ISSN: 2634 - 8845

Journal of Earth and Environmental Sciences Research

Research Article

Open Access

Groundwater Quality and Risk Assessment of Heavy Metal Pollution in Middle-West Part of Bangladesh

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ABSTRACT

Bangladesh is a densely populated and developing country that faced severe water contamination, crisis, and security. About 100% of the population has access to the availability of freshwater, but the purity of water is always concerned. The groundwater of Bangladesh is under increasing threat from over-exploitation, population growth, rapid urbanization, and pollution from industries, domestic and agricultural sources. For the assessment of heavy and toxic metal contamination in shallow groundwater, the study collected 40 water samples from different stations in the middle-west part of Bangladesh. The results showed that three metals ion, viz. iron, manganese, and lead exceeded the concentration limit of WHO (2011) in most of the water samples indicating severe human health hazard. The single-factor pollution index (I_i) and compound pollution index (*CPI*) value of these three (3) metals were very high, i.e., much greater than 1. The other metal concentrations were found within the safe permissible ranges. The values of heavy metal pollution indices, viz. heavy metal pollution index (*HMPI*), heavy metal evaluation index (*HMEI*), degree of contamination (C_d), Nemerow Index (*NeI*), and ecological risk measurement (*ERI*) showed that most of the water samples were found medium to high levels of contamination in the study area. The analysis results revealed that an average of 32.6%, 15.6%, and 51.8% of the water samples was found low, medium, and high risk from heavy metal, respectively. There were 20 samples found highly contaminated with heavy metals out of 40 samples. The study results revealed that both the geogenic and anthropologic activities influenced the groundwater system of the area. It suggested that the groundwater quality should go under a continuous monitoring process for sustainable water quality management in the area. The study findings could help with further planning of potential future remediation measures for policymakers.

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Received: March 05, 2021; **Accepted:** March 15, 2021; **Published:** March 31, 2021

Keywords: Bangladesh, Drinking Water, Groundwater, Heavy Metal, Pollution Indices, Risk Assessment, Toxicity

Introduction

The most valuable unlimited natural resources 'groundwater' is crucial for livelihood, food security, meet all demand for irrigation and human consumption, and play a vital role in every development process. The groundwater of Bangladesh is under increasing threat from over-exploitation, population growth, rapid urbanization, and pollution from industries, domestic and agricultural sources.

The groundwater is considered the largest source of drinking and irrigation purposes water for most of the lower-middle-income and developing countries. About 97% of the world's unfrozen fresh water found beneath the earth's surface as groundwater, and it offers about 50% of present drinkable water supplies, 40% of the industrial water demand, and 20% of the water used for irrigation purposes [1]. Though, some countries where fully depend on groundwater for drinking purposes. For instance, in Southeast Asian and Pacific nations, an average of 66% of households in municipal areas and 60% of households in rural areas rely on groundwater for drinking [2].

Heavy metals pollution in groundwater is increasing rapidly in Bangladesh along with the rapid agricultural expansion and urbanization. Heavy metals as a type of insistent toxic pollutants are non-biodegradable in the environment. Thus, the residual trace metals in the water environment are threatening human health and eco-security [3,4]. The major sources of trace metals in the groundwater are atmospheric precipitation, agricultural wastes, discharge of industrial wastewater, agro-pesticides leaching, and urban sewage, mineral mining, and infusion of surface runoff [5]. Heavy metals are insoluble in the receiving water, and most of them are transformed from the aqueous phase to the solid phase and finally deposited in the topsoil and then it leaching into the groundwater basement [6]. Due to this process, the contents of heavy metals in aquifers sediments were higher than those in the aqueous phase; hence, that can be regarded as the accumulation library of heavy metals [7, 8]. However, the heavy metals in the sediments can be released into the water phase again, causing secondary pollution of the water and chronically damaging the Eco environment [9]. The heavy metals as non-degradable toxic substances in the water can be enriched via food waves and drinking water from low to high-level organisms. Such enrichment leads to direct or indirect accumulation of heavy metals in the human body, causing chronic poisoning and threatening human health or even life [4].

Many heavy metal indices models such as degree of contamination, heavy metal evaluation index, contamination factor, and health risk evaluation [10,11], and water assessment indices [12] were developed for assessing water quality considering physicochemical parameters. Grading water quality indicators largely depends on indicator concentration and the rate of relative toxicity. One of the most applicable methods is the Water Quality Index (WQI) that summarizes the quality of water for potable and other household purposes [13, 14]. Though, WQI needs weights for the different chemical components. Experts usually subjectively assign these [15]. Moreover, numerous water quality indices were proposed for the assessment of water quality based on heavy metals [16, 17]. One of these indices is the heavy metal pollution index (*HMPI*). This method considered the maximum acceptable limit and maximum permissible limit of each heavy metal for water quality classification. According to current regulatory guidelines, several heavy metals are now being considered under the non-relaxation category [18]. Hence, *HMPI* cannot be calculated using the latest regulatory guidelines. Though, the heavy metal pollution index (*HMPI*) method [12] overcomes this and other limitations of the previous methods. This index is based on only the highest desirable concentration and does not depend on the maximum allowable concentration (Si). Additionally, similar indices are the heavy metal assessment index (*HMEI*), the single-factor pollution index (I_i), the Nemerow index (*NeI*), and the ecological risks index (*ERI*) of heavy metals in groundwater [18, 19, 20].

This study aims to assess the heavy metals contamination in groundwater in the middle-west part of Bangladesh as well as focuses on the degrees and potential ecological risks of heavy metal contamination in groundwater. The outcomes provide essential information on the suitability of the water source for potable or other uses.

Methods and Materials

Sample collection and analysis

Geographically the explored area is positioned at 23°42' and 24°12' north latitudes and 89°22' east longitudes. The total area is 1621.15 sq km and is bounded by the Ganges river (Padma river) and the other three branch rivers created a big deltaic flood plain (Fig. 1). The population of that area is around 2 million and the maximum of the people involve in agricultural activities [21]. The maximum temperature mainly observes in May-June and the lowermost in December-January. The area received total rain of 1167 mm/y. Up to 90% of yearly rainfall happens throughout the monsoon period (July to October) whereas less than 5% of rain occurs through the dry period (November to March) [21]. During this period with almost no effective rainfall, cultivation is not possible without groundwater irrigation. Around 95% of mining groundwater used for agricultural activities and the remaining for consumption as drinking water. But groundwater abstracting is not controlled by the authority. So, groundwater should assess the most efficient in terms of drinking purposes in the study area.

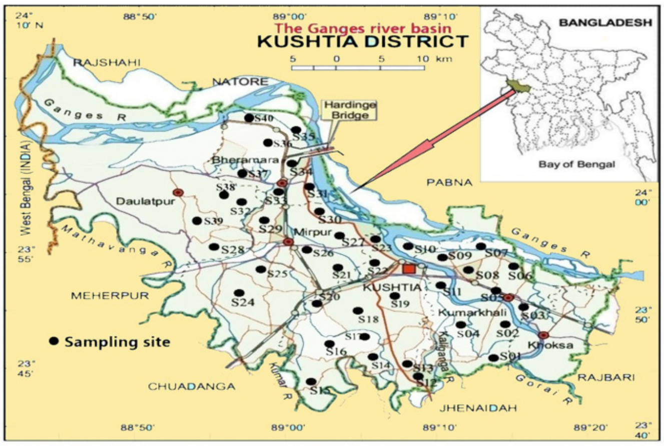

Figure 1: Map of sampling station

Procedure of chemical analysis

A total of 40 sampling sites of the Ganges basin area in the middle-western part of Bangladesh (Fig. 1) were designated for this investigation during the post-monsoon (POM) season. Groundwater samples were collected randomly from the selected hand/engine pumping wells and their depths were ranges from 22 to 125 m. Before sample collection, bottles were washed with 50% HNO3 and rinsed with distilled water. After pumping the wells for 15–20 min. then samples were collected and filtered to avoid debris. For metal analysis, they were preserved by acidified with concentrated AR grade HNO_3 and kept at 4°C. Trace elements viz. iron (Fe), boron (B), manganese (Mn), lead (Pb), chromium (Cr), copper (Cu), cobalt (Co), and zinc (Zn) were measured by the well-recognized method through Perkin-Elmer Atomic Absorption Spectrophotometer (AAS: Model 3110). US-APHA [22] methods were followed in every phase of all the above quantitative analyses. The quality control was kept in all metal analyses as stated by individual instruction manuals and method precision and more than 95% in confidence interval (*CI*) with the correlation coefficient, r=~1 of respective calibration curves. Each method was recalibrated after running ten (10) samples and all quantitative analyses were executed in triplicate to ensure precision. Chemical and spectrometry analyses were carried out in the own laboratory of IES and Central Science Lab, University of Rajshahi, Bangladesh.

Risk calculation of heavy metal pollution

Two types of risk assessment methods of trace heavy metal pollution degree were used to assess the heavy metal pollution in the groundwater in the study area, which is shown below:

Single-Factor Pollution Index (Ii)

Single-factor pollution index (I_i) is used to evaluate how a single heavy metal pollutes groundwater at a sampling station:

$$I_i = \frac{c_i}{s_i} \qquad (1)$$

Where C_i is the measured content of contaminant i in groundwater water (mg/L), and S_i is the evaluation standard of pollutant i in groundwater (mg/L). Here, we followed the WHO guideline value (2011). When I_i is >1, the content of that heavy metal exceeds the standard [23]. The results of the single-factor pollution index of heavy metals in groundwater in the study zone are shown in Table 4 and 5.

Compound pollution index (CPI)

Compound pollution index (CPI) was used to evaluate the heavy trace metal pollution in water, which is expressed as follows equation (2):

$$CPI = \sum_{i=1}^{m} \frac{I_i}{m} \qquad (2)$$

Where I_i is a single-factor index of heavy metal and m is the number of heavy metal types. $CPI<1$ indicates no heavy metal contamination in water samples; $CPI\geq1$ indicates heavy metal contamination [7]. The results were shown in Table 4 and 5.

Pollution indices

Heavy metal pollution index (HMPI)

The heavy trace metal pollution index (*HMPI*) model has been recognized by assigning the weightage (W_i) for a particular parameter and selecting the groundwater parameter on which the index has to be based. The rating is nearly 0 to 1, and its selection reveals the consequence of each water quality parameter. It can be defined as inversely proportional to the suggested standard (S_i) for each parameter [24, 25]. The concentration limits (i.e., the highest permissible value for drinking water (S_i) and maximum desirable value (I_i) for each parameter) were taken from the WHO standard (2011). The heavy metal pollution index (*HPI*) was used for assigning a rating or weightage (W_i) for each particular parameter, is calculated using Equation (3) [24].

$$HMPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

Where W_i is the unit weight of the *i*th parameter, Q_i is the sub-index of the *i*th parameter, and *n* is the number of parameters.

The sub-index Q_i is calculated by,

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{(S_i - I_i)} \quad (4)$$

Where M_i, I_i, and S_i donate for the 'monitored value,' 'ideal value' and 'standard values' of the *i*th parameter respectively. The negative sign (−) denotes a numerical difference between the two values, ignoring the algebraic sign.

Heavy metal evaluation index (HMEI)

The heavy metal evaluation index (*HMEI*) model is consistent with the *HMPI* method, which gives an insight into the overall quality of the groundwater to heavy trace metals [26,27], and it was computed by the following equation (5),

$$HMEI = \sum_{i=1}^{n} \frac{H_c}{H_{mpc}} \quad (5)$$

Where H_c is the monitored value and H_{mac} is the maximum permissible concentration (*mpc*) of *i*th parameters.

The degree of contamination (Cd)

The degree of contamination (C_d) is accepted from [28], and the C_d was determined by the following equation (6):

$$C_d = \sum_{i=1}^{n} C_{fi} \quad (6)$$

Where $Cfi = (C_{ai}/C_{ni}) - 1$ and C_{fi} is the contamination factor, C_{ai} is the analytical value and C_{ni} is the upper acceptance concentration for the *i*th component, and *n* is indicated for the normative value. Here, C_{ni} is taken as the maximum permissible concentration (*MPC*).

Nemerow Index (NeI)

This method is a multifactorial and combined assessment approach where the index is computed using the following equation (7) [29, 30].

$$\text{NeI} = [\{(\text{M}_\text{i} / \text{I}_\text{i})^2_{\text{mean}} + (\text{M}_\text{i} / \text{I}_\text{i})^2_{\text{max}}\}/\text{n}]^{1/2} \quad (7)$$

Where $(M_i/I_i)_{\text{mean}}$ is the average value of (M_i/I_i) of all target heavy metals of a groundwater sample and $(M_i/I_i)_{\text{max}}$ is the maximum value of (M_i/I_i) among all target heavy metals detected in the water sample. This method classifies the water quality into four classes: insignificant contaminated (*NeI*<1), slightly contaminated (1≤*NeI*<2.5), moderately contaminated (2.5≤*NeI*<7), and heavily contaminated (*NeI*≥7).

Ecological risks measurement

We used the ecological risk index (*ERI*) [31, 32] to evaluate the possible environmental hazards associated with heavy toxic metals in groundwater. The ecological risk index was computed as:

$$ERI = \sum_{i=0}^{n} \left[T_i \times \left(\frac{M_i}{I_i}\right)\right] \quad (8)$$

Where T_i is the biological toxicity factor of the *i*th target heavy metal. The toxic-response factor of trace metals is given as: Cd = 30; Cu, Pb = 5; Cr = 2; and Zn, Mn = 1 [33, 34]. The index categories the groundwater quality into four classes, low risk (*ERI*<110), moderate risk (110≤*ERI*<200), considerable risk (200≤*ERI*<400), and very high risk (*ERI*≥400). The calculated results of ERI are mentioned in Table 6.

Results and discussion

Trace metal in samples and toxicity

Trace metals and metalloids, among an extensive limit of contaminations, are steady of a health concern due to their toxicity capacities at a very little concentration and can show an opposing effect on living existences, and tendency to bioaccumulate in lipids and tissues of biotics over time [35]. These metals such as Cr, Pb, Hg, Cd, As, and Co have no useful effects in the body system, moreover, long time exposure may cause more acute interruptions in the normal operations of the human organ systems where the metals deposited [36]. Though some trace metals like Cu, Zn, Fe, and Mn, as micronutrients, are required by the body in limited amounts for metabolic actions, and the same elements, at higher amounts can cause opposing health effects [37]. The key anthropogenic sources of trace metals in groundwater are natural matters leached into the soil or rocks, residue from agrochemicals, controlled release from the sewage treatment plant and industrial run-off, and unrestrained releases or escape from landfill spot and chemical accidents or calamities. The groundwater contamination in Bangladesh with excessive trace metal, especially arsenic, has become an alarming situation.

Chromium (Cr^{3+} and Cr^{6+}) is a naturally occurring trace metal that is usually found in very trace concentrations in groundwater and not influenced by point-source contamination [38]. The major sources of chromium discharge in Bangladesh are the tanning industry and landfills or other solid waste. Chromium (+6) easily enters cell membranes, and Cr (+3) does not [39]. In the human body, the maximum concentrations of Cr accumulated in lymph nodes, kidneys, liver, lungs, and spleen, and continuing exposure can damage the liver and kidneys [40]. WHO, US-EPS and BDWS recommended the permissible highest value of Cr in drinking water of 0.05 mg/L.

Mn is an element vital to the proper working of humans, animals, and plant metabolism, as it is obligatory for the operative of several cellular enzymes and can aid to activate hydrolases, kinases, transferases, decarboxylases. But excessive consumption (over 1.8 mg/L) of Mn-rich water, then showed neural symptoms that are alike Parkinson's disease [41]. Memory damage, hallucinations, disorientation, and impulsive instability also concerns by manganese overdose [42] The secondary extreme contaminant level of 0.5 mg/L for Mn because higher concentrations yield offensive taste, odor, color, staining, and corrosion [43].

Iron (Fe) is the burning issue of rural drinking water in Bangladesh. Although a low level of iron is essential in the human diet and plant metabolism and cannot do much harm, it encourages objectionable bacterial growth ('iron bacteria') inside a waterworks and supply system, resulting in the deposition of a slushy coating on the piping [44]. Besides, high iron content (over 0.3 mg/L) leads to an excess which can cause stomach problems, vomiting, diabetes, nausea, and hemochromatosis [45].

Copper (Cu) is an indispensable element in animals and plants which shows a significant role in metabolism. Temporary exposure to Cu in potable water can lead to gastrointestinal suffering, long-time exposure can lead to copper toxicosis, which results in liver and kidney damage, anemia, hepatic cirrhosis, and deterioration of the basal ganglia [46]. An excess of copper in aquatic environments is seriously harmful to fish and other aquatic lives [47].

Zinc (Zn) is a naturally occurring trace element and an essential nutrient for body metabolism and development, particularly for newborns and young children. However, drinking water containing high levels of Zn can lead to stomach cramps, neurological problems, vomiting; and chronic exposure to Zn is liable for depressed copper consumption, iron shortage, depressed levels of HDL cholesterol [48].

Cadmium (Cd) is a very toxic trace element with a very long half-life, and it occurs naturally with zinc minerals. This element can release to groundwater from buried wastes containing metal refinery byproducts and electronic components, and by coal-burning [49]. It can consume by eating vegetables grown in contaminated soil and fish or other seafood from contaminated or drinking water holds cadmium. Acute exposure can cause nausea, cancer, diarrhea, anemia, bone marrow disorders, muscle cramps, liver injury, and kidney failure [50].

Lead (Pb) is another omnipresent toxic trace metal and substantial public health concern in the environment [43]. It can cause different biochemical effects when exposed to it for a relatively short time duration These effects may comprise interfering with red-blood-cell chemistry, delays in usual physical and mental growth in an infant, hearing and learning capacities of children, scarcity in attention span, kidney disease, stroke, cancer, and rises in the blood pressure of adults [51]. The highest permissible concentration of Pb in drinking water set by WHO and BDWS is 0.01 and 0.05 mg/L respectively.

Table 1 and 2 shows the concentration of heavy metals present in groundwater sources collected from a different station in sampling sites. The concentration of Fe was the highest in all water samples with almost total samples exceeding the maximum allowable limit (MAL) and one of the samples having the highest concentration (17.86 mg/L). The mean concentration of this metal is 5.072 mg/L with a standard deviation of ±5.317 (Table 2). The quality of the source of water may be the reason for the variation of Fe concentration noticeable in the water samples, which is linked to the quality of treatment of the water sources. It was observed that 87.5% of the samples surpassed the MAL limits set by WHO for Mn, with the highest concentration noticeable in S29 (5.66 mg/L) [43]. The mean value of Mn is 1.614 mg/L with a variance of 2.218 and a standard deviation of ±1.489. Besides, about 50% of the samples exceeded the WHO guideline for the lead (Pb) concentration. But the other metal concentrations remained within the safe ranges.

Table1: Concentration (mg/L) of analyzed metals

S. No.	Fe	Cr	Mn	Co	Cd	Pb	B	Cu	Zn
S1	12.42	0.06	2.92	0.07	0.002	0.03	1.80	1.87	2.07
S2	9.81	0.06	1.32	0.06	0.001	0.02	0.09	0.98	0.68
S3	2.09	0.07	1.51	0.03	0.001	0.00	0.06	0.12	0.92
S4	14.73	0.03	0.91	0.08	0.007	0.02	2.91	2.43	2.55
S5	15.35	0.00	4.05	0.01	0.008	0.01	2.80	1.00	1.08
S6	17.86	0.07	2.89	0.04	0.000	0.04	1.01	2.09	2.54
S7	3.01	0.03	1.65	0.09	0.000	0.02	0.04	0.03	1.33
S8	6.99	0.04	5.51	0.05	0.001	0.00	0.09	0.99	0.49
S9	1.09	0.06	0.70	0.04	0.003	0.00	0.00	1.02	2.00
S10	0.92	0.01	0.98	0.02	0.000	0.00	0.00	0.81	1.11
S11	0.51	0.06	0.09	0.05	0.000	0.02	0.77	2.55	0.95
S12	0.90	0.02	1.00	0.04	0.000	0.01	0.97	1.34	3.00
S13	3.91	0.04	1.79	0.05	0.002	0.04	1.10	1.04	2.07
S14	11.8	0.00	3.89	0.00	0.001	0.03	1.87	2.09	1.70
S15	9.08	0.00	2.21	0.00	0.004	0.00	0.05	0.99	2.09
S16	0.81	0.01	0.90	0.02	0.002	0.02	0.87	0.04	1.00
S17	0.51	0.04	0.09	0.02	0.000	0.04	0.56	0.05	0.44
S18	0.23	0.00	0.76	0.00	0.001	0.01	0.32	1.55	0.95
S19	1.81	0.01	0.88	0.00	0.001	0.03	0.51	0.43	1.43
S20	0.21	0.01	0.99	0.00	0.002	0.01	0.99	0.56	2.12
S21	2.12	0.04	3.71	0.03	0.000	0.02	0.07	3.00	4.11
S22	5.76	0.00	2.00	0.04	0.003	0.04	1.12	2.00	1.06

S23	3.06	0.03	1.99	0.02	0.004	0.09	1.09	1.11	2.19
S24	4.98	0.04	4.09	0.00	0.005	0.10	0.43	0.98	1.08
S25	1.00	0.03	0.08	0.04	0.000	0.02	2.23	0.77	1.23
S26	0.60	0.01	0.71	0.03	0.001	0.00	0.06	0.56	0.96
S27	0.23	0.02	0.07	0.02	0.001	0.00	0.01	1.37	1.00
S28	4.08	0.01	1.09	0.02	0.002	0.01	0.76	1.04	2.44
S29	15.98	0.09	5.66	0.08	0.003	0.00	3.12	2.09	3.01
S30	11.76	0.06	2.09	0.06	0.000	0.05	1.87	3.00	2.50
S31	7.91	0.01	0.01	0.03	0.001	0.06	2.30	1.23	2.3
S32	0.30	0.04	0.05	0.06	0.005	0.00	0.76	0.09	0.09
S33	0.20	0.00	0.00	0.01	0.001	0.00	0.80	0.11	0.11
S34	5.12	0.06	0.12	0.03	0.000	0.03	1.00	0.99	1.32
S35	2.65	0.03	2.98	0.03	0.003	0.01	1.03	1.00	2.01
S36	0.32	0.02	0.34	0.04	0.002	0.00	0.01	0.04	0.70
S37	1.09	0.01	0.90	0.01	0.004	0.00	0.00	0.09	0.16
S38	2.08	0.02	0.10	0.03	0.002	0.00	0.00	0.12	0.90
S39	4.60	0.05	1.40	0.01	0.002	0.01	0.06	0.44	0.34
S40	15.00	0.06	2.11	0.04	0.000	0.02	1.12	1.11	2.00
WHO Standard	0.3	0.05	0.1	0.05	0.003	0.01	2.4	2	3

Table 2: Destructive statistics of metals parameter

Metals	Mean	Minimum	Maximum	Variance	Std. deviation (±)	WHO Standard (2011)	
						Acceptable	Permissible
Fe	5.072	0.2	17.86	28.274	5.317	0.3	-
Cr	0.031	BDL	0.09	0.0006	0.0239	0.05	-
Mn	1.614	BDL	5.66	2.218	1.489	0.1	0.3
Co	0.0325	BDL	0.09	0.0006	0.0235	0.05	-
Cd	0.0019	BDL	0.008	3.71E-06	0.0019	0.003	-
Pb	0.043	BDL	1.00	0.0238	0.1545	0.01	-
B	0.866	BDL	3.00	0.762	0.873	1.4	5
Cu	1.078	0.03	4.11	0.674	0.8201	2	5
Zn	1.501	0.09	3.01	0.804	0.897	3	10

Pearson's correlation matrix

The Pearson's correlation matrix of analyzing groundwater metal parameters is presented in Table 3. In some cases, the dissimilatory matrix value for the same pair of parameters is observed. The statistical result showed that iron (Fe) is strongly positively correlated (r>0.5, p=0.01, at 95% *CI*) with boron (B), manganese (Mn), and copper (Cu). On the other hand, chromium (Cr) with cobalt (Co), and copper (Cu) with zinc (Zn) are significantly positively correlated with each other. Other metals are not significantly correlated with each other. This matrix Table would provide important information to evaluate the water quality of the study areas.

Table 3: Pearson's correlation matrix for tested metals in groundwater

Parameter	Fe	Cr	Mn	Co	Cd	Pb	B	Cu	Zn
Fe	1								
Cr	0.352	1.000							
Mn	0.593	0.255	1.000						
Co	0.329	0.579	0.116	1.000					
Cd	0.244	-0.202	0.232	-0.054	1.000				
Pb	0.028	0.070	0.267	-0.211	0.245	1.000			
B	0.621	0.106	0.282	0.296	0.318	-0.034	1.000		
Cu	0.517	0.279	0.407	0.281	-0.058	0.023	0.451	1.000	
Zn	0.394	0.213	0.359	0.222	-0.064	-0.034	0.401	0.657	1.000

Risk Assessment of Heavy Metal Pollution in Groundwater

Two methods viz, single-factor pollution index (I_i) and compound pollution index (*CPI*) uses for the risk assessment of heavy metal contamination in groundwater. When I_i is greater than1, the concentration of the heavy metal exceeds the standard guideline [23]. The results of the single-factor pollution index of heavy metals in groundwater in the study areas are showed in using Table 4 and 5. The I_i values for Fe in all sites are >>1, indicating Fe contents significantly exceeded the standard value. The mean value of Ii for Fe is 16.91, which is very higher than 1. Thus, the metal contents in water samples could significantly affect the heavy metal pollution indices value. Same as iron (Fe), another metal, manganese (Mn) has a very high level with a mean value of 16.14, which is extremely higher than the standard value. Also, lead (Pb) is very toxic and highly poisonous to humans and plants. The Ii values of this toxic metal are greater than 1 for 50% of samples. The mean value of Pb is 4.28 (>1). The results revealed that the other metals such as Cr, Co, Cd, B, Cu, and Zn have a lower value of I_i (<1). The concentration of those metals in groundwater samples of the study area remains in the range of WHO guidelines (2011). Table 5 indicated the summary of the total result of the single-factor pollution index (I_i) for the sampling sites.

Besides, same as single-factor pollution index (Ii), the value of compound pollution index (*CPI*) is below 1 indicating no metal pollution occurred in water. The CPI value of several water samples (S1 to S10, S12 to S16, S18 to S26, S28 to S31, S34, S35, S37 to S40) is higher than 1, showing the degree of trace metal pollution. The average value of *CPI* is 4.54; i.e., samples are highly contaminated by heavy metals.

Table 4: Values of single-factor pollution index (I_i) and compound pollution index (*CPI*) to assessment degree of heavy metal pollution in groundwater

S. ID	Fe	Cr	Mn	Co	Cd	Pb	B	Cu	Zn	CPI
S1	41.40	1.20	29.20	1.40	0.67	3.00	1.29	0.94	0.69	8.86
S2	32.70	1.20	13.20	1.20	0.33	2.00	0.06	0.49	0.23	5.71
S3	6.97	1.40	15.10	0.60	0.33	0.00	0.04	0.06	0.31	2.76
S4	49.10	0.60	9.10	1.60	2.33	2.00	2.08	1.22	0.85	7.65
S5	51.17	0.00	40.50	0.20	2.67	1.00	2.00	0.50	0.36	10.93
S6	59.53	1.40	28.90	0.80	0.00	4.00	0.72	1.05	0.85	10.81
S7	10.03	0.60	16.50	1.80	0.00	2.00	0.03	0.02	0.44	3.49
S8	23.30	0.80	55.10	1.00	0.33	0.00	0.06	0.50	0.16	9.03
S9	3.63	1.20	7.00	0.80	1.00	0.00	0.00	0.51	0.67	1.65
S10	3.07	0.20	9.80	0.40	0.00	0.00	0.00	0.41	0.37	1.58
S11	1.70	1.20	0.90	1.00	0.00	2.00	0.55	1.28	0.32	0.99
S12	3.00	0.40	10.00	0.80	0.00	1.00	0.69	0.67	1.00	1.95
S13	13.03	0.80	17.90	1.00	0.67	4.00	0.79	0.52	0.69	4.38
S14	39.33	0.00	38.90	0.00	0.33	3.00	1.34	1.05	0.57	9.39
S15	30.27	0.00	22.10	0.00	1.33	0.00	0.04	0.50	0.70	6.10
S16	2.70	0.20	9.00	0.40	0.67	2.00	0.62	0.02	0.33	1.77
S17	1.70	0.80	0.90	0.40	0.00	4.00	0.40	0.03	0.15	0.93
S18	0.77	0.00	7.60	0.00	0.33	1.00	0.23	0.78	0.32	1.22
S19	6.03	0.20	8.80	0.00	0.33	3.00	0.36	0.22	0.48	2.16
S20	0.70	0.20	9.90	0.00	0.67	1.00	0.71	0.28	0.71	1.57
S21	7.07	0.80	37.10	0.60	0.00	2.00	0.05	1.50	1.37	5.61
S22	19.20	0.00	20.00	0.80	1.00	4.00	0.80	1.00	0.35	5.24
S23	10.20	0.60	19.90	0.40	1.33	9.00	0.78	0.56	0.73	4.83
S24	16.60	0.80	40.90	0.00	1.67	10.00	0.31	0.49	0.36	17.90
S25	3.33	0.60	0.80	0.80	0.00	2.00	1.59	0.39	0.41	1.10
S26	2.00	0.20	7.10	0.60	0.33	0.00	0.04	0.28	0.32	1.21
S27	0.77	0.40	0.70	0.40	0.33	0.00	0.01	0.69	0.33	0.40
S28	13.60	0.20	10.90	0.40	0.67	1.00	0.54	0.52	0.81	3.18
S29	53.27	1.80	56.60	1.60	1.00	0.00	2.23	1.05	1.00	13.17
S30	39.20	1.20	20.90	1.20	0.00	5.00	1.34	1.50	0.83	7.91
S31	26.37	0.20	0.10	0.60	0.33	6.00	1.64	0.62	0.77	4.07
S32	1.00	0.80	0.50	1.20	1.67	0.00	0.54	0.05	0.03	0.64
S33	0.67	0.00	0.00	0.20	0.33	0.00	0.57	0.06	0.04	0.21
S34	17.07	1.20	1.20	0.60	0.00	3.00	0.71	0.50	0.44	2.75
S35	8.83	0.60	29.80	0.60	1.00	1.00	0.74	0.50	0.67	4.86

S36	1.07	0.40	3.40	0.80	0.67	0.00	0.01	0.02	0.23	0.73
S37	3.63	0.20	9.00	0.20	1.33	0.00	0.00	0.05	0.05	1.61
S38	6.93	0.40	1.00	0.60	0.67	0.00	0.00	0.06	0.30	1.11
S39	15.33	1.00	14.00	0.20	0.67	1.00	0.04	0.22	0.11	3.62
S40	50.00	1.20	21.10	0.80	0.00	2.00	0.80	0.56	0.67	8.57
Mean	16.91	0.63	16.14	0.65	0.63	4.28	0.62	0.54	0.50	4.54

Table 5: Summery of single-factor pollution index (I_i) and water categorization

Result	Fe	Cr	Mn	Co	Cd	Pb	B	Cu	Zn
No. of samples exceeding I>1	39	11	34	7	7	20	6	7	2
% of samples exceeding I>1	97.5	27.5	85	17.5	17.5	50	15	17.5	5
Category	Category	LD/LP	HD/HP	LD/LP	LD/LP	MD/MP	LD/LP	LD/LP	ND/NP

HD/HP-highly dominated/polluted; MD/MP- moderately dominated/polluted; LD/LP- low dominated/polluted

Heavy metal pollution indices

Heavy metal pollution index (*HMPI*), heavy metal evaluation index (*HMEI*), the degree of contamination (C_d), Nemerow Index (*NeI*), and ecological risks measurement (*ERI*) indices were used to evaluate heavy metal contamination in groundwater samples for the study area. That index value is a single-valued and unitless figure. The value of indices is presented in Table 6.

The calculated mean value of *HMPI* were 27.651 with minimum and maximum values are 15.630 and 119.740 respectively (Table 6). The results of *HMPI* index revealed that there are 53% of samples are risk-free, but 14% and 33% of samples are medium and highly contaminated, respectively (Table 6). The high *HMPI* may be due to wastewater from industrial and agricultural activities and domestic sewage. Additionally, geogenic causes of metal pollution was heavily observed in this study area [12]. The HMPI index values of the samples in the Kumarkhali Sub-district (S1 to S11) of the study area were found higher than the critical pollution index.

Table 6: Values of various pollution indices

Parameter	Mean	Minimum	Maximum	Category/Degree of pollution
HMPI	27.651	15.630	119.740	<45 : Low (53%) 45–90 : Medium (14%) >90 : High (33%)
HMEI	40.908	0.048	712.928	<10 : Low (18%) 10–20: Medium (12%) >20: High (70%)
Cd	17.877	0.682	708.730	<10: Low (31%) 10–20: Medium (25%) >20: High (44%)
NeI	39.503 1.751 (except Fe, Mn, Pb)	-	-	<1: Unpolluted (0%) 1≤ NeL<2.5: Slightly polluted (0%) 2.5≤ NeL< 7: Moderately polluted (0%) ≥7: Heavily polluted (100%)
ERI	61.082	0.151	651.480	<110: Low risk (61%) 110≤ERI<200: Moderate risk (9%) 200≤ERI<400: Considerable risk (18%) ≥400: Very high risk (12%)
Average	Low pollution level in samples: (53+18+31+0+61)% = 163; average: 32.6% Medium pollution level in samples: (14+12+25+0+27)% = 78; average= 15.6% High pollution risk of the samples: (33+70+44+100+12)% = 51.8%			

As well, the *HMEI*, C_d, *NeI*, and *ERI* indices were used for a better understanding of the contamination status. The *HMEI* values ranged from 0.048 to 712.928 with a mean of 40.908 (Table 6). There is a huge difference between the ranges of values. Based on the water quality categorization of *HMEI*, approximately 18%, 12%, and 70% of sampling stations were classified as low, medium, and high heavy metal contamination, respectively. This index value gives serious indication than the *HMPI* method. The potential ecological risk of groundwater in the study area in terms of ecosystem services was assessed using the *ERI* method. The *ERI* values of the study area varied from 0.151 to 651.480 with a mean of 61.082 (Table 6). Like the *HMPI* index, about 61% of the sample from the area were found to expose low ecological risk to the groundwater system. However, the other samples were classified in the class of moderate (9%), considerable (18%), and very high (12%) ecological risks.

The computed values of the Nemerow Index (*NeI*) of the samples are gotten very high in correspondence to other indices. These higher values are mainly caused by the higher concentration of Fe, Mn, and Pb. Without those metal concentrations, the computed value become dropped to 1.751 from 39.503. If we consider the Fe, Mn, and Pb load in samples, 100% of samples fall in the heavily polluted category. In the case of the degree of contamination, the results showed that a higher concentration of C_d occurred in groundwater with a mean value of 17.877 mg/L, which was higher than the acceptable value. The permissible limit of C_d for drinking purposes is less than 10 mg/L [7, 12]. The ranges of C_d value were obtained from 0.682 to 708.730 mg/L. However, 31, 25, and 44% of samples are low, medium, and high at risk from metal toxicity.

Conclusions

The analysis results showed that there were three (3) metals viz. iron (Fe), manganese (Mn), and lead (Pb) that exceeded the permissible limits of the WHO standard in most of the groundwater samples. The single-factor pollution index (*Ii*) and compound pollution index (CPI) values of these three metals were very high i.e., much greater than 1. Other metal concentrations remained in the safe ranges. Heavy metal pollution indices viz. *HMPI*, *HMEI*, *Cd*, *NeI*, and *ERI*, showed that most of the water samples have a medium to a high level of metal pollution occurred. The maximum water samples were contaminated by Fe, Mn, and Pb with high concentrations. The results revealed that on average 32.6, 15.6, and 51.8% of samples were low, medium, and high risk from heavy metal. The study revealed that about 50% of the total samples were highly contaminated by trace heavy metals. it observed that the regional groundwater system was contaminated by geogenic and anthropologic activities in the area. The heavy metal pollution indices showed the reliability in characterizing the groundwater contamination concerning heavy metals. Groundwater monitoring is imperative for ensuring its sustainable management. It is important to develop methods that reduce the complexity of data to understandable numbers that managers and policymakers can readily use. The study findings can help for further planning of potential remediation measures.

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