Manganese in potable water of nine districts, Bangladesh: Human health risk

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Abstract

Safe drinking water is directly linked to good human health. An excessive amount of manganese (Mn) in drinking water supplies causes people show symptoms of neurotoxicity. In this study, the level of Mn in potable water sourced from tube wells located in 9 (nine) districts of Bangladesh was monitored. In total 170 (one hundred and seventy) water samples were collected and Mn was quantified by atomic absorption spectroscopy (AAS). The levels of Mn found in the tube well water samples of Sirajganj, Meherpur, Chuadanga, Jhenaidah, Magura, Faridpur, Jashore, Satkhira, and Khulna were 0.37–1.86, 0.10–4.11, 0.30–0.76, 0.26–0.94, 0.01–0.18, 0.21–1.78, 0.08–1.23, 0.05–0.27 and 0.01–2.11 mg/L, respectively. Results revealed that Mn level was beyond the highest contaminated levels of 0.1 mg/L and 0.4 mg/L, which are recommended by Bangladesh Drinking Standard (BDS) and World Health Organization (WHO), respectively. The maximum Mn contaminated level reached up to 4.11 mg/L (mean: 0.53 mg/L). The Mn level in tube well water exceeded 51.1% and 75.9% set by the recommended value of WHO and BDS, respectively. Furthermore, the calculated hazard quotient (HQ) value for Mn was observed to be greater than unity, indicating both children and adults risked potential non-carcinogenic health issues. The water supply authorities should take steps to provide Mn-free drinking water for communities.

Introduction

Drinking water is essential for people to maintain good health. In safe drinking water, a trace level of essential minerals is necessary for proper bodily functioning. Too little or too much in the way of mineral levels will badly affect human health. In Bangladesh, groundwater is the main source of drinking water. A few parts of the coastal area such as the Bagherhat and Satkhira districts use harvested rainwater for drinking purposes (Islam et al. 2019). Impurities of trace elements in potable water are one of the major health concerns particularly for children because they might pose toxic metals. For example, in Bangladesh the permissible level of arsenic (As) in potable is 0.05 mg/L (ECR, 1997). However, it has been reported that As levels in potable water are above the standard level (Rahman and Hashem, 2019; Rahman et al. 2015, Chakraborti et al. 2010). Hence, the quantification of trace elements in potable water is necessary.

Manganese (Mn) is widely disseminated in the biosphere in a combined state. It is the 12th most abundant element and forms almost 0.1% of the earth's surface (Bouchard et al. 2007; Keen et al. 2013). It is an indispensable element for the human body (Aschner et al. 2007) so that various physiological processes function properly (Erikson et al. 2005). Exposure to high amounts of Mn can be neurotoxic (Keen et al. 2013; Wasserman et al. 2006) and causes cognitive and psychiatric impairment (Grandjean and Landrigan, 2006; Guilarte and Chen, 2007). For the immune system's good functioning, Mn plays an essential role (Erikson and Aschner, 2003). It acts as a constituent of metalloenzymes (Keen et al. 2013).

Usually, Mn in the groundwater ranges from 1-100 µg/L (Keen et al. 2013). Many countries, for example those in the European Union, United Kingdom, Canada, United States, and Japan recommended that Mn in potable water should be no more than 50 µg/L (Iyare, 2019), yet in Bangladesh it is 100 µg /L (ECR, 1997). Bowler et al. (2006) reported that anthropogenic activities are responsible for Mn exposure, which might be the source of damage done to the central peripheral nervous systems. The Mn level in groundwater is increasing gradually which is an issue of concern globally (Bouchard et al. 2018; Groschen et al. 2009). Some recent studies investigated many factors (urbanization and industrialization, leakage of wastewater sewages, corrosion of pipes, temperature, pH, decomposition of organic matter, and reduction of iron as well as many other hydrological and geological factors) that influence the release of Mn in drinking water (Hou et al. 2020; Zhang et al. 2020). Hasan and Ali (2010) reported that the occurrence of Mn in

groundwater of Bangladesh has consequences for as benign water supply. It is stated that environmental exposure to Mn causes human health risks (O'Neal and Zheng, 2015) and Mn in potable water increases the rate of all cancers (Spangler and Reid, 2010).

Various factors, for example the concentration of Mn, competition of other metals, etc., are responsible for Mn absorption by the gastrointestinal tract (Aschner and Aschner, 2005). Typically, Mn in food products ranges from 0.4–20 µg/g (Keen et al. 2013). Drinking water contaminated by Mn poses can endanger children's health and especially the nervous system (Frisbie et al. 2012). Children who are exposed to Mn higher than 400 µg/L achieved poorer education outcomes compared to those with less Mn in their body (Khan et al. 2012). Thus, Mn in drinking water is a potential threat for children. Wasserman et al. (2006) discovered that the consumption of larger amounts of Mn in water (mean, 800 µg/L) by children at the age of 10 years resulted in them showing notably lower intelligence quotient (IQ). Many researchers stated that Mn is a poisonous substance that causes shortfalls in learning and IQ in children (Ericson et al. 2007; Henn et al. 2011; Yousef et al. 2011; Riojas-Rodríguez et al. 2010; Menezes-Filho et al. 2011; Kim et al. 2009; Wright et al. 2006). Moreover, during pregnancy, a higher Mn level causes low fetal weight and risk of infant mortality to increase (Zota et al. 2009; Hafeman et al. 2007; Spangler and Spangler, 2009).

Therefore, this study aims to examine the Mn level in potable water of the Sirajganj, Meherpur, Chuadanga, Jhenaidah, Magura, Faridpur, Jashore, Satkhira, and Khulna districts of Bangladesh, in order to ensure safe drinking water. These regions are currently experiencing increasing Mn contamination in drinking water due to its geology, hydrogeology, enormous industrialization, and many other anthropogenic activities. The obtained data were compared with the World Health Organization (WHO) and national drinking water standard of Bangladesh (BDS). This monitoring study is very crucial to for improving public awareness of this problem around the world.

Materials And Methods

Reagents

In all experiments, the stock solution was prepared from the analytical reagent (AR). The standard Mn solution was purchased from Fluka-Analytical, Switzerland.

Description of the study area

The study area was randomly selected based on previously published work and is recognized as an elevated As-contaminated area in Bangladesh. Chakraborti et al. (2010) reported maximum As concentrations of 216, 1230, 841, 592, 1050, 750, 1630, 1120, and 3143 µg/L in groundwater sources of Sirajgong, Meherpur, Chuadanga, Jhenaidah, Magura, Satkhira, Faridpur, Jashore, and Khulna, respectively. These amounts were up to 314 and 63 times higher than the WHO and BDS recommended values, respectively. Despite the dangers posed by As-contamination, groundwater is the main source of drinking water in this investigated area. During each sample collection, the survey personnel met with a local administrative officer to gather information on the village demography and then randomly selected households' tube well where samples were collected.

Water sample collection and analysis

Tube well (TW) water samples were collected from 9 (nine) randomly selected districts in Bangladesh, specifically Sirajganj, Meherpur, Chuadanga, Jhenaidah, Magura, Faridpur, Jashore, Satkhira, and Khulna. From each district, a different number of tube well (TW) water samples were put into plastic 500 mL high-density polyethylene (HDPE)

bottles acidified with 1% nitric acid (Merck KGaA, Germany) from the tube well. Before collecting the water samples from the TW, for the first 10–15 min (depending on the depth) water was allowed to run so that a steady stream flow of water from the aquifer water layer was possible. In total 170 (one hundred and seventy) water samples were collected and identified as follows: Sirajganj (40): SJ01 to SJ40, Meherpur (10): MHR01 to MHR10, Chuaganga (10): CA01 to CA10, Jheniadah (10): JH01 to JH10, Magura (10): MR01 to MR10, Satkhira (12): SA01 to SA12, Faridpur (10): FR01 to FR10 (10), Jashore (26): JE01 to JE26, and Khulna (42): KN01 to KN42. The sample identification (ID) of these 9 (nine) districts is depicted in Table 1 to Table 6, and the sampling location is shown in Fig. 1. The water samples were preserved at 4°C until required for analysis. The Mn was quantified employing atomic absorption spectroscopy (SpectrAA220, Varian, Australia) with direct flame (air-acetylene) at the wavelength of 279.5 nm (Rahman et al. 2016; Rahman et al. 2019).

Health risk calculation

The recommended US-EPA (2011) method was applied to assess the chronic daily intake (CDI) of Mn and hazard quotient (HQ) for both children and adults. Equation (1) served for calculating the CDI:

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Health risk calculation

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Here C indicates the true Mn concentration in groundwater (mg L^{-1}), IR_{water} represents the water ingestion rate which was considered to be 2.1 L day^{-1} for children and 3.5 L day^{-1} for adults (Hossain et al. 2013), EF indicates the exposure frequency ($365 \text{ days year}^{-1}$), ED represents exposure duration (10 and 70 years for children and adults, respectively), BW means body weight of children ($<15 \text{ years}$) and adults ($\geq 15 \text{ years}$) which are approximately 31.97 kg and 50 kg, respectively (NCHS, 2000; Ghosh et al. 2020); AT is the average time ($365 \times 10 = 3650 \text{ days}$ for children and $365 \times 70 = 25550 \text{ days}$ for adults).

The HQ was assessed using the following equation (US-EPA, 2004): **See formula 2 in the supplementary files.**

R_fD_o refers to the oral reference dose ($\text{mg kg}^{-1} \text{ day}^{-1}$) and the R_fD_o for Mn was $0.14 \text{ mg kg}^{-1} \text{ day}^{-1}$ (US-EPA, 2020). $HQ < 1$ means that the population is safe from certain harmful effects over a lifetime of Mn exposure, but $HQ > 1$ stands for adverse non-carcinogenic health effects felt by the population exposed to Mn.

Quality control

The limit of detection (LOD) of the AAS for Mn was determined to be $9.0 \mu\text{g/L}$, which was obtained from 3 (three) times the standard deviation (SD) of the blank responses. Certified reference material (CRM), blanks, duplicates, and continuing calibration verification (CCV) were conducted after every 10 samples throughout the Mn analysis. The mean recovery ($n=10$) from CRMs (TraceCERT, Sigma-Aldrich) was within the 85–104% range, thus confirming the accuracy of the Mn analysis.

Results And Discussion

The mean Mn level was 0.53 mg/L (range $0.01\text{--}4.11 \text{ mg/L}$) which exceeded 1.3 and 5.3 times the recommended levels of WHO (0.4 mg/L) and BDS (0.1 mg/L), respectively (Table 1).

Mn in TWs water of Sirajganj district

Table 2 shows the Mn in TWs water of Sirajganj district in the tube well. It seems that all (40) of the tested samples' Mn level exceeded the BDS level. The largest and smallest amount of Mn in TWs water was found in samples SJ33 (1.86 mg/L) and SJ31 (0.37 mg/L), respectively. In the meantime 95% (38 out of 40) of TWs water Mn level was beyond the WHO (2008) guideline (0.4 mg/L). It implies that the Mn level was 1.03–4.65 times higher than the WHO guideline and 3.7–18.6 times higher than the BSD (0.1 mg/L) value (ECR, 1997). In contrast to BIS (2012), there was no acceptable (0.1 mg/L) and permissible (0.3 mg/L) Mn level of the tested TW water samples. The worst groundwater and TWs in Sirajganj district have been consistently reported over a long period of time, due to it being a severe flood-affected area and the many industries do not dispose of their waste in a planned way (Ali et al. 2019; Akter et al. 2010). Uddin et al. (2019) reported that a Mn concentration (1.58 mg/L) was considered hazardous for both drinking and irrigation in the Sirajganj district, whereas Akter et al. (2010) reported high Mn concentration (3.58 mg/L) in the industrial effluents in the Belkuchi, Sirajganj that could impact TWs and subsequent human health. Hou et al. (2020) reported many factors for the elevated level of Mn in groundwater. Therefore both natural and anthropogenic sources contribute to the concentration of Mn in TWs in the investigated area.

Mn in TWs water of Meherpur and Chuadanga district

Table 3 represents the Mn level that exists in Meherpur district. It appears that this Mn level ranged from 0.10 to 4.11 mg/L. The maximum and minimum Mn in TWs water were found in the samples MHR04 and MHR06, respectively. Referring to the Mn in TWs water samples from MHR06, MHR07, MR08, and MHR10, these exceeded the WHO guideline. In fact, it is indicated that 40% (4 out of 10) TWs water sample exceeded the WHO guideline. It also clear that Mn in TW water sample from MHR06 was 10.3 times higher than the WHO permissible level. On the other hand, except for MHR02 and MHR04, the remaining TWs had a Mn level greater than the BDS. However, 80% (8 out of 10) TWs water samples' Mn level as found in Meherpur district did not meet the BDS. Hasan and Ali (2010) reported the Mn concentration (0.806–1.336 mg/L) for the 17 most contaminated districts including Meherpur, 1.34 mg/L (maximum). However, the sources of Mn in TWs of the investigated area could be due to the ground flow of the Padma River (close to the sampling area), irrigation, industrialization, etc. Hou et al. (2020) reported river network areas do influence the amount of Mn released in groundwater.

Accordingly, Table 3 shows the Mn in TWs water samples for the Chuadanga district. Here, only 2 (two) TWs water samples (CA04 and CA10) had a Mn level meeting the WHO guideline. The other 8 (eight) TWs water samples (CA01, CA02, CA03, CA05, CA06, CA07, CA08, and CA09) showed Mn levels way above the WHO guideline. Conversely, all the TWs water samples' Mn level exceeded the BDS limit several times. It is noted that 90% (except CA10) of the TWs water samples had Mn levels beyond what was permissible. The Mn in all TWs water samples crossed the acceptable limit (BIS, 2012).

Mn in TWs water of Jhenaidah and Magura district

Likewise, Mn in TWs water of Jhenaidah and Magura districts is depicted in Table 4. The maximum (0.94 mg/L) and minimum (0.26 mg/L) amounts of Mn were found in TWs water samples of JH08 and JH05, respectively. 90% (9 out of 10) of TWs water samples exceeded the WHO guideline and all the water samples' Mn level was above the BDS level. It appears that the Mn level was 26 to 94 times higher than the BDS. In comparison with BIS (2012), only 1 (one) TW water (JH05) was close to the permissible level (0.3 mg/L) and unfortunately, there was no acceptable level (0.1 mg/L) of Mn in the investigated TWs water samples.

In the same way, Mn in TWs water samples from the Magura district are summarized in Table 4. The Mn level was found between 0.01 to 0.18 mg/L. Here, all the TWs water samples indicated a Mn level below the WHO guideline recommendation. In the case of BDS, only two TWs water samples (MR08 and MR10) and the rest of the TWs water samples' Mn was below the BDS. Conversely, TWs water samples of MR08 and MR10, Mn were above the acceptable level, while the remaining TWs water samples (MR01, MR02, MR03, MR04, MR05, MR06, MR07, MR09) had acceptable amounts of Mn (BIS, 2012).

Geologically, there are many oxbow lakes (baors) in Jhenaidah and Magura districts and the decomposition of different biomass could influence the Mn released to the groundwater. Rahman et al. (2016) reported Mn concentrations of 10–370 µg/L in TWs of different primary schools in Magura districts. Our findings are within that range. Hasan and Ali (2010) reported relatively more Mn (~0.971 mg/L) in the groundwater of Magura district.

Mn in TWs water of Satkhira and Faridpur districts

Table 5 depicts the Mn in TWs water of Satkhira district and it ranged from 0.05–0.27 mg/L. Here, the Mn level in all the tested TWs water samples was below the WHO guideline and 66.7% (8 out of 12) of TWs water surpassed the BDS stipulation. In only 4 (four) TWs water samples (SA03, SA06, SA09, and SA11) was the Mn level below the BDS.

In contrast to BIS (2012), 8 (SA01, SA02, SA04, SA05, SA07, SA08, SA10, and SA12) TWs water samples, the Mn level was below the permissible level, while the remaining 4 (SA03, SA06, SA09, and SA11) TWs water samples had acceptable Mn levels.

Satkhira is situated in the coastal belt region and recognized as one of the most vulnerable areas in Bangladesh in terms of safe drinking water (Didar-UI et al. 2015, Hasan et al. 2018). Hasan et al. (2018) reported a Mn concentration 0.6 mg/L in the groundwater of the Khulna-Satkhira coastal belt region. Aktaruzzaman et al. (2013) reported Mn (0.129–0.195 mg/L) in water and sediments (13.6–24.0 mg/L) in the shrimp farms operating in Satkhira district. Hydrological and hydrogeological factors mainly contribute to the release of Mn in TWs in this region.

Similarly, Mn in TWs water of the Faridpur district is summarized in Table 5. It seems that the maximum and the minimum Mn in TWs water were sample FR02 (1.78 mg/L) and FR01 (0.21 mg/L), respectively. For only two TWs water samples (FR02 and FR08) was the Mn within the WHO permissible level and the other 80% (FR01, FR03, FR04, FR05, FR06, FR07, FR09, FR10) TWs water samples contained Mn beyond the WHO guideline. Compared to BDS, all the Mn in TWs water sample values were above the permissible level. It is clear that Mn in TWs water level was 21 to 114 times higher than the BDS. Except for the TW water sample FR01; the remaining TWs water samples contained Mn beyond the permissible level of BIS (2012). Hasan and Ali (2010) reported a maximum Mn concentration in the Faridpur district's groundwater of 0.806 mg/L and this is similar to our findings.

Mn in TWs water of Jashore district

Table 6 shows the Mn level at the district of Jashore. The highest and lowest level of Mn was found at 0.08 (JE01) and 1.23 (JE18), respectively. Except for two (JE15 and JE18), Mn in all the TWs water samples, 24 (92.3%) crossed the BDS. Ghosh et al. (2020) reported that 87% of TW samples in the Jashore district exceeded the BDS. On the other hand, the amount of Mn found was closer to the WHO guideline for 4 (JE02, JE03, JE09, and JE14) TWs water samples, while Mn was below the WHO guideline for 12 (twelve) TWs water samples. The rest of the 38.5% (10 out of 26) TWs water samples contained Mn levels beyond the WHO guideline and it was 1.13 to 3.08 times higher. In terms of BIS (2012) and BDS, Mn in 7.7% (2 out of 26) of TWs water samples was within the acceptable limit. However, 92.3% (24 out of 26) of TWs water samples contained Mn beyond the BDS, and sometimes was actually several times higher than the BDS guideline recommendation. A recent study reported a Mn concentration of 0.05–0.93 mg/L in different TWs of Jashore, Bangladesh (Ghosh et al. 2020) which is similar to our findings. They also evaluated the hazardous effects of Mn on children and adults. The sources of Mn that contribute to the TWs are most likely domestic sewage, industrialization, poor management and indiscriminate disposal of industrial wastewater, river networks, etc.

Mn in TWs water of Khulna district

Correspondingly, Mn in TWs water of the Khulna district is illustrated in Table 7. It appears that the highest and lowest Mn levels in the water sample were 2.11 mg/L and 0.01 mg/L, respectively. The Mn in TWs water of KN01, KN02, KN03, KN05, KN06, KN07, KN08, KN09, KN10, KN11, KN12, KN12, KN14, KN15, KN16, KN17, KN18, KN20, KN21, KN27, KN28, KN29, KN35, KN36, and KN42 was below the BDS as well as below the BIS (2012) acceptable limit. Of the samples, 40.5% (17 out of 42) exceeded the BDS for Mn and 26.2% (11 out of 42) was beyond the WHO guideline. The Mn in TWs water of KN19, KN23, KN24, KN25, KN30, KN31, KN33, KN34, KN38, KN39, KN40, and KN41 was above the permissible level of BIS (2012). Islam et al. (2020) reported Mn, 0.01–22.4 (mean 0.47) mg/L in TWs from various households situated in the coastal region of Khulna. They detected a non-carcinogenic hazardous effect. Khulna is situated in the Rupsa River network and Islam et al. (2018) reported that the amount of Mn in Rupsa

River water ranged from 0.2–2.19 (mean 0.70) mg/L, which is similar to our findings in different TWs in that region. An important outcome of this data is that the background concentrations of Mn in a particular region significantly correlated with the Mn concentration in TWs. However, the main sources of Mn in TWs in these regions are industrialization, coastal region, river network areas, etc. The extensive corrosion of pipelines which is evident in the presence of saline water can dictate the solubility of iron and Mn in TWs. Hou et al. (2020) reported that on the inner wall of such pipes, hydrous Mn-oxides are deposited which can potentially be leached in drinking water.

Descriptive data of Mn in TWs water of 9 (nine) districts

Table 8 lists the Mn in TWs water of 9 (nine) districts and of these, Sirajganj recorded the worst quality water in terms of Mn contamination. The Mn level in all the tested TWs water was beyond the BDS and 95% surpassed the WHO guideline. Likewise, Chuadanga, Jheniadah, and Faridpur districts' Mn level (above 0.1 mg/L) was such that their TWs water were not fit to drink. The Mn in TWs of Meherpur, Magura, Jashore, Satkhira, and Khulna districts was beyond the official Bangladesh permissible limit of 80%, 20%, 92.3%, 66.7%, and 40.5%, respectively. Except for Magura and Satkhira Mn in TWs water was within or below the WHO guideline. Conversely, Mn in TWs of Meherpur, Chuadanga, Jhenaidah, Faridpur, Jashore, and Khulna districts crossed the WHO guideline (on some occasions several times higher) at the levels of 40%, 70%, 90%, 80%, 38.5%, and 26.2%, respectively. Overall, the Mn levels in TWs water were 48.9% and 77.7% outside the WHO and BDS, respectively.

The mean Mn in TWs water from Sirajganj, Meherpur, Chuadanga, Jhenaidah, Faridpur, Jashore, Satkhira, and Khulna districts was 9.0, 7.0, 4.6, 6.1, 8.1, 4.5, 1.4 and 3.3 times higher than the BDS guideline, respectively. Only the mean Mn level in TWs water of Magura district was closer to BDS. It was shown that the mean Mn in TWs water from Magura, Satkhira, and Khulna was below the WHO guideline. Conversely, it was higher than the WHO permissible level in districts like Sirajganj, Meherpur, Chuadanga, Jhenaidah, Faridpur, and Jashore, at 2.3, 1.8, 1.2, 1.5, 2.0, and 1.1 times, respectively. The mean Mn value in TWs water collected in this study at Magura district was greater than the mean value reported by Rahman et al. (2016). In this work, the mean Mn value in TWs of Faridpur district was higher than that documented by Bhuiyan et al. (2016). The mean value of Mn in TWs of other districts, i.e. Rangpur, Narayanganj (Araihazar), and Noakhali was reported to be 0.685, 0.793, and 0.140 mg/L, respectively (Wasserman et al. 2006; Islam et al. 2017; Rahman et al. 2015).

One study reported that consumption of a Mn concentration higher than 0.4 mg/L reduced intellectual functions of children (age 10 years) in Bangladesh (Wasserman et al. 2006), while in Canada it was reported for children in the 5.9-13.7 age range (Kuller et al. 2019). Another analysis suggested that infants had increased risk of mortality during the first year of life if they were exposed to drinking water with a Mn concentration > 0.4 mg/L when compared to infants not exposed to this danger (Hafeman et al. 2007).

Data comparison with recent studies

Table 9 depicts the Mn data comparison with recent studies in Bangladesh. Recently, Ghosh et al. (2020) reported 2.11 mg/L Mn in tube well water, which is 1.71 times higher than the same area in this study. Islam et al. (2017) found Mn in TWs water at Rangpur district ranging from 0.085–4.96 mg/L. It is noticeable that the lower level of Mn in TWs was below BDS but the upper level of Mn in TWs water was 49.6 times greater than the BDS. When comparing the Mn in Magura district with a previous study, the lower level was the same (0.01 mg/L) but the upper level was higher (0.3699 mg/L) (Rahman et al. 2016). In comparison to the Noakhali district, Mn in TWs water varied between 0.0189–0.4995 mg/L (Rahman et al. 2015), in which the upper limit was lower than this study except for Magura and Satkhira districts. However, it is clear from Table 8 that the maximum Mn in TWs water of this study, as

well as the previous study, was beyond the BDS. The maximum Mn in the TWs level of the previous study done on Noakhali and Rangpur (Rahman et al. 2015; Islam et al. 2017) as well as the Sirajganj, Meherpur, Chuadanga, Jhenaidah, Faridpur, Jashore and Khulna districts in the present study exceeded the WHO guideline. The maximum Mn concentration was detected at 4.11 mg/L in the current study, which is 41.1 and 10.3 times greater than the WHO and BDS limits, respectively (Table 9).

Health risk assessment

The mean CDI and HQ of Mn for both children and adults in each district are tabulated in Fig. 2. The increasing pattern of mean CDI values of Mn for both children and adults follows this sequence: Magura < Satkhira < Khulna < Jashore < Chuadanga < Jhenaidah < Meherpur < Faridpur < Sirajgonj (Fig. 2A). The estimated mean CDIs of Mn for both children and adults in most cases are very low (Fig. 2A). The decreasing pattern of HQs (mean value) for Mn are as follows: Sirajganj (children 0.42 and adults 0.45) > Faridpur (children 0.38 and adults 0.41) > Meherpur (children 0.33 and adults 0.35) > Jhenaidah (children 0.29 and adults 0.31) > Chuadanga (children 0.22 and adults 0.23) < Jashore (children 0.21 and adults 0.22) > Khulna (children 0.15 and adults 0.16) > Satkhira (children 0.06 adults 0.07) > Magura (children 0.028 and adults 0.03). The mean HQs for Mn in the study area for children and adults are less than unity (Fig. 2B), confirming there are no potential non-carcinogenic health risks posed by Mn through drinking water. However, the maximum HQ for Mn in Meherpur (MHR06) (1.93 for children and 2.05 for adults) and Khulna (KN39) (1.05 for adults) was determined greater than unity (Fig. S1 in supplementary information). The HQ of Mn for children was more than unity at only one sample, whereas that for adults was greater than unity at two water samples, which indicated a significantly high risk to the exposed population. A recent study noted that the HQ of Mn for children in the Jashore district was higher than unity at one sample but for adults was at sixteen samples (Ghosh et al. 2020).

Conclusion

Manganese-free potable water is essential for good health. The study results should help the relevant authorities identify the districts/areas that need to be safeguarded. Most of the tube well water Mn level did follow the WHO or Bangladesh drinking standard. The Mn level in tube well water exceeded the recommend value of the WHO and Bangladesh drinking standard by 51% and 76%, respectively. The maximum HQ value for children and adults was observed to be greater than unity in one and two samples, respectively, which suggests potential non-carcinogenic health risks are evident in the study area. It is very important to identify the tube wells which are safe or not safe for drinking purposes. The authorities should take the initiative to provide safe drinking water to the people so that they remain in good health. Before installing any water supply device, the water quality should be checked and subjected to treatment strategies if necessary. The data emanating from this will be helpful in the long-term. Increased awareness, low-cost water supply, development of cost-effective household water treatment systems, and effective water safety planning at the household level will all help to reduce the risks associated with Mn in drinking water. These findings are important for future research to evaluate the exact sources of Mn contamination in drinking water in the investigated area and how they should be managed properly. This study recommends long-term monitoring of Mn in drinking water to prevent risks to health and ensure that good resource management policies are implemented.

Declarations

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Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

The authors declare that the submitted manuscript is original. Authors also acknowledge that the current research has been conducted ethically and the final shape of the research has been agreed by all authors. Authors declared that this manuscript does not involve researching about humans or animals.

Consent to Participate

The authors consent to participate in this research study.

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The authors consent to publish the current research in ESPR journal.

Authors Contributions

Md. Aminur Rahman: visualization/conceptualization, investigation, methodology, and writing-review. Md. Abul Hashem: investigation, methodology, supervision, data managing-organizing, writing-original draft, writing-review, and editing. Md. Sohel Rana: sampling and data collection. Md. Rashidul Islam: review and editing. All authors read and approved the final manuscript.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

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Tables

Table 1. Descriptive statistics of Mn in tube well water (n= 170) collected from nine districts, Bangladesh

Parameters	Range	Median	Mean	Standard deviation	WHO Standard ^a	Bangladesh Standard ^b	Exceeded (%)	
							WHO Standard ^a	Bangladesh Standard ^b
Mn (mg/L)	0.01–4.11	0.41	0.53	0.52	0.4 ^a	0.1 ^b	51.12	75.88

^a Safe limit provided by both USEPA (2017) and WHO (2011); ^b maximum allowable concentration provided by (ECR, 1997) and BBS/UNICEF (2011)

Table 2. Mn content in TWs water of Sirajganj district

Sample ID	Upazila	Mn (mg/L)	Sample ID	Upazila	Mn (mg/L)
SJ01	Sadar	0.87	SJ21	Ullapara	1.47
SJ02	Sadar	0.79	SJ22	Ullapara	1.36
SJ03	Sadar	1.45	SJ23	Raygonj	0.75
SJ04	Sadar	0.64	SJ24	Raygonj	0.87
SJ05	Sadar	0.95	SJ25	Raygonj	0.64
SJ06	Sadar	0.75	SJ26	Raygonj	0.95
SJ07	Sadar	0.96	SJ27	Raygonj	0.84
SJ08	Sadar	0.99	SJ28	Raygonj	0.97
SJ09	Sadar	0.72	SJ29	Raygonj	0.71
SJ10	Sadar	0.41	SJ30	Raygonj	0.75
SJ11	Sadar	0.40	SJ31	Raygonj	0.37
SJ12	Sadar	0.73	SJ32	Belkuchi	1.67
SJ13	Sadar	0.83	SJ33	Belkuchi	1.86
SJ14	Sadar	0.96	SJ34	Belkuchi	0.94
SJ15	Kazipur	0.55	SJ35	Belkuchi	1.36
SJ16	Shahjadpur	0.62	SJ36	Belkuchi	0.85
SJ17	Shahjadpur	0.52	SJ37	Kamarkahand	0.69
SJ18	Ullapara	1.46	SJ38	Kamarkahand	0.78
SJ19	Ullapara	1.34	SJ39	Kamarkahand	0.59
SJ20	Ullapara	1.05	SJ40	Kamarkahand	0.74

Table 3. Mn content in TWs water of Meherpur and Chuadanga district

Sample ID	Upazila	Mn (mg/L)	Sample ID	Upazila	Mn (mg/L)		
Meherpur	MHR01	Sadar	0.12	Chuadanga	CA01	Sadar	0.52
	MHR02	Sadar	0.10		CA02	Sadar	0.56
	MHR03	Sadar	0.17		CA03	Sadar	0.42
	MHR04	Sadar	0.10		CA04	Sadar	0.39
	MHR05	Sadar	0.18		CA05	Sadar	0.76
	MHR06	Sadar	4.11		CA06	Sadar	0.41
	MHR07	Sadar	0.44		CA07	Sadar	0.40
	MHR08	Sadar	0.63		CA08	Sadar	0.46
	MHR09	Sadar	0.32		CA09	Sadar	0.41
	MHR10	Sadar	0.83		CA10	Sadar	0.30

Table 4. Mn content in TWs water of Jhenaidah and Magura district

Sample ID		Upazila	Mn (mg/L)	Sample ID		Upazila	Mn (mg/L)
Jhenaidah	JH01	Shailkupa	0.58	Magura	MR01	Mohammadpur	0.01
	JH02	Shailkupa	0.41		MR02	Mohammadpur	0.09
	JH03	Shailkupa	0.63		MR03	Mohammadpur	0.01
	JH04	Shailkupa	0.53		MR04	Mohammadpur	0.03
	JH05	Shailkupa	0.26		MR05	Mohammadpur	0.04
	JH06	Shailkupa	0.85		MR06	Mohammadpur	0.05
	JH07	Shailkupa	0.71		MR07	Mohammadpur	0.04
	JH08	Shailkupa	0.94		MR08	Mohammadpur	0.12
	JH09	Shailkupa	0.65		MR09	Mohammadpur	0.05
	JH10	Shailkupa	0.56		MR10	Mohammadpur	0.18

Table 5. Mn content in TWs water of Satkhira and Faridpur district

Sample ID		Upazila	Mn (mg/L)	Sample ID		Upazila	Mn (mg/L)
Satkhira	SA01	Sadar	0.15	Faridpur	FR01	Alfadanga	0.21
	SA02	Sadar	0.17		FR02	Alfadanga	1.78
	SA03	Sadar	0.07		FR03	Alfadanga	0.42
	SA04	Sadar	0.16		FR04	Alfadanga	0.54
	SA05	Sadar	0.25		FR05	Bhanga	0.85
	SA06	Sadar	0.05		FR06	Bhanga	1.14
	SA07	Sadar	0.13		FR07	Bhanga	1.14
	SA08	Sadar	0.27		FR08	Bhanga	0.31
	SA09	Sadar	0.06		FR09	Bhanga	0.79
	SA10	Sadar	0.14		FR10	Bhanga	0.96
	SA11	Sadar	0.08		-	-	-
	SA12	Sadar	0.13		-	-	-

Table 6. Mn content in TWs water of Jashore district

Sample ID	Upazila	Mn (mg/L)	Sample ID	Upazila	Mn (mg/L)
JE01	Sadar	1.23	JE14	Sadar	0.37
JE02	Sadar	0.37	JE15	Sadar	0.08
JE03	Sadar	0.39	JE16	Sadar	0.27
JE04	Sadar	0.48	JE17	Sadar	0.14
JE05	Sadar	1.11	JE18	Sadar	0.09
JE06	Sadar	0.57	JE19	Sadar	0.37
JE07	Sadar	0.32	JE20	Sadar	0.17
JE08	Sadar	0.55	JE21	Sadar	0.27
JE09	Sadar	0.36	JE22	Sadar	0.29
JE10	Sadar	0.33	JE23	Sadar	0.35
JE11	Sadar	0.24	JE24	Sadar	1.06
JE12	Sadar	0.45	JE25	Sadar	0.52
JE13	Sadar	0.64	JE26	Sadar	0.57

Table 7. Mn content in TWs water of Khulna district

Sample ID	Upazila	Mn (mg/L)	Sample ID	Upazila	Mn (mg/L)
KN01	Sadar	0.05	KN22	Sadar	0.29
KN02	Sadar	0.04	KN23	Sadar	0.40
KN03	Sadar	0.06	KN24	Sadar	0.68
KN04	Sadar	0.11	KN25	Sadar	0.45
KN05	Sadar	0.06	KN26	Sadar	0.30
KN06	Sadar	0.01	KN27	Sadar	0.06
KN07	Sadar	0.04	KN28	Sadar	0.01
KN08	Sadar	0.02	KN29	Sadar	0.01
KN09	Sadar	0.03	KN30	Sadar	0.71
KN10	Sadar	0.03	KN31	Sadar	0.51
KN11	Sadar	0.03	KN32	Sadar	0.12
KN12	Sadar	0.03	KN33	Sadar	1.23
KN13	Sadar	0.06	KN34	Sadar	1.32
KN14	Sadar	0.02	KN35	Sadar	0.01
KN15	Sadar	0.01	KN36	Sadar	0.02
KN16	Sadar	0.01	KN37	Sadar	0.16
KN17	Sadar	0.02	KN38	Sadar	1.43
KN18	Sadar	0.02	KN39	Sadar	2.11
KN19	Sadar	0.81	KN40	Sadar	0.96
KN20	Sadar	0.04	KN41	Sadar	1.56
KN21	Sadar	0.04	KN42	Sadar	0.08

Table 8. Descriptive data of Mn in TWs water of 9 (nine) districts

District	Unit (mg/L)				Guideline		Exceeded (%)	
	Min.	Max.	Mean	SD	WHO (2011)	ECR (1997)	WHO (2011)	ECR (1997)
Sirajganj (n=40)	0.37	1.86	0.90	0.35	0.4	0.1	95	100
Meherpur (n=10)	0.10	4.11	0.70	1.22	0.4	0.1	40	80
Chuadanga (n=10)	0.30	0.76	0.46	0.13	0.4	0.1	70	100
Jhenaidah (n=10)	0.26	0.94	0.61	0.20	0.4	0.1	90	100
Magura (n=10)	0.01	0.18	0.06	0.05	0.4	0.1	0	20
Faridpur (n=10)	0.21	1.78	0.81	0.47	0.4	0.1	80	100
Jashore (n=26)	0.08	1.23	0.45	0.29	0.4	0.1	38.5	92.3
Satkhira (n=12)	0.05	0.27	0.14	0.07	0.4	0.1	0	66.7
Khulna (n=42)	0.01	2.11	0.33	0.52	0.4	0.1	26.2	40.5

Table 9. Mn level comparison water with recent studies in Bangladesh

Sampling area	Water Source	Mn (mg/L)	Reference
Noakhali	Tube well	0.0189-0.4995	Rahman et al. 2015
Magura	Tube well	0.01-0.3699	Rahman et al. 2016
Rangpur	Tube well	0.085-4.96	Islam et al. 2017
Jashore	Tube well	0.02-2.11	Ghosh et al. 2020
Sirajganj	Tube well	0.37-1.86	This study
Meherpur	Tube well	0.10-4.11	
Chuadanga	Tube well	0.30-0.76	
Jhenaidah	Tube well	0.26-0.94	
Magura	Tube well	0.01-0.18	
Faridpur	Tube well	0.21-1.78	
Jashore	Tube well	0.08-1.23	
Satkhira	Tube well	0.05-0.27	
Khulna	Tube well	0.01-2.11	

Figures

Figure 2

Chronic daily intake (CDI) (A), and Hazard quotient (B) of Mn through water ingestion for the nine districts of Bangladesh

Supplementary Files

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- [FigureS1.docx](#)