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Groundwater Contamination and Health Risk Evaluation of Naturally Occurring Potential Toxic Metals of Hatiya Island, Bangladesh

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ABSTRACT

Groundwater meets the majority portion of drinking water needs, particularly in the rural area of Bangladesh. Groundwater has been continuously contaminated by potentially harmful metals as a result of natural processes as well as some anthropogenic activities, creating a variety of health impacts. The current research aimed to evaluate the naturally occurring level of metal contamination and the human health risk associated with deep groundwater in the Hatiya Island. Because of the arsenic, iron, and salinity problem in shallow groundwater, the inhabitants of the Hatiya Island use deep groundwater. During the field investigation, no shallow tubewells were observed; therefore, only deep groundwater samples were collected. The total sample size collected throughout the Hatiya island was 17. Five metals (Zn, Fe, Mg, Mn, and Cu) were analyzed using an Atomic Absorption Spectrophotometer (AAS). The concentrations of studied potential risky metals were ranked as follows: Mg > Zn > Fe >Mn> Cu. The detected values of all metals except Fe were found within the drinking water limits of WHO (2017), BIS (2012), and BDWS (1997), where only 29.41% of the Fe sample exceeded the standard drinking limits. According to the metal evaluation index (MEI) and degree of contamination (C_d), the groundwater of the study area is free from contamination but the metal pollution index (MPI) and nemerow pollution index (NI) exhibited little pollution in the mid-western part of the study area. The hazard quotient (HQ) values revealed no oral and dermal health risk for individual metals (Cu, Zn, Fe, Mn). On the other hand, the hazard index (HI) values exhibited no risk for combined metals as none of the values exceeded the safety limit value of 1. According to the HQ and HI results, the deep groundwater on Hatiya Island is non-carcinogenic and risk-free for children and adults. However, children were more susceptible to oral health risks than adults. In contrast, adults were more vulnerable to dermal health risks than children.

Keywords: drinking water, toxic elements, pollution indices, Hatiya Island.

INTRODUCTION

Groundwater is a vital natural resource essential for drinking, irrigation, industry, and other economic sectors [Bodrud-Doza et al., 2019]. Because of being pathogen-free and availability, groundwater is considered as a prime source of potable water in most countries of the world [Kumar et al., 2019; Rahman et al., 2021a]. In Bangladesh, approximately 98% of the population uses groundwater as potable water [Shamsudduha et al., 2019]. Rapid population growth and the pollution of surface waters in recent times have generated an excessive demand for groundwater resources [Islam et al., 2017; Bodrud-Doza et al., 2019]. However, groundwater contamination through naturally occurring potentially toxic metals (PTM) has become a major concern throughout the scientific community and the world's policymakers [Bundschuh et al., 2017; Nwankwo et al., 2020; Tomašek et al., 2022]. Elements such as arsenic (As), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), boron (B), lead (Pb), cadmium (Cd), nickel (Ni), etc, are potentially toxic and they got released into groundwater from chemical weathering of rock and minerals [Singh 2005; Rango et al., 2009]. Anthropogenic sources like urbanization, industrialization, solid waste dumping, agricultural activity, etc., also release PTMs in the shallow groundwater [Kumar et al., 2016; Pugazhendhi et al., 2018; Bhattacharjee et al., 2019].

PTMs are relatively dense, non-biodegradable, persistent, and can bio-accumulate in nature even at low concentrations, they might be poisonous [Ali et al., 2019]. The consumption of water contaminated with metals may cause adverse health effects, such as hypertension, cancer, vascular disease, restrictive lung disease, bleeding from the gastrointestinal tract, neurological disorder, and effects on reproduction, if these elements are present in excessive amounts in the groundwater and ingested over time [Muhammad et al., 2011; Ormachea Munoz et al., 2013; Lu et al., 2015; Nkpaa et al., 2018; Singh et al., 2018]. Excessive consumption of Cu in drinking water, for example, causes abdominal upset, nausea, diarrhea, and may result in liver tissue impairment [USNRC, 2000]. Drinking excessively iron-infused water may cause an unusual metallic taste and contribute to fatigue, weight loss, and joint inflammation [Ahmed et al., 2019]. If humans are exposed to a higher level of chromium (Cr) they can suffer from hematological, gastrointestinal, hepatic neurological, renal, and cardiovascular problems and even death can be occurred [Adimalla and Li, 2018]. The toxic metal Cd is carcinogenic for humans, and obsessive intakes of Cd may end up to bone damage, renal infection, and respiratory problems [Bernard, 2008; Belabed and Soltani, 2018]. Longer periods of excessive Mn intake via drinking water can lead to a neurological disorder, including a reduction in intellectual capacity and DNA damage [WHO, 2011; Annaduzzaman et al., 2018]. If Zn is ingested through drinking water for a long time, it causes vomiting, anemia, and stomach cramps [Singh et al., 2018]. Besides, this lead (Pb), mercury (Hg), and boron (B) in groundwater also have detrimental consequences on human health. Therefore, assessing the contaminants and health risks of groundwater is crucial and can be considered as a means of determining how environmental pollution impacts human health [Tirkey et al., 2017; Rahman et al., 2020]. For the reasons mentioned earlier, the analyses of groundwater contamination and health risks (HRAs) are crucial. They serve as a tool for investigating the relationship between environmental pollution and human health [Tirkey et al., 2017; Rahman et al., 2020].

Few PTMs (As, Fe, Mn, B, and F^-) were also found in groundwater in excessive amounts at different locations in Bangladesh where arsenic is the main contaminant [Ahmed et al., 2004; Islam et al., 2017; Rahman et al., 2018; Rahman et al., 2021a,b]. In coastal plains and delta plains, elevated concentrations of arsenic (> 10 μg/L) were found at shallow aquifers (<150 m), and above 60–80% of the tubewells were found arsenic-contaminated [Ahmed et al., 2004]. Additionally, higher salinity levels in shallow and deep aquifers of different coastal areas also constrained the groundwater use as drinking water. A recent investigation revealed that around 6.5–24.4 million Bangladesh residents face challenges related to obtaining secure water due to salinity, arsenic, and freshwater scarcity in aquifers [Shamsudduha et al., 2019].

Hatiya is a remote island located in the Meghna River Estuary in the central coastal region of Bangladesh. More than two hundred thousand people live there and according to the population and housing census 2011, around 34% of the population is illiterate [BBS, 2011]. As a result, many people are not conscious of drinking water and the adverse impact of the PTMs present in the groundwater. Sometimes they might not even know that groundwater may contain harmful elements. Unfortunately, there has been no scientific research conducted to know about the state of PTMs and their associated human health risk in the groundwater of whole Hatiya Island. Considering this unknown status PTMs and the associated health risk of drinking groundwater of Hatiya Island, the current study is aimed to identify the contamination level of PTMs in groundwater, its spatial distribution on the Hatiya Island, and their potential human health risk through oral and dermal exposure pathways.

MATERIALS AND METHODS

Study area

The study area is a remote deltaic island located at the mouth of the Meghna River estuary. The Island is administratively situated in the Noakhali district which is comprised of seven unions, namely; Burir Char union, Char Ishwar union, Jahajmara union, Nalchira union, Sonadia union, Sukh Char union, Tamaruddin union and covers an area of 849 km^2 [BBS, 2011] (Fig. 1). The study area lies between longitude 91.0023° E to 91.197° E and latitude 22.077° N to 22.4° N. The large confluence of the Ganges, Brahmaputra, and Meghna (GBM) river systems formed the GBM delta, and the study area is a part of the delta [Whitehead, 2018]. The morphology of the island is continuously changing due to erosion and accretion phenomena and around 13 km of the landmass of the northern island eroded in the last 45 years [Kabir et al., 2020]. Topographically, the island is characterized by a low-lying and gently sloping landmass with an average elevation of about 2.4 m [Ghosh et al., 2015]. Every year billion tons of sediments pass through the eastern and western channels of Hatiya Island to the Bay of Bengal of which a small portion deposits around the southern and south-eastern parts of the island [Goodbred et al., 2003].

Hydrogeological settings

The hydrogeology of the coastal plains of Bangladesh is a complex combination of upstream freshwater flows, tides in the Bay of Bengal, tropical cyclones, storm surges, and other meteorological phenomena in the sea [FAO, 1985]. Thick sedimentary deposits from the Quaternary period have played a major role in developing the aquifer along the coast [Zahid et al., 2018]. A sub-division of shallow and deep aquifers was established at 150 m based on experimental data on water chemistry changes resulting from the highest depth of river incision during the last glacial maximum [Ravenscroft and McArthur, 2004]. Aggarwal et al. [2000] classified the aquifers according to the isotopic composition of the groundwater into three groups based on the age of the groundwater i.e., 70–100 m (First aquifer), 200–300 m (Second aquifer), and >300 m (Third aquifer). The potential secure aquifers are mainly located below 150 meters in these coastal areas since the upper

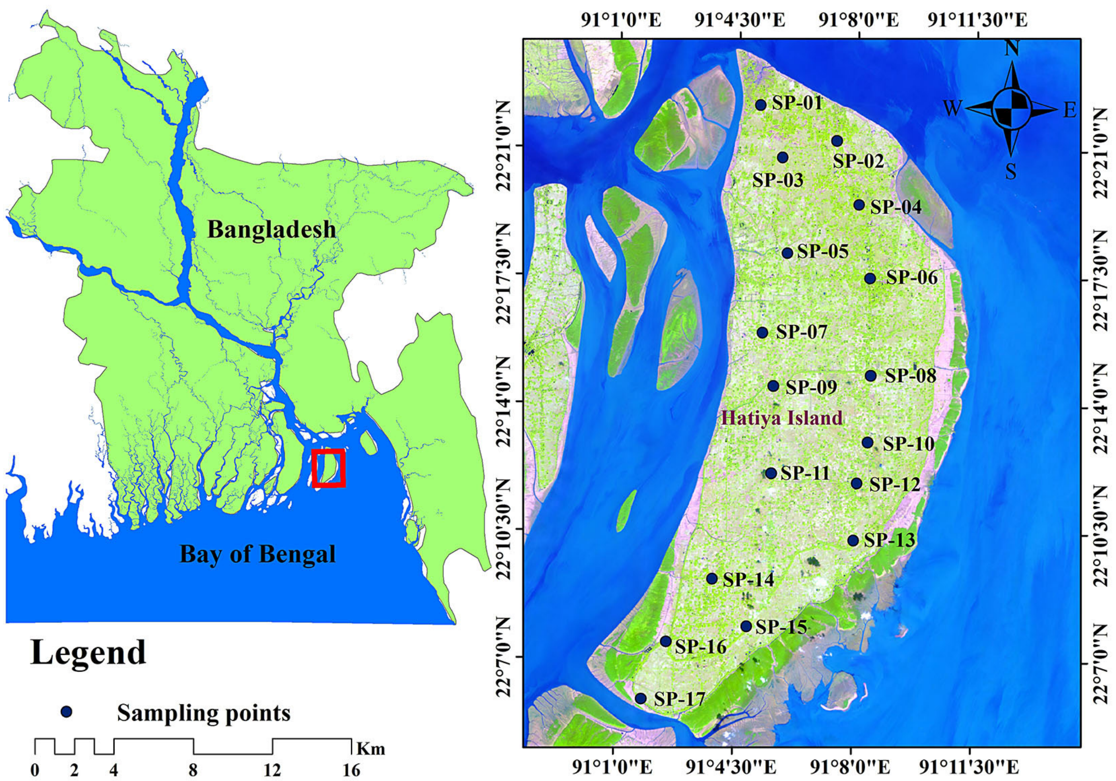

Figure 1. Map showing the location of the study area. The blue color indicatesthe water body surrounding Hatiya Island and the green color indicates vegetation in the Hatiya Island

aquifers (30–150 meters) are brackish and are therefore avoided [Ravenscroft et al., 2005].

A modified lithologic succession (around 300 m) of Hatiya Island, Noakhali is shown in Figurre 2 [BWDB, 2013] where the distribution, extent, as well as interconnectivity of aquifers and aquitards can be determined. The lithology of the study area ranges from silty clay, silt, very fine sand, and fine sand. The upper 70 m of the surface layer comprises silty clay and silt, which is unsuitable for groundwater extraction. The depth below 70 m to up to 135 m includes alternating layers of very fine sand and fine sand. Below 135 m, a 35 m thick aquitard separates the shallow aquifers from the deep aquifers. Again, the rest of the layers comprised alternating very fine sand to fine sand with a minor silty clay layer at a depth of 180–185 m and 247–255 m. The very fine sand and fine sand layers can be used as aquifers but fine sand layers are more suitable for groundwater extraction, especially the two layers extending from around 185–205 m and 255–285 m.

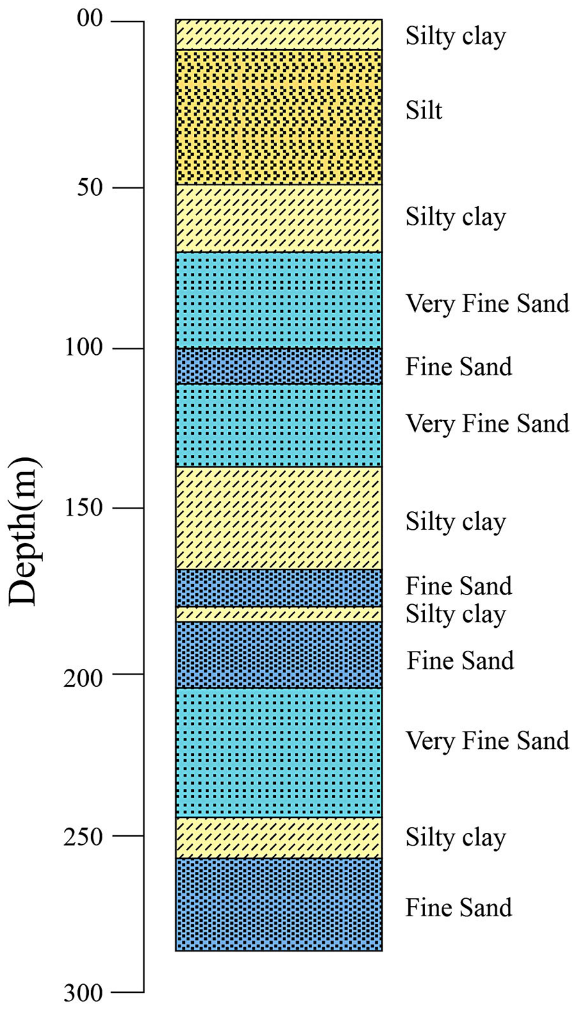

Figure 2. A modified lithologic succession of Hatiya Island, Bangladesh. Source: Bangladesh water development board [BWDB, 2013]

Groundwater sample collection

The groundwater samples were collected from 17 tubewells in February 2021 covering the whole Hatiya Island. Due to arsenic and salinity problems, people do not use shallow groundwater (< 150 m) for drinking purposes. As a result, no shallow tubewells were found on the Hatiya Island during fieldwork. Only deep tubewells (> 150 m) were found available and water samples were collected from those tubewells. The locations of each sampling point were determined using a portable GPS device. Each sample was collected in 100 mL bottles of high-density polyethylene using the standard procedure described in Rahman et al. [2021a]. Immediate after collection the water samples were sent to the laboratory of the Institute of Mining, Mineralogy & Metallurgy, BCSIR Jaypurhat, Bangladesh for chemical analysis.

Analysis of groundwater sample

At first, 100 ml of water from each sample was collected into separate beakers. Then, 5 ml ultra-pure concentrated HNO_3 were added to the beaker to digest the sample water. After that, the samples were kept on an electric stove and boiled at 130°C until they reached 50 ml with light in colour. After digestion, the analysis of heavy metals was carried out using atomic absorption spectroscopy (AAS, model ICE 3300, Thermo Scientific, UK) following standards provided by American Public Health Association, APHA [1995]. The calibration curve was created using standard solutions. To avoid contamination, the samples were handled with care. Chromic acid and distilled water were used to clean the glassware appropriately. Chemicals and reagents of analytical grade were employed throughout the study.

A metal standard medium was initially prepared with analytical grade chemicals, reagents, and distilled water to calibrate the instruments according to the APHA, 1995 standard technique. Standard testing samples were conducted (including blank, spike, duplicate, quality control, and check samples). Most importantly, all standards including calibration, quality, and check samples were traceable to NIST (National Institute of Standard and Technology), USA. The recovery ranges of the used standards were carefully observed; they were within 100 ± 5%. Moreover, the detection limits were calculated from the relative standard deviation for each element. The detection limits were 0.025 for Fe, 0.005 for Mn, 0.01 for Zn, 0.01 for Cu, and 0.05 for Mg. Calibration curves with R^2> 0.995 were accepted for concentration calculations of each element.

Pollution evaluation indices

Metal pollution index

MPI is an evaluation technique that determines the combined effects of heavy metals on the overall quality of groundwater. To express the relative importance of each parameter a rating was done between 0 and 1. To calculate the MPI, the water standards provided by the World Health Organization [2017] were used for each chemical parameter in mg/L. The relative weight (Wi) of each parameter is calculated in the first stage using Equation 1 by Mohan et al. [1996].

The maximum permissible concentration (MAC) for each water quality parameter is inversely related to unit weight (wi).

$$\mathrm{wi}\alpha\frac{1}{\mathrm{MAC}} \;\Rightarrow\; \mathrm{wi}=\frac{\mathrm{K}}{\mathrm{MAC}} \tag{1}$$

where: K = constant of proportionality. In the second step, individual quality rating (qi) is performed by equation 2.

$$\mathrm{Qi}=\sum_{\mathrm{i}=1}^{\mathrm{n}}\frac{\{\mathrm{Mi}(-)\mathrm{Ii}\}}{(\mathrm{Si}-\mathrm{Ii})}\times 100 \tag{2}$$

where: Mi denotes the measured value of the metals in the water sample, Ii denotes the ideal value, and Si indicates the standard value. The minus sign (–) denotes the numerical difference between the two values, but the algebraic sign is ignored. Third, the overall index was created by adding these sub-indices together.

$$\mathrm{MPI}=\frac{\sum_{\mathrm{i}=1}^{\mathrm{n}}\mathrm{QiWi}}{\sum_{\mathrm{i}=1}^{\mathrm{n}}\mathrm{Wi}} \tag{3}$$

where: Qi is the sub-index of the i^{th} parameter, Wi is the unit weightage for the i^{th} parameter, and n is the number of considered parameters. For drinking water, the critical value is usually 100, according to Prasad and Bose (2001). Again, an adjusted three-class scale has been used in the current investigation. The classes are; low level < 45, medium level 45-90, and high level > 90 for MPI values [Bodrud-Dozaa et al., 2016; Alfaifi et al., 2021].

Metal evaluation index

Metal evaluation index (MEI) assigns a general water quality rating for heavy metals and it was estimated by using the following equation 4 [Edet and Offiong, 2002]:

$$\mathrm{MEI}=\sum_{\mathrm{i}=1}^{\mathrm{n}}H_c/H_{mac} \tag{4}$$

where: H_c represents the monitored value for parameter i and H_{mac} represent the maximum allowable concentration (MAC) of parameter i. The maximum permissible concentrations of Cu, Zn, Fe, Mg, and Mn are 2, 3, 2, 50, and 0.4 mg/L respectively [WHO, 2017]. To rank the metal pollution level of groundwater, the index was divided into three categories like low MEI ≤ 10, medium MEI (10–20), and high MEI > 20 [Edet and Offiong, 2002; Bodrud-Doza et al., 2019].

Nemerow pollution index

The nemerow pollution index (NI) was used for the determination of groundwater metal pollution levels. The index considers the average and highest values of the single factor pollution index and prioritizes highly polluting factors. This is expressed by formulae 5.

$$NI=\sqrt{\frac{\left[\left(\frac{1}{n}\right)\Sigma\left(\frac{Ci}{Si}\right)\right]^2+\left[\mathrm{Max}\left(\frac{Ci}{Si}\right)\right]^2}{2}} \tag{5}$$

where: n is the number of indices, C_i is the measured concentration of heavy metal i, and S_i is the standard value. As per the *NI*, the types of heavy metal contamination in groundwater fall into six categories: no pollution (<0.5), clean (0.5–0.7), warm (0.7–1.0), polluted (1.0–2.0), medium pollution (2.0–3) and severe pollution (> 3.0) [Zhong et al., 2015].

Contamination index

Contamination index (C_d) has already been utilized in studies for assessing metal contamination levels [Mustafa, 2008]. C_d is the summation of the contamination factors of the different parameters that exceed their respective permissible values, as indicated in Eq. 6.

$$C_d = \sum_{i=1}^{n} Cfi \tag{6}$$

where, $Cfi = \frac{CA_i}{CN_i} - 1$, Cfi= contamination factor for the parameter i, CA_i= measured value of the *i^th^* component, and CN_i= maximum allowable concentration of the *i^th^* component. The letter N signifies the normative value, and the values for CN_i were obtained from the MACs listed in Table 2. C_d was divided into three groups as follows: low (C_d < 1), medium (C_d = 1–3), and high (C_d > 3) [Backman et al., 1998; Edet and Offiong, 2002].

Human health risk assessment

The health risks associated with metals or metalloids are quantitatively assessed and are expressed as either carcinogenic or non-carcinogenic health risks [USEPA, 2009]. In this study, chronic daily intake (CDI), hazard quotient (HQ), and hazard index (HI) were evaluated for non-carcinogenic health risks using the standard approach recommended by the USEPA [1989].

The chronic daily intake

The assessment considered both the oral and dermal exposure pathways, and the chronic daily intake (CDI) of components via the oral and dermal pathways was estimated as follows.

$$\text{CDI}_{\text{oral}} = \frac{(\text{CW} \times \text{IR} \times \text{EF} \times \text{ED})}{(\text{BW} \times \text{AT})} \tag{7}$$

$$\text{CDI}_{\text{Dermal}} = \frac{(\text{CW} \times \text{SA} \times \text{K}_\text{P} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF})}{(\text{BW} \times \text{AT})} \tag{8}$$

where: CDI_{oral} and $\text{CDI}_{\text{Dermal}}$ denote the exposure dosage (mg/kg/day) by oral intake and dermal route, respectively, and are computed using the values of the parameter from Table 1.

The hazard quotient

USEPA [1989] evaluated non-carcinogenic health risks of exposure to metals of concern by comparing the estimated amount of pollutants from different routes of exposure (oral and dermal) with an established reference dose (RfD) to determine the hazard quotient (HQ). The HQ value less than 1 indicates no non-carcinogenic health risk, while the HQ value greater than 1 indicates an unacceptable health risk [USEPA, 2001]. HQ was calculated by:

$$\text{HQ} = \frac{\text{CDI}}{\text{RfD}} \tag{9}$$

where: HQ represents the hazard quotient and RfD represents the reference dose (mg/

Table 1. Parameters for determining metal exposure by oral consumption and the dermal exposure pathways

Parameters	Unit	Oral values	Dermal values	References
CDI (Chronic daily intake)	mg/kg/day	-	-	-
CW (Conc. of trace metal in water)	mg/L	-	-	Analysed values
IR (Ingestion rate)	L/day	2.2 (Adult) 1 (Child)	-	Wu et al., 2009; Bodrud-Doza et al., 2019
EF (Exposure frequency)	Days/Year	365	350	USEPA, 2004
ED (Exposure duration)	Year	60 (Adult) 10 (Child)	30 (Adult) 6 (Child)	USEPA, 2004; Wu et al., 2009; Rahman et al., 2021a
ET (Exposure time)	hr/day	-	4 (Adult) 0.5 (Child)	USEPA, 2011
BW (Body weight)	kg	70 (Adult) 20 (Child)	70 (Adult) 20 (Child)	USEPA, 2004; Giri and Singh, 2015; Rahman et al., 2021a
AT (Average time)	Days	21,900 (Adult) 3650 (Child)	10950 (Adult) 2190 (Child)	Wu et al., 2009; USEPA, 2004; Wongsasuluk et al., 2014
SA (Skin-surface area)	m^2	-	1.8 (Adult) 0.66 (Child)	USEPA, 2004
Kp (Permeability coefficient)	m/hr	-	0.001 (Cu), Fe (0.001), Mn (0.001), 0.0006 (Zn)	USEPA, 2004

kg/day). The RfD values of Cu, Fe, Mn, and Zn for oral toxicity are 0.04, 0.3, 0.02, and 0.3, respectively. In the case of dermal exposure, the values are 0.012, 0.045, 0.008, and 0.06 respectively [Wu et al., 2009; Bodrud-Doza et al., 2019].

Hazard index

The HQs determined for each metal at a single station are summed and expressed as hazard index (HI) to estimate the total potential for non-carcinogenic consequences caused by more than one metal [USEPA, 1989].

$$HI = HQ_1 + HQ_2 + + HQ_3 + \dots\dots + HQ_n \quad (10)$$

Health risks from toxic elements were classified as either HI > 1 (risky/unsafe) or HI < 1 (no adverse effects on health/safe) by the USEPA [1989].

Data analysis

Metal concentration data were initially categorized into three groups based on the Bangladesh drinking water standard [BDWS, 1997], Bureau of Indian Standards [BIS, 2012], and World Health Organization [WHO, 2017]. All data were analyzed using PAST software version 4.03 and Microsoft Excel version 2019. A descriptive statistical analysis of metals, including minimum, maximum, mean, and standard deviation values, was conducted using Microsoft Excel version 2019. Using inverse distance weighting (IDW) interpolation techniques in ArcGIS 10.2.2, colour gradient maps were constructed to illustrate the spatial distribution of NI values.

RESULTS AND DISCUSSION

Metal concentrations in the groundwater

Five potentially toxic metals (PTMs) i.e. Zn, Fe, Mn, Cu, and Mg were analyzed to determine the contamination level in the groundwater of the Hatiya Island. The summary statistics are presented in Table 2. Among 17 samples, Cu was detected in only two samples SP-09 & 10 located at the central part of the island, and their concentrations were sequentially 0.041 and 0.15 mg/L. Both values were below WHO [2017] drinking water standards. Zn was detected in all samples and their concentration ranged between 0.0674–2.0471 mg/L with an average value of 0.4307 mg/L which falls below the WHO [2017], BIS [2012], and BDWS [1997] drinking water guideline values. The range of Fe in the groundwater of the study area was 0.004 mg/L to 0.497 mg/L with a mean value of 0.195 mg/L. It was found that 5 samples (29.41%) exceeded the WHO [2017] and BIS [2012] drinking water standards but no sample crossed the BDWS [1997] limits. The Mn concentration ranged from 0.0 to 0.043 mg/L with a mean value of 0.0099 mg/L. The mean values of Mn fell within all the standards limits. Again, the highest concentration of Mg in the groundwater of the research area was 18.14 mg/L, with an average value of 7.20 mg/L which does not exceed any drinking water standards. Almost all the samples fall within the standard limit. The mean concentrations of the analyzed metals followed a descending order of Mg> Zn > Fe >Mn> Cu.

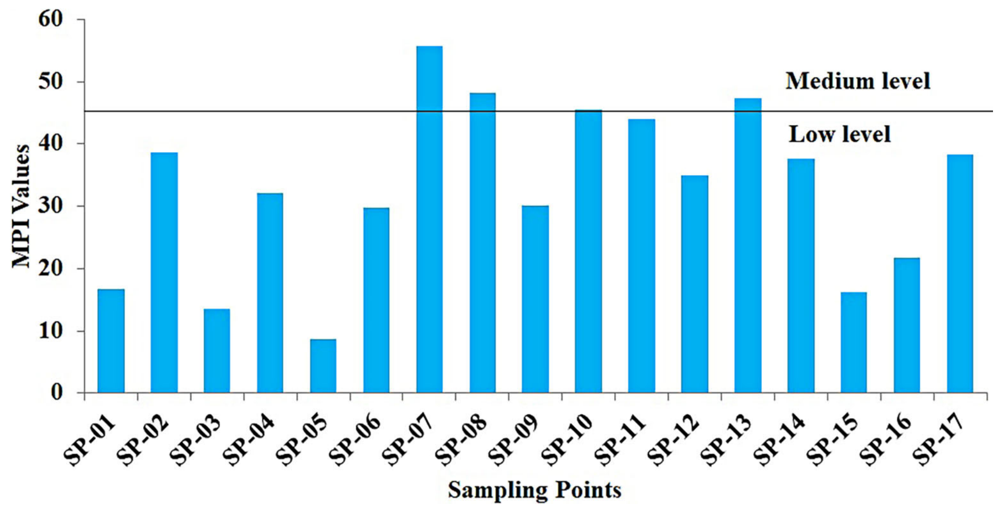

Figure 3. Metal pollution index (MPI) of the selected heavy metals from the Hatiya Island, Bangladesh

Table 2. An overview of the analysed parameters and a comparison of drinking water standards to the studied parameters

Sampling point	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)
SP-01	BDL	1.4015	0.309	6.1993	0.04
SP-02	BDL	0.2164	0.069	8.2596	BDL
SP-03	BDL	0.2397	0.221	4.1659	BDL
SP-04	BDL	0.3144	0.108	13.1902	BDL
SP-05	BDL	0.1633	0.251	8.0846	BDL
SP-06	BDL	0.1182	0.123	7.8584	BDL
SP-07	BDL	0.0832	0.112	6.8126	0.002
SP-08	BDL	0.9276	0.124	6.1323	0.024
SP-09	0.041	0.1558	0.497	6.2541	BDL
SP-10	0.15	0.8598	0.004	12.5236	BDL
SP-11	BDL	0.3127	0.036	5.5246	BDL
SP-12	BDL	2.0471	0.375	1.9076	0.01
SP-13	BDL	0.1116	0.141	4.2785	0.017
SP-14	BDL	0.0678	0.207	2.0995	0.012
SP-15	BDL	0.0674	0.205	7.9229	BDL
SP-16	BDL	0.0676	0.343	18.1493	0.043
SP-17	BDL	0.1678	0.191	3.1145	0.02
Min.	0	0.0674	0.004	1.9076	0
Max.	0.15	2.0471	0.497	18.1493	0.043
Mean	0.00561	0.43070	0.19505	7.20455	0.0099
SD	0.03711	0.56058	0.12937	4.19390	0.01436
WHO limit (2017)	2	3	0.3	50	0.4
BIS limit (2012) Desirable	0.05	5	0.3	30	0.1
BIS limit (2012) permissible	1.5	15	No relaxation	100	0.3
BDWS (1997)	1	5	0.3–1	30–35	0.1

BDL: Below detection limit; BDWS:Bangladesh drinking water Standards; WHO: World Health Organization, BIS: Bureau of Indian Standard

Metal pollution index

The MPI (metal pollution index) model is a handy tool for evaluating the overall metal pollution level of groundwater. The MPI values ranged from 8.6 to 55.73 with an average value of 32.86. According to the classification of Bodrud-Dozaa et al. [2016] and Alfaifi et al. [2021], only 4 out of 17 samples (SP-07, 08, 10, & 130) fall in the moderate class, and the rest all fall in the low category (Fig. 3). Moderate class samples were located in the central portion of the Island and their values were relatively high because of higher Fe and Mn values. No sample exceeded the critical value of 100 proposed by Proshad and Bose [2001].

Metal evaluation index

The MEI (metal evaluation index) measures the groundwater quality emphasizing metal quantity in the samples. MEI was calculated for Cu, Fe, Mn, Zn, and Mg where the maximum MEI values were 1.99 and the average MEI value was 0.9681. Among low, medium, and high classes provided by Edet and Offiong [2002] all the 17 sampling stations were found within the limit of low class (MEI < 10) which indicates the suitability of the groundwater for drinking purposes. Higher MEI values were mainly found in sampling points no-01, 09, 12, & 16 (Fig. 4).

Nemerow pollution index

The Nemerow pollution index (NI) also quantifies groundwater pollution from different heavy metals in the sampled areas. NI values for groundwater samples ranged from 0.14 to 1.31, with an average value of 0.57. According to the NI classification scheme, the groundwater of the study area falls into four categories named no pollution, clean, warm, and polluted. Warm type water was found in the northern and southern tips of Hatiya Island. Contaminated water is only found in the central-western part of Hatiya Island (Fig. 5).

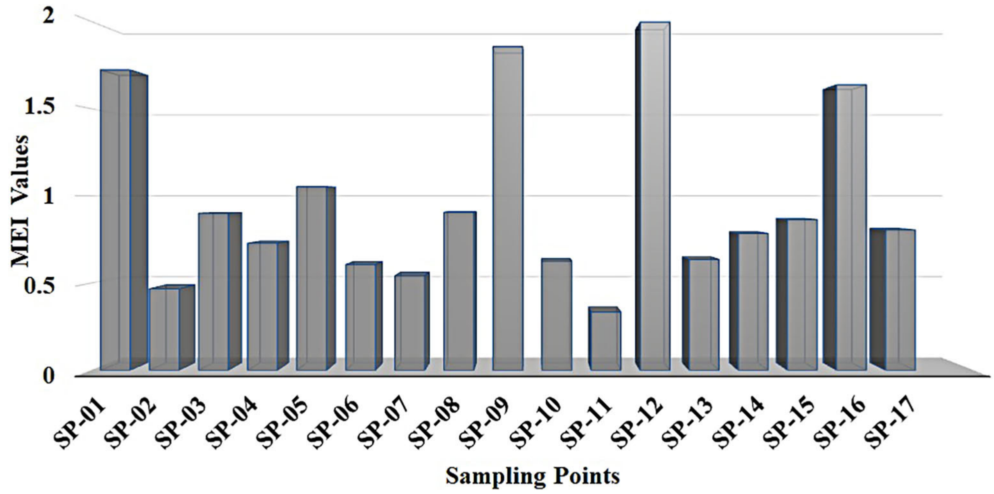

Figure 4. Metal evaluation index (MEI) of the selected heavy metals from the HatiyaIsland, Bangladesh

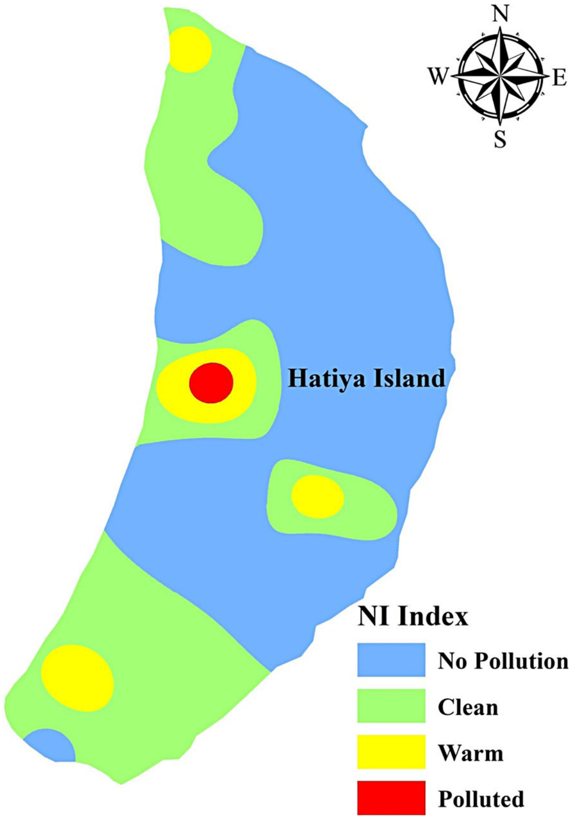

Figure 5. Nemerow pollution index (NI) values of the analysed metals from the HatiyaIsland, Bangladesh

Degree of contamination

To determine the extent of metal pollution at the sampling sites, the degree of contamination (C_d) was used. The minimum value of C_d was -4.70 at sampling point no. 10 and the maximum C_d value was -2.52 at sampling point no. 16. The mean value of all sampling points was -3.32. The C_d values in this study revealed that all the sampling sites (SP-01 to SP-17) exhibited no potential Risk (Fig. 6).

The calculated pollution indices (MPI, MEI, NI, C_d) in the present study were very low compared to other studies conducted in different areas of Bangladesh and other deltaic regions. The low indices values of the analyzed samples were mainly due to the lesser concentration of the metals. The samples were collected from deep tubewells where the source of metals in groundwater is geologic activity and there is no chance of anthropogenic metal pollution. A comparative statement of different pollution indices for groundwater associated with metal contamination in coastal Bangladesh and other parts of the world is presented in Table 3.

Health risk assessment (HRA)

The present study carried out health risk assessments (HRA) of adults and children to assess the potential non-carcinogenic health risk of Cu, Zn, Fe, and Mn in groundwater through oral intake and dermal pathways. The HQ values for Cu, Fe, Mn, and Zn in oral exposure pathways were all less than 1 for both adults and children, which suggests these elements individually do not pose any risks to the local community. Even the HI values of these metals did not exceed the critical value 1 implying that the deep groundwater of the Hatiya Island is safe for drinking for the aforementioned metals for both children and adults. Among these findings, the HI values for children were higher than those for adults at all sampling sites, indicating that children could be vulnerable compared to adults (Fig. 7).

Furthermore, the HQ values of the analyzed metals also revealed that adults and children were safe in dermal contact with groundwater as none

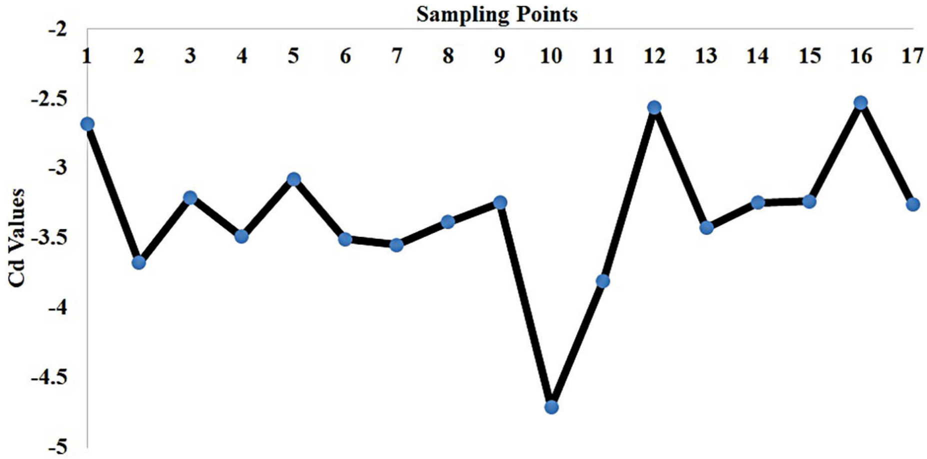

Figure 6. Degree of contamination (C_d) of the selected heavy metals from the Hatiya Island, Bangladesh

Table 3. Comparison of pollution indices analysed in the present study with other studies conducted in Bangladesh and other parts of the world

Study Area	MPI	MEI	NI	C_d	Reference
Hatiya Island	8.6–55.73	0.33–1.99	0.14 – 1.3	–4.70 to –2.52	Present study
South-eastern coastal area of Bangladesh	67.20–328.71	17.47–58.90	NA	8.47 to 49.90	Deeba et al., 2021
MeghnaGhat, Narayanganj	99.98–100.01	16.40–273.43	NA	− 1.43 to 8.12	Rahman et al., 2020b
Coastal region, Bangladesh	–39.43–8,718.43	0.38–65.25	NA	–2.62 to 62.25	Islam et al., 2020
Dhaka, Bangladesh	6.75–138.74	0.275–7.227	NA	NA	Sharmin et al., 2020
DamurhudaUpazila, Chuadanga District	NA	6.50–20.81	2.19 – 8.62	2.37 to 16.49	Bodrud-Doza et al., 2019
Central Bangladesh	5.59–425.89	0.89–33.65	NA	0.19 to 32.63	Bodrud-Doza et al., 2016
Red Sea coast, southern Saudi Arabia	18.03–242.07	NA	NA	4.88 – 88.82	Alfaifi et al., 2021
Kadava River Basin, India	476.99–1833.65	522.89–2010.05	NA	231.56 to 1373.22	Wagh et al., 2018
Himachal Pradesh, India	10.73–107.5	10.31–46.869	NA	1.31 to 37.869	Rajkumar et al., 2020
West Bokaro coalfield, India	3–42	NA	NA	NA	Tiwari et al., 2016
Satluj River Basin, India	65.85 – 362.4	NA	NA	NA	Singh et al., 2013

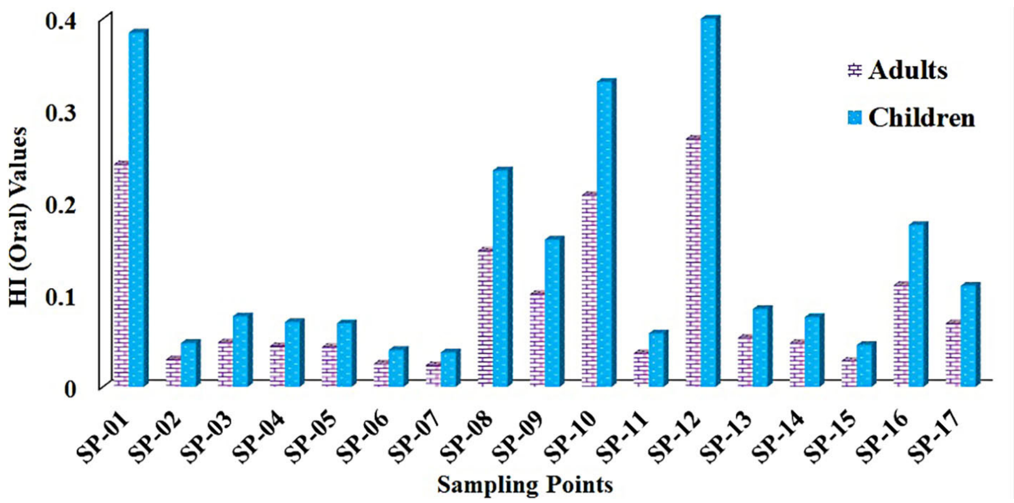

Figure 7. Hazard index (Oral) of the selected metals from the groundwater of Hatiya Island, Bangladesh

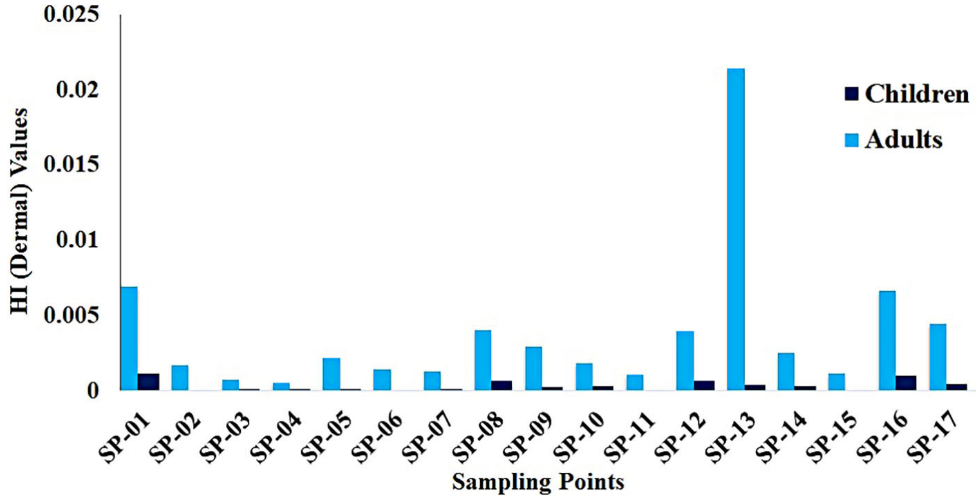

Figure 8. Hazard index (Dermal) of the selected metals from the groundwater of Hatiya Island, Bangladesh

of the metal values exceeded 1. The hazard index (HI) values were also found <1, representing no dermal health risk. At all sampling locations, the HI values for adults were higher than for children, suggesting that adults were more vulnerable than children in the dermal aspect (Fig. 8).

CONCLUSIONS

The present study assessed the Cu, Fe, Zn, Mg, and Mn concentrations in deep groundwater collected from the Hatiya Island in central coastal Bangladesh. Because of arsenic and salinity problems, people do not use shallow groundwater. Except for Fe, all other metals fall within the standard limits of drinking water according to WHO (2017), BIS (2012), and BDWS (1997). In the case of Fe, it was found that 29.41% of groundwater samples exceeded the BIS (2012) and WHO (2017) standard limits. The results of MEI suggested that all the 17 samples fall in a low degree of pollution. In the case of the metal pollution index (MPI), only 4 samples exceeded the lower limit of 45 but no sample crossed the critical limit. According to the nemerow pollution index (NI), polluted water is only found in the central-western part of Hatiya Island. The Cd values of analyzed metals revealed no contamination of groundwater. No oral and dermal health risk was found for individual metals (Cu, Zn, Fe, Mn) and combined metals, which indicates the deep groundwater of whole Hatiya Island was non-carcinogenic risk-free for both children and adults. From this study, it can be concluded that the deep groundwater of Hatiya Island is metal contamination-free and relatively safe for drinking.

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