	Ahmed *et al.* (2010a)
Khagrachhari	4.28	0.61	0.050	Ahmed *et al.* (2010a)
Rangamati	0.41	0.11	0.053	Ahmed *et al.* (2010a)
Bandarban	5.21	1.27	0.047	Ahmed *et al.* (2010a)
Lahshmipur	3.235	0.652	0.003	Bhuiyan *et al.* (2016)
Comilla	0.05–7.83	Bdl-3.94	0.01–0.08	Ahmed *et al.* (2010b)
Chandpur	Bdl-8.86	Bdl-0.38	0.05–0.07	Ahmed *et al.* (2010b)
Brahmanbaria	0.10–6.96	Bdl-1.63	0.04–0.07	Ahmed *et al.* (2010b)
Noakhali	0.003	0.0139	–	Rahman *et al.* (2015)
Teknaf, Cox's Bazar	1.254	0.226	0.004	Deeba *et al.* (2021)

Table 3 | Average concentrations of Fe, Mn, and Pb in groundwater in southern Bangladesh

	Metals' concentration(mg/L)			
Area/district	**Fe**	**Mn**	**Pb**	**Reference**
Faridpur District	5.9516	0.00063	0.0006	Bodrud-Doza *et al.* (2016)
Gopalganj District	5.13	0.201	–	Atikul *et al.* (2018)
Khulna	1.12	0.33[a]	–	Adhikary *et al.* (2012), Rahman *et al.* (2021)
Magura	2.148	0.144	–	Rahman *et al.* (2016a, 2016b)
Chuadanga	1.3	0.28		Bodrud-Doza *et al.* (2019a)
Satkhira	4.9	0.14[a]	0.034	Rakib *et al.* (2020)
Jashore	1.400	0.470	–	Ghosh *et al.* (2020)
Jhikargachha, Jashore	0.03	0.02	–	Chakraborty *et al.* (2022)
Kushtia	5.072	1.614	0.043	Islam & Mostafa (2021a)
Khulna City Corporation	0.3551	0.1029	–	Dhar *et al.* (2021)
Ganges River Basin, Kushtia	8.11	3.11	0.07	Islam & Mostafa (2021b)
Barishal Municipality Area	0.70	0.980	–	Islam *et al.* (2018a)
Pirojpur	–	–	0.001	Amin & Hasan (2011)
Patuakhali	–	0.004	Nd	Islam *et al.* (2017b)
Barguna and Patuakhali	5.84	0.66	–	Islam *et al.* (2017c)

[a]Rahman *et al.* (2021).

(0.003 mg/L), Malnicherra Tea garden area (0.075 mg/L), Rangamati (0.4 mg/L), and Sunamganj (0.0043 mg/L). The highest concentration of Mn was in Bandarban (1.27 mg/L). Except for Noakhali (0.0139 mg/L) and Malnicherra tea garden area (007 mg/L), all the Mn concentrations in Eastern Bangladesh exceeded (14 out of 16) the permissible limits of BWDS, WHO, USEPA, EU, and Indian standards. Table 2 shows that the highest concentration of Pb was in Rangamati (0.053 mg/L) and except Lahshmipur (0.003 mg/L), Teknaf, and Cox's Bazar (0.004 mg/L), all the concentrations of Pb exceeded the permissible limits of WHO, USEPA, EU, New Zealand,

Table 4 | Average concentrations of Fe, Mn, and Pb in groundwater in Central Bangladesh

Area/District	Metals' concentration(mg/L) Fe	Mn	Pb	Reference
Dhaka metropolitan city	0.0896	0.0588	0.0496	Sharmin *et al.* (2020)
Dhaka District (groundwater supply)	4.10	0.238	–	Nahar *et al.* (2014)
Manikganj District	0.81	0.455	–	Rahman *et al.* (2016a, 2016b)
Singair, Manikganj	7.11	2.08	0.019	Halim *et al.* (2014)
Narayanganj Town	–	0.8895	0.2285	Seddique *et al.* (2004)
Meghnaghat industrial area, Narayanganj	–	–	0.182	Mirza *et al.* (2020)
Tongi municipality, Gazipur	0.08	0.29	Bdl	Bakali *et al.* (2014)
Municipal areas, Tangail	0.255	–	0.307	Sultana *et al.* (2013)
Munshiganj	2.122	0.421	–	Halim *et al.* (2009)
BSIC, Mymensingh City	0.81	Bdl		Islam *et al.* (2018a)
Sadar Upazila, Jamalpur	0.363	1.075	0.016	Zakir *et al.* (2020)
Sherpur	0.29	0.29	–	Rahman *et al.* (2005)
Netrokona	1.1	0.3		Akter *et al.* (2016)

Table 5 | Average concentrations of Fe, Mn, and Pb in groundwater of Northern Bangladesh

Area/district	Metals concentration (mg/L) Fe	Mn	Pb	Reference
Rajshahi City	3.1	1.47	1.167	Mostafa *et al.* (2017)
Rajshahi City	3.4	–	1.63	Helal Uddin *et al.* (2011)
RNPP Area, Pabna	0.21701	0.00101	0.007	Uddin *et al.* (2017)
Bogra	0.045	–	–	Saha & Ali (2007)
Naogaon	0.28	0.17	–	Rahman *et al.* (2005)
Sirajganj	5.29	1.58	–	Uddin *et al.* (2019)
Chapai Nawabganj	0.18[a]	1.44	0.096	Shaha & Zaman (2011), Islam *et al.* (2017d)
Lalpur Upazila, Natore District	0.21–2.45	0.25–3.41	–	Ahmmed & Khandoker (2019)
Joypurhat district	0.793	–	–	Islam *et al.* (2018b)
Three Upazilas of Joypurhat District	0.42	Bdl	5.01	Kumar *et al.* (2017a, 2017b)
Western Bangladesh	2.700	0.800	0.005	Seth *et al.* (2009)
Rangpur City Corporation	0.35	0.080	–	Islam *et al.* (2018a)
Rangpur	0.38	0.67	Bdl	Yesmeen *et al.* (2018)
Dinajpur	0.15	0.13	Nd	Islam *et al.* (2016)
Setabganj Municipality, Dinajpur District	0.3452	0.406	–	Hossain *et al.* (2020)
Thakurgaon	0.49	0.2	–	Bhuiyan *et al.* (2015)
Gaibandha	0.51	0.15	–	Rahman *et al.* (2005)
Panchagarh	0.017	0.008	–	Saha *et al.* (2017)
Kurigram	16.6	1.69	–	Moni *et al.* (2019)

[a]Islam *et al.* (2017d).

Australian, and Iranian standards, but 7 out of 11 were below the Indian and BDWS standard limits. The main causes of Fe and Mn contamination in groundwater were geogenic, but Pb contamination in groundwater was anthropogenic (Hasan *et al.* 2018; Shakil *et al.* 2020; Islam & Mostafa 2022b). The analysis results showed that the Fe, Mn, and Pb concentrations exceeded the permissible limits by 75.0% (all permissible limits), 87.5% (permissible limits of BWDS, WHO, USEPA, EU, and Indian standards), and 36.36% (all permissible limits), respectively (not shown in the Table). The average concentrations of Fe, Mn, and Pb in eastern Bangladesh are in the following order: Fe (6.832 mg/L) > Mn (1.27 mg/L) > Pb (0.053 mg/L) in Sylhet, Bandarban, and Rangamati, respectively (Table 2).

Southern Bangladesh includes the southern part of the Dhaka division and the Khulna and Barisal divisions. The highest concentrations of Fe, Mn, and Pb in groundwater were 8.11, 3.11, and 0.07 mg/L, respectively, in the Ganges River basin in the Kushtia district of Bangladesh, which were far above the permissible limits of the WHO and other standards (Table 3). The concentrations of Fe in groundwater in Faridpur (5.9516 mg/L), Gopalganj (5.13 mg/L), Barguna-Patuakhali (5.84 mg/L), Kushtia (5.072 mg/L), and Satkhira (4.9 mg/L) were much higher than all-standard (0.3–1.0 mg/L) limits. Except Jhikargachha, Jashore (0.03 mg/L), and Barishal Municipality Area (0.70 mg/L), all the concentrations of Fe exceeded (11 out of 13) all permissible limits. The study observed a relationship among these heavy metals, i.e., whenever the Fe concentration was higher, the other two metals were also higher in concentration. The highest concentration of Mn was found in the Ganges River basin in the Kushtia district (3.11 mg/L), but all the concentrations of Mn exceeded (11 out of 14) the permissible limits (BDWS, WHO, USEPA, EU, and Indian standards) except for the Faridpur District (0.00063 mg/L), Jhikargachha, Jashore (.02 mg/L), and Patuakhali (0.004 mg/L). The highest concentration of Pb (0.07 mg/L) was in Ganges Basin Areas, Kushtia, but all concentrations of Pb were below the permissible limits. The analysis results show that the Fe and Pb concentrations exceeded all permissible limits of 84.61% and 16.66%, respectively, but Mn concentrations exceeded BDWS, WHO, USEPA, EU, and Indian standards limits of 78.57%.

Central Bangladesh consists of Mymensingh and the northern part of Dhaka division. In central Bangladesh (Table 4), the Fe, Mn, and Pb concentrations in 13 different cities and towns were obtained from 13 published articles. The average concentrations of Fe, Mn, and Pb in different cities and towns were in descending order: Singair, Manikganj (Fe 7.11 mg/L) > Singair, Manikganj (Mn 2.08 mg/L) > Municipal areas, Tangail (Pb 0.307 mg/L), where the Fe and Mn concentrations were high. The review work showed that the highest average concentrations of Fe and Mn were 7.11 and 2.08 mg/L, respectively, in Singair Upazila and Manikganj in central Bangladesh, whereas the BDWS permissible limits of Fe and Mn were 0.3–1.0 and 0.1 mg/L, respectively. The Fe concentrations in Dhaka (4.10 mg/L) and Munshiganj (2.122 mg/L) were higher than the permissible limits. In Table 4, the concentration of Fe (4 out of 11) exceeded all permissible limits. Except Dhaka Metropolitan city (0.0588 mg/L) and Mymensingh city (below detection level), all the Mn concentrations in Table 4 exceeded (9 out of 11) the national (BDWS) and international permissible limits (WHO, USEPA, EU, and Indian standard). The highest concentration of Pb was 0.307 mg/L in Tangail. The Pb concentrations in Narayanganj Town and Narayanganj District were 0.22285 and 0.182 mg/L, respectively, which were higher than the permissible limits. In central Bangladesh, the concentrations of Pb in three out of seven samples exceeded all permissible limits. In Table 4, all concentrations of Fe and Pb were higher than all-standard limits except for Tangail (Fe: 0.225 mg/L), Dhaka metro (Fe: 0.0896 mg/L), Gazipur (Fe: 0.08 mg/L), Sherpur (Fe: 0.29 mg/L), and Gazipur (Pb: 0.0006 mg/L). The analysis results show that the Fe and Pb concentrations exceeded all permissible limits by 36.36 and 42.85%, respectively, but the Mn concentrations exceeded permissible limits (BDWS, WHO, USEPA, EU, and Indian standards) by 81.81%.

Rajshahi and Rangpur divisions are known as northern Bangladesh. In northern Bangladesh (Table 5), the average concentrations of Fe, Mn, and Pb were in the following order: Fe (16.6 mg/L) > Mn (1.69 mg/L) > Pb (Kumar *et al.* 2017a, 2017b) (Table 5). The minimum average concentration of Fe was in Bogra (0.04 mg/L), and the maximum was in Kurigram (16.6 mg/L). The Fe concentrations of Rajshahi city (5.486 mg/L) and Sirajganj (5.29 mg/L) were much higher than the all-standard limits. The concentrations of Fe in 6 out of 19 samples exceeded the all-standard limits, but Chapai Nawabganj (0.18 mg/L), Nagoan (0.28 mg/L), Bogra (0.045 mg/L), Rooppur Nuclear Power Plant (RNPP) area, Pabna (0.217 mg/L), Dinajpur (0.15 mg/L), and Panchagarh (0.017 mg/L) exceeded all-standard limits except BDWS limit. Table 5 shows that the highest concentration of Mn was in Kurigram (1.69 mg/L). All concentrations of Mn exceeded (9 out of 11) permissible standard limits (BDWS, WHO, USEPA, EU, and Indian standards) except for the RNPP area, Pabna (Mn 0.00101 mg/L), and Panchagarh (Mn 0.008 mg/L). The highest concentration of Pb was in Joypurhat (5.01 mg/L). All concentrations of Pb were above (four out of eight) all permissible standard limits except for the RNPP area of Pabna (0.007 mg/L). The results showed that the Fe and Pb concentrations exceeded the all-standard limits of 31.58 and 50%, respectively, but Mn concentrations of 56.25% samples exceeded the standard limits of BDWS, WHO, USEPA, EU, and Indian standards.

The distribution of Fe, Mn, and Pb concentrations in groundwater in Bangladesh showed a wide range of variations. Tables 2–5 showed that highest concentrations of Fe, Mn, and Pb in Bangladesh were found to be 16.6, 3.11, and 5.01 mg/L in Kurigram, the Ganges River basin in Kushtia, and Joypurhat districts, respectively. The study showed that the Fe and Pb concentrations exceeded all permissible limits by 55.93% (33 out of 59) and 37.50% (12 out of 32), respectively, but the Mn exceeded permissible limits of BDWS, WHO, USEPA, EU, and Indian standards limits by 75.44% (43 out of 57) (not shown in the tables). The concentrations of Fe, Mn, and Pb were found to be higher in southern and central Bangladesh, but northern and eastern Bangladesh had relatively lower concentrations (BGS and DPHE 2001; Hasan & Ali 2010). In deep tub wells (>150 m depth), the water contains a relatively lower concentration of manganese than that of shallow tube wells (BGS and DPHE 2001; Hasan & Ali 2010). Several reports showed that Mn absorbed Fe oxide and other minerals. The reducing processes of Fe (III) mobilize Fe and release and absorb Mn (McMahon *et al.* 2018). Iron-bearing rocks like Fe oxides or hydroxides, magnetite, hematite, pyrite, siderite, and limonite may dissolve and release iron into the aquifer water and are the main source of Fe (Islam & Mostafa 2023). Mn-bearing minerals like rhodochrosite, rhodonite, braunite, pyrochroite, and manganite release Mn into aquifer water, but Pb is continuously released into the groundwater in large amounts by anthropogenic activities (Keen & Zidenberg 2003; Das *et al.* 2007; Groschen *et al.* 2009; Hasan *et al.* 2018; Islam & Mostafa 2022c; Ren *et al.* 2022).

The concentration of Fe^{2+} in an aqueous medium rises as a result of the weathering of those minerals in the presence of organic matter, dissolved O_2 and CO_2, and nitrate or sulfate at a specific pH (Marion *et al.* 2008; Islam & Mostafa 2023). By establishing an equilibrium condition, the microbial oxidation of released Fe^{2+} can change it into Fe^{3+} and reduce the anions (Rott & Lamberth 1993; Islam & Mostafa 2023).

In central Bangladesh, the average Pb concentration was high. The most frequent natural sources of Fe and Mn in groundwater include the weathering of rocks and minerals that contain these elements (Islam & Mostafa 2021c). Fe and Mn may also be introduced to the local groundwater through industrial effluent, acid mine drainage, sewage, and landfill leachate (Islam *et al.* 2023). Pb can be released into groundwater from geogenic and anthropogenic sources. Pb can leach into groundwater from industrial activities, plumbing fixtures or well components, certain solders used to connect pipes and joints, mining, gasoline, coal, and as a water additive.

Compare the Fe, Mn, and Pb concentration in groundwater with different countries

In Table 6, Fe concentrations in most groundwater in different countries exceeded permissible limits for different standards. The highest concentration of Fe was found in the Ha Nam province, Vietnam (26.475 mg/L), and the lowest Fe concentrations were found in some parts of African countries, i.e., Algeria, Ethiopia, and Nigeria. In Bangladesh, the average Fe concentration was found to be 3.2 mg/L; in some selected areas, it was about 5.68 mg/L, and it varied from 0.08 to 3.6 mg/L in different states of India. This study observed that Fe concentrations in groundwater in different countries were found to be higher than the standard limits, causing severe health hazards. The highest concentration of Mn was in the El-Dakhla Basin, Egypt; Fe (2.18 mg/L); and Andhra Pradesh (2.17 mg/L), but the highest concentration of Pb was found in Lagos State, Nigeria (2.4 mg/L). The quality of groundwater is affected by several natural or geogenic processes, including evaporation, mineral dissolution, secondary mineral precipitation, cation and anion exchange, redox reactions, microbial processes, erosion, ore formation, weathering of rocks, and mixing of waters (Wu *et al.* 2016; Bodrud-Doza *et al.* 2019a, 2019b).

To compare Fe, Mn, and Pb concentrations in Bangladesh and other Asian and African countries, diverse geological, industrial, and environmental factors should be considered. Elevated Fe and Mn concentrations in groundwater sources have been observed in some regions due to geogenic factors, but they are not exclusive to Bangladesh and can be found in various parts of the world. Regions with geological conditions conducive to high Fe and Mn levels might experience similar challenges, but concentrations can vary across different areas. Anthropogenic activities and industrial pollution can contribute to Pb contamination in the groundwater of Bangladesh, and other Asian and African countries. Rapid industrialization and urbanization can lead to Pb contamination in water sources. Similar challenges might be faced by countries undergoing industrial development, urbanization, and mining activities.

Many Asian and African countries are facing tremendous challenges due to industrialization, urbanization, and groundwater contamination. Geologically similar regions might face comparable issues regarding elevated Fe, Mn, and Pb concentrations. The specific sources of contamination, industrial activities, and regulatory frameworks can vary significantly among countries. Different countries have different levels of infrastructure and

Table 6 | Concentrations of Fe, Mn, and Pb in groundwater of different countries

	Metals' concentration(mg/L)			
Area/country	**Fe**	**Mn**	**Pb**	**Reference**
Bangladesh	3.2	0.580	–	BGS and DPHE (2001), Hoque *et al.* (2014)
24 selected districts, Bangladesh	1.43	1.69	0.011	Tahera *et al.* (2016)
Selected 13 zones of Bangladesh	5.68	1.70	–	Islam *et al.* (2014)
Terminal of the Xiangjiang River, China	0.580	0.379	0.773	Huang *et al.* (2015)
Southeast Suzhou City, China	0.922	0.266	0.00047	Wang *et al.* (2022)
Myingyan Township, Myanmar	0.940	0.342	<1	Bacquart *et al.* (2015)
Industrial hub of Unnao, India	0.551	0.622	0.432	Dwivedi & Vankar (2014)
Cambodia	1.392	0.2904	0.0064	Peter *et al.* (2017)
Ha Nam province, Vietnam	26.475	0.675	<0.001	Nguyen *et al.* (2009)
Vehari, Pakistan	1.62	0.82	0.1475	Khalid *et al.* (2020)
Muzaffarabad, Azad Jammu and Kashmir, Pakistan	0.2791	0.0684	0.1612	Ali *et al.* (2019)
Balat-Teneida area, El-Dakhla Basin, Egypt	10.6	2.18	–	Khozyem *et al.* (2019)
Punjab, India	0.199	0.661	0.087	Vig *et al.* (2022)
Southeast Iran	0.084	0.010	0.009	Hadi *et al.* (2022)
Potable Water Sources, Nigeria	0.00–43.09	0.00–30.0	0.00–33.50	Izah *et al.* (2016)
West Tripura, northeast India	1.36	0.10	0.02	Brindha *et al.* (2020)
Barpeta, Assam, India	3.696	0.749	0.00285	Jain *et al.* (2018)
Cauvery river basin, Tamil Nadu, India	0.08	0.31	0.38	Vetrimurugan *et al.* (2017)
Barpeta, Assam, India	0.66770	0.27960	0.00963	Nabanita & Sarma (2012)
South of Setif, East Algeria	0.055	–	0.017	Lazhari *et al.* (2018)
Jimma Town, Southwest Ethiopia	0.03–0.95	0.00–0.55	0.0174–0.183	Abraham *et al.* (2021)
Lagos State, Nigeria.	4.23	–	2.4	Oyeku & Eludoyin (2010)
Ranga Reddy, Andhra Pradesh, India	1.186	2.171	0.0447	Purushotham *et al.* (2013)

resources for monitoring and addressing these issues. It is essential to consider each country's unique context. While some similarities might exist, the severity of contamination, affected regions, and regulatory responses can differ widely. Concerning Mn and Pb concentrations, most of the groundwater was found to be contaminated with these heavy metals, which threatened human health. Groundwater contamination sources are geological as well as anthropogenic in many parts of the world (Islam & Mostafa 2021a).

Effect of Fe, Mn, and Pb on human health

The Fe concentrations in groundwater varied remarkably among the collected data from several published articles. The Fe, Mn, and Pb concentration ranges are 16.6 mg/L (Kurigram) to 0.003 mg/L (Noakhali), 0.00063 mg/L (Faridpur District) to 3.11 mg/L (Ganges Basin Areas, Kushtia District), and 0.0006 mg/L (Faridpur District) to 5.01 mg/L (Joypurhat), respectively (Tables 2–5). Higher concentrations of Fe, Mn, and Pb in drinking water pose a severe threat to human health (Table 7).

Elevated Fe and Mn in drinking water are the causes of chronic intoxication, lung embolism, bronchitis, impotence, nerve damage, and Parkinsonism (Adeyeye *et al.* 2020; Islam & Mostafa 2021b). Excessive levels of Fe and Mn can damage skin cells, causing infections and wrinkles. In addition, such water does not remove the soap residue from the body, resulting in clogged skin pores and an oil accumulation that causes a variety of skin issues, including eczema or acne. In addition, high Fe in water content leads to an overload, which can cause diabetes, hemochromatosis, stomach problems, and nausea. It can also damage the liver, pancreas, and heart. Pb in water occurs only in trace levels but is more toxic to the human body. There is no safe level of Pb in drinking

Table 7 | Impact of Fe, Mn, and Pb contaminated drinking water on human health

Metals	Impact on Humans	Reference
Iron (Fe)	Create Genetic and metabolic diseases, persistent intoxication, lung embolism, bronchitis, impotence, parkinsonism, damage nerve and development of a benign pneumoconiosis, called siderosis.	Fraga & Oteiza (2002), Muhammad *et al.* (2014), Adeyeye *et al.* (2020); Adegbola & Adewoye (2012).
Manganese (Mn)	Neurological disorder, adverse effects on nervous system, behavioral changes, lethargy, weakness, destroy cardiovascular system, damage sperm, loss of sex drive, pneumonia.	SON (2007), Jessica *et al.* (2020), Azab *et al.* (2010), Nwaichi & James (2012).
Lead (Pb)	Damage central nervous system, liver, DNA, reproductive system, hematological system, brain, kidneys. It impairs hemoglobin synthesis, renal function, deafness, blindness, retardation, decrease libido, fatigue, change the genetic code, miscarriage in women and death, causes rheumatoid arthritis, irreversibly decrease IQ, energy level, neurobehavioral problems like impulsivity, distractibility, and short attention span, headaches, nausea, vomiting, increase blood pressure, anemia, changes blood composition and reduce energy level.	Sankhla & Kumar (2019), Majumder *et al.* (2021), Bhuyan & Islam (2017), Idris *et al.* (2013), Nwaichi & James (2012), Fu & Wang (2011), Dabai *et al.* (2013), Muhammad *et al.* (2014), Vivien *et al.* (2012), Henson & Chedrese (2004), Jessica *et al.* (2020)

water. However, national and international organizations fix the Pb level in drinking water close to zero. Even at modest exposure levels, lead showed negative impacts on a child's neurodevelopment. The studies on the population and toxicokinetic modeling revealed a direct correlation between lead levels in children's blood and drinking water (Levallois *et al.* 2018).

Challenges for mitigating of heavy metals contamination

The contaminations of Fe and Pb in the groundwater were found to be comparatively higher in northern Bangladesh and that of Mn was in southern Bangladesh (Table 8). The higher concentrations of these heavy metals enter the aquifers through leaching and percolation of rainwater, i.e., geogenic processes, but in some cases, anthropogenic activities also influence the higher concentrations. Fe and Mn are naturally present in aquifer soils in certain geological formations and released into groundwater through weathering processes (Islam & Mostafa 2022a), which are considered major challenges to mitigating the crisis. However, some industrial activities, such as mining operations, metal manufacturing, and the iron and steel production industries, contribute to elevated levels of Fe and Mn in groundwater. The large amounts of Pb released into groundwater are mainly due to anthropogenic activities (Islam & Mostafa 2021a, 2021b). Lead pipe and plumbing systems also release Pb into groundwater. Most geogenic sources of heavy metal contamination in groundwater are difficult to understand due to several factors that influence the geochemistry of the area. The study observed that the contamination of groundwater with Fe, Mn, and Pb is a vital issue for ensuring safe drinking water in lower- to middle-income countries like Bangladesh, India, and other countries. However, immediate steps, including water quality monitoring, public awareness programs, reducing the use of chemical fertilizers, and the mandatory installation of effluent treatment plants, should be taken to reduce groundwater contamination in the areas.

Table 8 | The range of concentrations of Fe, Mn, and Pb in groundwater in different parts of Bangladesh

	Concentration range (mg/L)			
Metals	Eastern Bangladesh	Central Bangladesh	Southern Bangladesh	Northern Bangladesh
Fe	0.003–6.832	0.08–7.11	0.03–8.11	0.017–16.6
Mn	0.007–1.27	0.0588–2.08	0.00063–3.11	0.00101–1.69
Pb	0.003–0.053	0.016–0.307	0.0006–0.07	0.005–5.01

For efficient management of reducing the Fe, Mn, and Pb contaminations in groundwater and ensuring safe drinking water for all, the government and non-government organizations should come up with combined programs to reduce these heavy metal contaminations in drinking water; including enhancing monitoring of groundwater pollution; enforcing laws with sufficient human resources; taking suitable policies to mitigate the adverse health impact of Fe, Mn, and Pb in groundwater; putting in place cutting-edge treatment and supply systems; and informing the public about safe water usage.

CONCLUSION

The review was conducted to evaluate the status of Fe, Mn, and Pb contamination in groundwater. This study indicates that the Fe, Mn, and Pb concentrations in the groundwater of Bangladesh ranged from 0.003 to 16.6, 0.00063 to 3.11, and 0.0006 to 5.01 mg/L, respectively, and followed the order Fe > Mn > Pb. The study showed that the concentrations of Fe exceeded all-standard limits by 55.93%, while the concentration of Pb exceeded all-standard limits by 37.50%. However, the concentration of Mn exceeded the BDWS, WHO, USEPA, EU, and Indian standard limits by 75.44%. The review observed that the Fe and Mn sources in groundwater are geogenic, such as weathering and leaching of iron oxides and hydroxides bearing minerals and rocks, including magnetite, hematite, pyrite, siderite, and limonite, and Mn-bearing minerals like rhodochrosite, rhodonite, braunite, pyrochroite, and manganite, into the aquifers, but Pb is continuously released into the groundwater in large amounts by anthropogenic activities. It derives from industry dust piles, vehicle exhaust discharge, lead pipes, faucets, fixtures, and batteries. The higher concentrations of these elements in drinking water may harm human health, and thus the groundwater should be treated before drinking. The study observed that several reasons, including inadequate monitoring, improper law enforcement, a lack of treatment and infrastructure facilities, and awareness of safe water, further aggravated the situation. The government and non-government organizations should come forward with combined programs to reduce these heavy metal contaminations in drinking water.

AUTHOR CONTRIBUTIONS

MZI contributed to literature review, data analysis, primary manuscript draft, and draft preparation and revision. MGM contributed to conceptualization, draft revision, and finalizing the manuscript for submission.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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