



# **Probabilistic Human Health Risk Assessment of Fe, As and Mn in the Groundwater of Dhamrai Upazila, Dhaka, Bangladesh**

**Sharmin Akter<sup>1</sup>, Partha Pratim Brahma<sup>1</sup>, Atkeeya Tasneem<sup>2\*</sup> and Md. Khabir Uddin<sup>3</sup>**

<sup>1</sup>*Department of Environmental Science and Disaster Management, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalganj-8100, Bangladesh.*

<sup>2</sup>*Department of Environmental Science and Disaster Management, Noakhali Science and Technology University, Noakhali-3814, Bangladesh.*

<sup>3</sup>*Department of Environmental Sciences, Jahangirnagar University, Dhaka-1342, Bangladesh.*

## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author SA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PPB and AT managed the literature searches. Author KU supervised and managed the analyses of the study. All authors read and approved the final manuscript.*

## **Article Information**

DOI: 10.9734/JSRR/2021/v27i430374

### Editor(s):

(1) Dr. Farzaneh Mohamadpour, University of Sistan and Baluchestan, Iran.

### Reviewers:

(1) Moatlhodi Letshwenyo, Botswana International University of Science and Technology (BIUST), Botswana.

(2) Jenny Kehl, University of Wisconsin- Milwaukee, USA.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/68771>

**Original Research Article**

**Received 20 March 2021**

**Accepted 25 May 2021**

**Published 28 May 2021**

## **ABSTRACT**

In Bangladesh, groundwater is the most important source of potable water. This study aims to investigate the amount of Fe, Mn and As in groundwater and to assess the health risks through oral ingestion of these trace metals. Groundwater samples were collected from 20 sample sites throughout the Baishakanda union, Dhamrai upazila for source appointment and risk assessment studies. The concentrations of Fe, Mn, and As were measured using an atomic absorption spectrophotometer. Mean concentration of trace metal level in respectively descending order as Fe>Mn>As. The study found an average concentration of Fe (1.8 mg/L), Mn (0.74mg/L), and As

\*Corresponding author: E-mail: attora2015@gmail.com;

(0.038 mg/L) in the groundwater sample where the mean value of Fe and Mn exceeds the DoE, WHO, and USEPA standards limit. On the other hand, the mean concentration value of As exceeds the WHO and USEPA standards limit. The non-carcinogenic human health risk was calculated by justifying HQ (Hazard Quotient) and HI (Hazard Index). A child (11.4056) is more vulnerable to non-carcinogenic human health risk than an adult (5.3769). Furthermore, As pollution in groundwater samples was found to pose a high carcinogenic risk, with children ( $3.84 \times 10^{-3}$ ) being more vulnerable to carcinogenic risk than adults ( $1.81 \times 10^{-3}$ ). The research area's groundwater was with a significant level of non-carcinogenic as well as cancer-risk (As) susceptibility in the local population.

*Keywords: Hazard Quotient (HQ); Hazard Index (HI); carcinogenic risk; health risk assessment; Bangladesh.*

## 1. INTRODUCTION

Groundwater, the water kept in soil and porous rock aquifers under the Earth's crust [1], is a crucial part of the biggest drinking water sources in Bangladesh [2]. Now in Bangladesh, groundwater supplies around 98% of drinking water [3] and 75% of irrigation water [4]. Because of infiltration of contaminants by the soil media, consistent temperature, natural quality, and low vulnerability groundwater are considered to be safe for drinking than surface water [5]. However, Groundwater can be polluted in many ways. It can be natural or anthropogenic. Septic systems, hazardous waste disposal, petroleum products, solid waste, surface impoundments, agricultural chemicals, establishment of wells, etc. are major anthropogenic causes. But nowadays, for increasing the trace elements such as arsenic (As), iron (Fe), and manganese (Mn) groundwater becomes polluted and sources of the trace elements are natural and artificial [6,7]. One of the major sources of this groundwater contamination by trace elements is industries, disposal of municipal solid waste in unsanitary landfills, etc [8].

Dhamrai upazila in Dhaka district has more than 130 industries including a textile mill, garments factory, rice mill, match factory, steel and engineering aluminum, jute mill, etc [9]. Besides Dhamrai in Savar upazila of Dhaka district has around 1500 industries including Dhaka Export Processing Zone (DEPZ), chemicals, ceramics, leather manufacturing, pharmacy, clothing, dyeing, and washing industries [10]. These industries are the major source of groundwater contamination [11]. By using this contaminated groundwater people face a lot of health issues [12]. As is a naturally occurring trace element that is widely dispersed in the air, water, and soil. In its inorganic form, it is deadly toxic. The utilization of As polluted groundwater is the

primary concern of As toxicity. It also causes skin lesions, gangrene in the leg, cancer in the lung, bladder, liver, and skin, etc. Taking this water via oral ingestion a large number of people are affected by these diseases [13]. Through oral ingestion, Fe and Mn could store in our body [14]. Neurotoxicity can be found in humans by consumption of Mn through oral ingestion [15]. By taking iron contaminated water through oral ingestion dysfunction of multiple organs and gastrointestinal distress can occur [16,17]. So, it is important to determine the health risk of these contaminants to estimate the health hazard.

The method of estimating the nature and probability of adverse health effects in humans who might be exposed to chemicals in polluted environmental media now or soon is known as human health risk assessment [18]. Human health risk assessment includes 4 basic steps such as identification of hazard, dose-response relationship, exposure assessment, and risk characterization [19]. Human health risk assessment is a useful way of justifying the degree of health risk faced by various contaminants [20].

This study aimed to determine the level of As, Mn, and Fe in the drinking water of the study area and predict the health risk of adults and children associated with exposure to these trace metals via oral ingestion.

## 2. MATERIALS AND METHODS

### 2.1 Study Area Description

Dhamrai upazila is about 40 kilometers north of Dhaka, Bangladesh's capital city. It is one of Dhaka district's six upazillas. The upazila is bordered on the north by the upazilas of Mirzapur, Kaliakair, and Nagarpur, on the south by Singair, on the east by Savar, and on the west by Saturia. Dhamrai is situated between

the latitudes of 90.02 and 90.14E and the longitudes of 23.50 and 24.02E. Dhamrai upazila has a total area of 307.4 km<sup>2</sup>. The alluvium soil of the Bongshi and Dholesshori rivers makes up Dhamrai upazila. Kolmai and Gazikhal are two other rivers [21].

## 2.2 Sample Collection and Analytical Technique

A total of 20 groundwater samples were collected from pre-selected sampling points in Dhamrai upazila (Fig. 1), with depths ranging from 40 to 250 feet during the winter season (December 2016). A map of the upazila and a handheld GPS receiver (Kansas USA) was used to locate the selected wells. Samples were collected in 250 mL polypropylene plastic bottles. To avoid precipitation of dissolved Fe as well as adsorption of trace metals on the bottle surface before filtration, 2 drops of concentrated HNO<sub>3</sub> were used to acidify the solution [22]. In the laboratory, these acidified groundwater samples were well-preserved in the refrigerator at 4 °C. Many of the samples had labels attached to them. The samples were then sent to the laboratory for analysis. Well-depth and other pertinent information were recorded at each sample site. The sampled wells were in use and were purged for 10 minutes before the field parameters were measured. The physicochemical parameters such as temperature, pH, and electrical conductivity (EC) were measured with calibrated portable instruments. The pH Meter (Model: SensionTM1, HACH International, USA) was employed to measure the pH of groundwater. Electrical conductivity (EC) was measured using a Conductivity Meter (JENWAY, Model: 4520)

and the temperature was also read from the same meter. The concentration of Fe, As, and Mn were measured by Atomic Absorption Spectroscopy (AAS Model: ASC-7000). The department of Environmental Science and Wazed Miah Science Research Centre, Jahangirnagar University Savar, Dhaka, provided materials and apparatus for this analysis. To ensure reproducibility and statistical validity, all samples were analyzed three times. Statistical analysis was done by MS-excel 2013.

## 2.3 Risk Analysis

Risk assessment is defined as the process of estimating the likelihood of any given magnitude of adverse health effects occurring over a specified period as a function of danger and exposure [23]. Each trace element or metalloid's health risk is normally assessed by quantifying the risk level and expressing it as a carcinogenic or non-carcinogenic health risk [24]. The slope factor (SF) for carcinogen risk characterization and the reference dose (RfD) for non-carcinogen risk characterization are the two key toxicity risk factors studied [25]. Metals were exposed by two routes: (1) direct ingestion of contaminated water and (2) dermal absorption of pollutants in water adhered to exposed skin [26]. The chronic daily intake by ingestion was calculated using Equations 1 which was adapted from the US Environmental Protection Agency [27-30].

$$CDI_{Oral} = \frac{(CW \times IR \times EF \times ED)}{(BW \times AT)} \quad (1)$$



Fig.1. Map of Dhamrai Upazila (source: Banglapedia, 30 June 2014)

Here, CDI = Chronic daily intake ( $\mu\text{g}/\text{Kg}/\text{day}$ )  
 CW = Concentration of trace metal in water ( $\mu\text{g}/\text{L}$ ),  
 IR = Ingestion rate (L/day; 2.2 for adult 1 for Child),  
 EF = Exposure frequency (Days/year, 365),  
 ED = Exposure duration [Year; for oral = 70 for Adult, 10 for Child],  
 BW = Body weight (Kg; 70 kg for Adult, 25 kg for Child),  
 AT = Average time (Days; 25,550 for Adult, 3650 for Child) [12,23,26,29–32].

The health risk from groundwater use was justified based on chronic (non-carcinogenic) and carcinogenic effects. The non-carcinogenic risk was calculated as Hazard quotient (HQ) by the following equation.

$$HQ = \frac{CDI}{RfD} \quad (2)$$

Where HQ is hazard quotient (unitless) and RfD ( $\mu\text{g}/\text{Kg}/\text{day}$ ) originates from risk-based concentration table [33].

For elemental risk assessment, the individual HQs are combined to form Hazard Index (HI). If the value of HQ and HI exceeds 1, there could be potential non-carcinogenic effects on health while HI less than 1 indicates no risk of health effects [34,35].

$$HI = HQ_1 + HQ_2 + \dots + HQ_n \quad (3)$$

Carcinogenic risks (CR) were calculated as the incremental probability of a person developing cancer over time as a result of exposure to a potential carcinogen [36,37]. The results measured the risk of exposure because of the adopted particular slope factor (CSF) of the carcinogens by Eq (4).

$$CR = CDI \times CSF \quad (4)$$

Where CR is cancer risk for each metal for the specific routes; CSF is called the slope factor of cancer-causing contaminants. CSF can vary for various routes [38] as As:  $1.5 \times 10^{-6}$  and  $3.8 \times 10^{-7} \text{ mg kg}^{-1} \text{ day}^{-1}$  for oral intake route [31,38-39]. The CR on the scale of  $10^{-6}$  to  $10^{-4}$  typically is to be permissible value [40]. The CR value is higher than  $10^{-4}$  dictated

the likelihood of potential cancer risk [36].

### 3. RESULTS AND DISCUSSION

#### 3.1 General Characteristics of Groundwater

Table 1 shows that the EC of the groundwater samples was between 2000-5000  $\mu\text{S}/\text{cm}$  where the average value was  $3500 \pm 688.25 \mu\text{S}/\text{cm}$ . According to [41] the maximum limit of EC is 500  $\mu\text{S}/\text{cm}$  and according to [42] 1500  $\mu\text{S}/\text{cm}$ . In terms of TDS, samples were between 188-420 mg/L where the mean value is  $260.8 \pm 60.56 \text{ mg}/\text{L}$ . According to [41] and [42], the maximum limit of TDS is 1000 mg/L and 1500  $\mu\text{S}/\text{cm}$  according to [43]. With this TDS value, they can be said as freshwater [44].

While sampling, the sampling water temperatures were between 24.3-29.9°C with an average temperature of  $25.95 \pm 1.14 \text{ }^\circ\text{C}$ . Water protection in coastal aquifers can be hampered by relative sea-level rise and saltwater intrusion, like Iran where the average EC is 3416  $\mu\text{S}/\text{cm}$  [45], Favignana island, Italy where the average EC is 3979  $\mu\text{S}/\text{cm}$  [46], China where the average is 1673  $\mu\text{S}/\text{cm}$  [47]. These values are greater than our EC value. Hence, the underlying groundwater recharges and flow conditions are vulnerable due to the absence of surface water.

In the water sample, values of Fe were between 0.3607-5.8631 mg/L with a mean value of  $1.8 \pm 1.59 \text{ mg}/\text{L}$ . As the safe limit is 0.3-1.0 mg/L nationally and globally, the mean value crossed the maximum level of Bangladesh and international standards. Mn was in the range of 0.09-2.39 mg/L with an average of  $0.74 \pm 0.62 \text{ mg}/\text{L}$ . Its mean also exceed the national and international limit. The value of As was between 0.01-0.06 mg/L with an average of  $0.038 \pm 0.016 \text{ mg}/\text{L}$ . Its national standard is 0.05 mg/L but the international standard is 0.01 mg/L. This means it crossed the international standard limit.

#### 3.2 As, Fe and Mn Concentration in Groundwater

Fig. 2(a) and 2(b) are the graphical presentations of As concentration in groundwater. It shows that in 20 samples most of them are safe according to the DoE standard of Bangladesh [42]. Sample 5 has the maximum

As the value of 0.06812 mg/L which is far beyond the WHO and USEPA standard level [41,43]. Fig. 2(b) shows that with the increase of depth, As concentration decreases. At the surface level, there are more chances of As pollution. Fig. 3(a) and 3(b) are the graphical presentations of Fe concentration in groundwater. It describes that almost half of the sample values are exceeded the limiting value according to DoE. The concentration of Fe is relatively low at the higher depth. But at the depth of 30.48 meters, it shows the highest concentration. Fig. 4(a) and 4(b) are the graphical presentations of Mn concentration in groundwater. It analyzes that according to DoE

except for one sample all the samples have a higher concentration of Mn. Though according to WHO almost 7 samples are within the safe limit. At lower depth, the concentration of Mn is very high but it relatively decreases at the higher depth.

Fig. 5 is the graphical representation of together As, Fe and Mn. There are many similarities in terms of their concentration. In terms of samples where Fe is high most of there, Mn is also high. On the lower surface As is very high but Mn and Fe are very high at the depth of almost 31 meters.

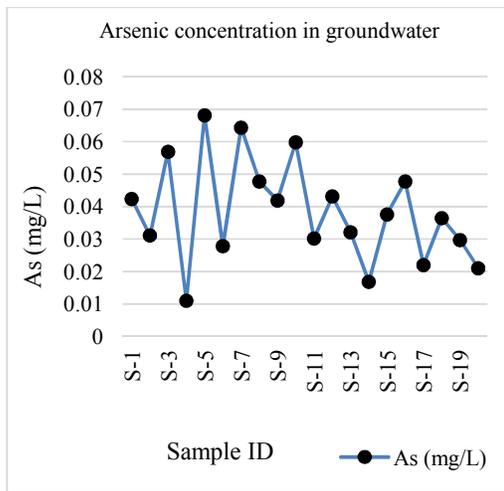


Fig. 2(a). As concentration of samples

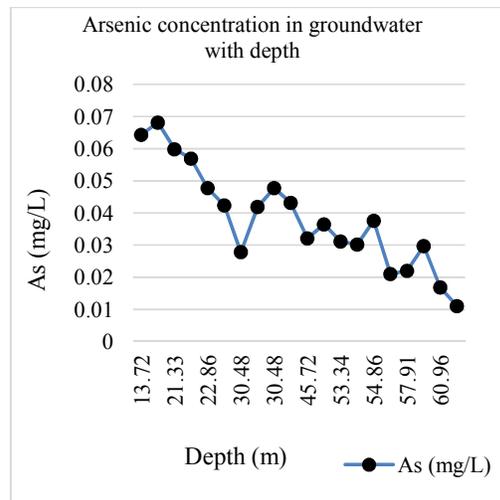


Fig. 2(b). As concentration of samples with depth

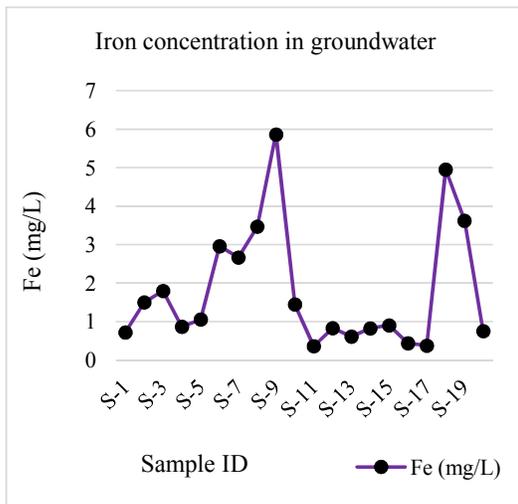


Fig. 3(a). Fe concentration of samples

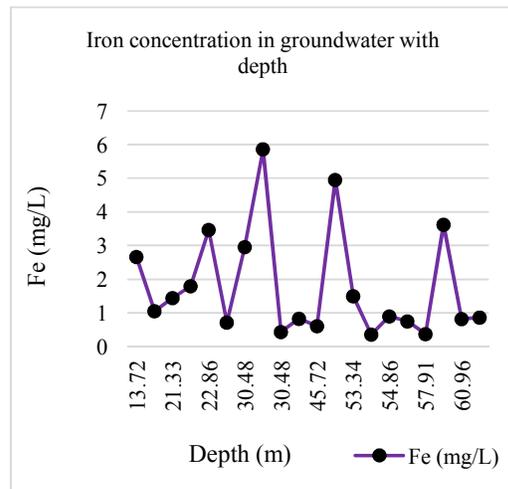


Fig. 3(b). Fe concentration of samples with depth

**Table 1. Descriptive statistics of the parameters in the studied samples**

Parameter	Descriptive statistics				Water quality standards		
	Minimum	Maximum	Mean	Standard deviation	DoE Bangladesh standard [42]	WHO standard [41]	USEPA standard [43]
Temperature (°C)	24.3	29.9	25.95	1.14	20-30	-	-
TDS(mg/L)	188	420	260.8	60.56	1000	1000	500
EC (µS/cm)	2000	5000	3500	688.25	1500	500	-
Fe (mg/L)	0.3607	5.8631	1.8	1.59	0.3-1.0	0.3	0.3
Mn (mg/L)	0.0914	2.3945	0.74	0.62	0.1	0.4	-
As (mg/L)	0.01102	0.0681	0.038	0.016	0.05	0.01	0.01

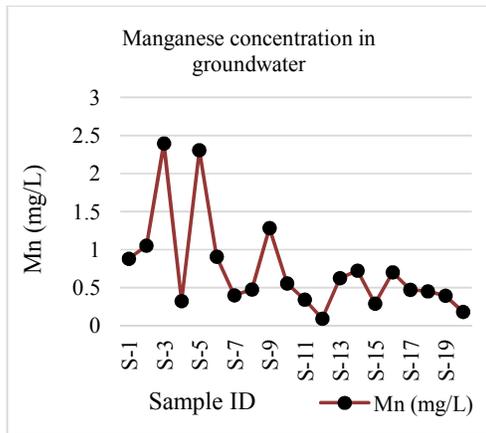


Fig. 4(a). Mn concentration of samples

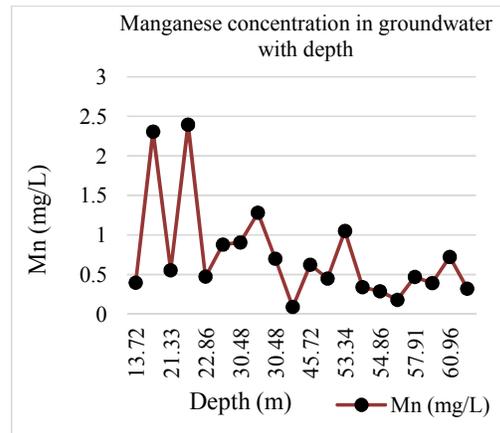


Fig. 4(b). Mn concentration of samples with depth

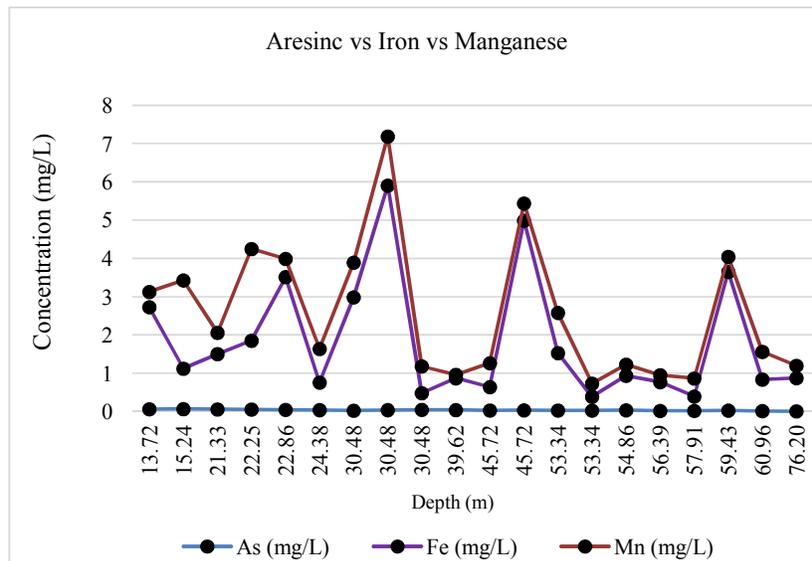


Fig. 5. The concentration of As, Fe, and Mn in groundwater

Table 2. Summary of HQ and HI of As, Fe, Mn, and CR of As (average of 20 groundwater samples)

Health risk	Inhabitants	HQ oral for As	HQ Oral for Fe	HQ oral for Mn	HI	Non-Carcinogenic risk
Non-Carcinogenic	Adult	4.0228	0.1886	1.1655	5.3769	High
	Child	8.5332	0.4	2.4724	11.4056	High
<b>Carcinogenic risk (CR) of As</b>						<b>Carcinogenic risk</b>
Carcinogenic	Adult	$1.81 \times 10^{-3}$				Very high
	Child	$3.84 \times 10^{-3}$				Very high

### 3.3 Human Health risk (HHR) Evaluation

Table 2 describes the summary of non-carcinogenic and carcinogenic risk on adults and children. The average HI of these trace elements is greater than 4 which indicate a higher chronic risk of these non-carcinogenic elements. Compared to an adult, HI values are two times higher in the child section. It indicates children are more vulnerable in terms of adults in the sampling areas. Carcinogenic risk for both adults and child exceeds the standard limit ( $10^{-6} - 10^{-4}$ ) [29].

However, the HQ oral (adult) for As, Fe, and Mn are in between respectively 1.154-7.136, 0.038-0.614, and 0.143-3.762 with the average of As  $4.02 \pm 1.65$ , Fe  $0.19 \pm 0.17$ , and Mn  $1.16 \pm 0.98$ . The HQ for oral use by the child for As, Fe, and Mn are in between respectively 2.44-15.34, 0.08-1.3, and 0.3-7.99 with the mean of As  $8.53 \pm 3.5$ , Fe  $0.4 \pm 0.35$ , and Mn  $2.47 \pm 2.08$ . The following order of average strength of HQ oral values in the study area is As>Mn>Fe for both adults and children. HI calculation is also done for adults and children. It indicates that for both adults and child it has a high non-carcinogenic risk. It is also proved that there is a very high risk of cancer due to the exposure of groundwater via oral ingestion for both adults and children. In this case, children are more vulnerable than adults

### 4. CONCLUSION

The physicochemical, and trace element status of tube-wells were investigated in this study. The study found that the concentration of As, Fe, and Mn found in the majority of tube-well water was significantly higher than the allowable limits suggested by WHO, though the concentration of three elements differed depending on the location and depth of tube wells. Elevated Fe, Mn, and As levels predominate in the 10 m to 40 m depth range. Furthermore, HQ values of Mn and As are the main contributors in HI for non-carcinogenic health risk in both adults and infants. The findings of the study clearly articulate that drinking such tube-well water contaminated especially by As concentration surely poses great health risks to the inhabitants who uses those water for drinking and other daily purposes. Finally, the shallow tube-well in the research area is not suitable for collecting drinking water. The study draws

attention of the people of Bangladesh to be aware of this vulnerability.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

### REFERENCES

1. Siebert S, Burke J, Faures JM, Frenken K, Hoogeveen J, Döll P, et al. Groundwater use for irrigation - A global inventory. *Hydrol Earth Syst Sci.* 2010;14(10):1863–80.
2. Rahman MM, Bodrud-Doza M, Muhib MI, Binte KF, Hossain MS, Akter S, et al. Human health risk assessment of nitrate and trace metals via groundwater in Central Bangladesh. *Pollution.* 2020;6(2):253–66.
3. Shamsudduha M, Joseph G, Haque SS, Khan MR, Zahid A, Ahmed KMU. Multi-hazard groundwater risks to the drinking water supply in Bangladesh: Challenges to achieving the sustainable development goals. *Multi-Hazard Groundw Risks to Drink Water Supply Bangladesh Challenges to Achiev Sustain Dev Goals;* 2019.
4. Shahid S, Chen X, Hazarika M. Evaluation of groundwater quality for irrigation in Bangladesh using Geographic information system. *J Hydrol Hydromechanics.* 2006;54(1):3–14.
5. Panaskar DB, Wagh VM, Muley AA, Mukate SV, Pawar RS, Aamalawar ML. Evaluating groundwater suitability for the domestic, irrigation, and industrial purposes in Nanded Tehsil, Maharashtra, India, using GIS and statistics. *Arab J Geosci [Internet].* 2016;9(13):1–16. [Cited 2021 Apr 11] Available: <https://link.springer.com/article/10.1007/s12517-016-2641-1>
6. Rahman MM, Sultana R, Shammi M, Bikash J, Ahmed T, Maruo M, et al. Assessment of the status of groundwater arsenic at singair upazila, Manikganj Bangladesh; Exploring the correlation with other metals and ions. *Expo Heal.* 2016;8(2):217–25.
7. Sharma C, Mahajan A, Kumar Garg U. Fluoride and nitrate in groundwater of south-western Punjab, India—occurrence, distribution and statistical analysis.

- Desalin Water Treat. 2016;57(9):3928–39.
8. Ravindra K, Mor S. Distribution and health risk assessment of arsenic and selected heavy metals in Groundwater of Chandigarh, India. *Environ Pollut* [Internet]. 2019;250:820–30. Available:https://doi.org/10.1016/j.envpol.2019.03.080
  9. BBS. District Statistics 2011 Dhaka District [Internet]. Dhaka, Bangladesh; 2011. Available:http://203.112.218.65:8008/WebTestApplication/userfiles/Image/DistrictStatistics/Dhaka.pdf
  10. Hasan M, Islam MA, Aziz Hasan M, Alam MJ, Peas MH. Groundwater vulnerability assessment in Savar upazila of Dhaka district, Bangladesh — A GIS-based DRASTIC modeling. *Groundw Sustain Dev* [Internet]. 2019;9:100220. Available:https://doi.org/10.1016/j.gsd.2019.100220
  11. Acharya S, Rijal ML. Distribution of industrial effluents in groundwater and surface water in the surroundings of Lumbini Sugar Industry, Sunwal. *Bull Nepal Hydrogeol Assoc.* 2020;5:105–17.
  12. Kavcar P, Sofuoglu A, Sofuoglu SC. A health risk assessment for exposure to trace metals via drinking water ingestion pathway. *Int J Hyg Environ Health* [Internet]. 2009;212(2):216–27. [Cited 2021 Apr 12]. Available:https://pubmed.ncbi.nlm.nih.gov/18602865/
  13. Muhib MI, Chowdhury MAZ, Easha NJ, Rahman MM, Shammi M, Fardous Z, et al. Investigation of heavy metal contents in cow milk samples from area of Dhaka, Bangladesh. *Int J Food Contam* [Internet]. 2016;3(1):16. [Cited 2021 Apr 12]; Available:https://foodcontaminationjournal.biomedcentral.com/articles/10.1186/s40550-016-0039-1
  14. Wasserman GA, Liu X, Parvez F, Ahsan H, Levy D, Factor-Litvak P, et al. Water manganese exposure and children's intellectual function in Araihasar, Bangladesh. *Environ Health Perspect.* 2006;114(1):124–9.
  15. Merrill RD, Shamim AA, Ali H, Jahan N, Labrique AB, Schulze K, et al. Iron status of women is associated with the iron concentration of potable groundwater in rural Bangladesh. *J Nutr* [Internet]. 2011;141(5):944–9. [Cited 2021 Apr 12]; Available:https://pubmed.ncbi.nlm.nih.gov/21451130/
  16. Heming N, Montravers P, Lasocki S. Iron deficiency in critically ill patients: Highlighting the role of hepcidin [Internet]. Vol. 15, *Critical Care.* BioMed Central. 2011;210. [Cited 2021 Apr 12]. Available:/pmc/articles/PMC3219406/
  17. El Midaoui A, Elhannouni F, Taky M, Chay L, Menkouchi Sahli MA, Echihabi L, et al. Optimization of nitrate removal operation from ground water by electrodialysis. *Sep Purif Technol.* 2002;29(3):235–44.
  18. Momot O, Synzynys B. Toxic aluminium and heavy metals in groundwater of Middle Russia: Health risk assessment. *Int J Environ Res Public Health.* 2005;2(2):214–8.
  19. Wu B, Zhang Y, Zhang X, Cheng S. Health risk from exposure of organic pollutants through drinking water consumption in Nanjing, China. *Bull Environ Contam Toxicol.* 2010;84(1):46–50.
  20. Bortey-Sam N, Nakayama SMM, Ikenaka Y, Akoto O, Baidoo E, Mizukawa H, et al. Health risk assessment of heavy metals and metalloids in drinking water from communities near gold mines in Tarkwa, Ghana. *Environ Monit Assess.* 2015;187(7):1–12.
  21. BBS. Statistical Yearbook of Bangladesh-2011 [Internet]. 31st ed. Bangladesh Bureau of Statistics. Ministry of Planning, Government of the People's Republic of Bangladesh. 2011;1–532. Available:http://203.112.218.65:8008/WebTestApplication/userfiles/Image/LatestReports/YB2011.pdf
  22. Rodger BB, Andrew DE, Eugene WR. Standard methods for the examination of water and wastewater. 23rd ed. Vol. 58, *American Public Health Association.* 2012;7250–7257.
  23. USEPA. National primary/secondary and drinking water regulations. [Internet]. Washington. D. C. Washington, D.C.; 2009. Available:https://www.epa.gov/dwreginfo/drinking-water-regulations
  24. Lim HS, Lee JS, Chon HT, Sager M. Heavy metal contamination and health risk assessment in the vicinity of the

- abandoned Songcheon Au-Ag mine in Korea. *J Geochemical Explor.* 2008;96(2-3):223-30.
25. Liu N, Ni T, Xia J, Dai M, He C, Lu G. Non-carcinogenic risks induced by metals in drinking source water of Jiangsu Province, China. *Environ Monit Assess.* 2011;177(1-4):449-56.
  26. USEPA (US Environmental Protection Agency). A risk assessment-multiway exposure spreadsheet calculation tool. United States Environmental Protection Agency; 1999.
  27. Giri S, Singh AK. Human health risk assessment via drinking water pathway due to metal contamination in the groundwater of Subarnarekha River Basin, India. *Environ Monit Assess.* 2015;187(3).
  28. Wongsasuluk P, Chotpantarat S, Siriwong W, Robson M. Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in Ubon Ratchathani province, Thailand. *Environ Geochem Health.* 2014;36(1):169-82.
  29. USEPA. Risk assessment guidance for superfund (RAGS). Volume I. Human health evaluation manual (HHEM). Part E. Supplemental guidance for dermal risk assessment. USEPA. 2004;1(540/R/99/005).
  30. Ecetoc. Aquatic Toxicity of Mixtures. Tech Rep. 2001;(1-64).
  31. EPA. Baseline human health risk assessment. vasquez boulevard and 1-70 superfund site denver, denver (Co). United States Environmental Protection Agency [Internet]. US Environmental Protection Agency, Region VIII; 2001. Available:<https://nepis.epa.gov/Exe/ZyPDF.F.cgi/P1006STM.PDF?Dockey=P1006STM.PDF>
  32. Weyer PJ, Cerhan JR, Kross BC, Hallberg GR, Kantamneni J, Breuer G, et al. Municipal drinking water nitrate level and cancer risk in older women: The Iowa women's health study. *Epidemiology.* 2001;12(3):327-38.
  33. Tahri M, Benyaïch F, Bounakhla M, Bilal E, Gruffat JJ, Moutte J, et al. Multivariate analysis of heavy metal contents in soils, sediments and water in the region of Meknes (Central Morocco). *Environ Monit Assess.* 2005;102(1-3):405-17.
  34. Kasier HF. The application of electronic computers to factor analysis. *Educ Psychol Meas.* 1960;XX(1):141-51.
  35. Sikder MT, Kihara Y, Yasuda M, Yustiawati, Mihara Y, Tanaka S, et al. River water pollution in developed and developing countries: Judge and assessment of physicochemical characteristics and selected dissolved metal concentration. *Clean - Soil, Air, Water.* 2013;41(1):60-8.
  36. Habib MA, Islam ARMT, Bodrud-Doza M, Mukta FA, Khan R, Bakar Siddique MA, et al. Simultaneous appraisals of pathway and probable health risk associated with trace metals contamination in groundwater from Barapukuria coal basin, Bangladesh [Internet]. Vol. 242, *Chemosphere.* Elsevier Ltd. 2020;125183. Available:<https://doi.org/10.1016/j.chemosphere.2019.125183>
  37. Islam ARMT, Al Mamun A, Rahman MM, Zahid A. Simultaneous comparison of modified-integrated water quality and entropy weighted indices: Implication for safe drinking water in the coastal region of Bangladesh. *Ecol Indic* [Internet]. 2020;113:106229. Available:<https://doi.org/10.1016/j.ecolind.2020.106229>
  38. De Miguel E, Iribarren I, Chacón E, Ordoñez A, Charlesworth S. Risk-based evaluation of the exposure of children to trace elements in playgrounds in Madrid (Spain). *Chemosphere.* 2007;66(3):505-13.
  39. Gao B, Gao L, Gao J, Xu D, Wang Q, Sun K. Simultaneous evaluations of occurrence and probabilistic human health risk associated with trace elements in typical drinking water sources from major river basins in China. *Sci Total Environ* [Internet]. 2019;666:139-46. Available:<https://doi.org/10.1016/j.scitotenv.2019.02.148>
  40. USEPA. National Primary Drinking Water Guidelines. Epa 816-F-09-004 [Internet]. 2009;1:7. Available:[https://www.epa.gov/sites/production/files/2016-06/documents/npwdr\\_complete\\_table.pdf](https://www.epa.gov/sites/production/files/2016-06/documents/npwdr_complete_table.pdf)
  41. WHO. Guidelines for drinking-water quality. World Health Organization. WHO Press, World Health Organization, 20 Avenue Appia, 1211 Geneva 27,

- Switzerland: World Health Organization. 2011;876–83.
42. DoE. Environmental law collection [Internet]. Department of Environment, Government of People's Republic of Bangladesh. Dhaka, Bangladesh: Ministry of Environment and Forest, Government of People's Republic of Bangladesh; 2019. Available: [http://doe.portal.gov.bd/sites/default/files/files/doe.portal.gov.bd/page/155eebe8\\_0092\\_4653\\_907d\\_421dc0890e6d/aian\\_sonkolon\\_ff-1-100.pdf](http://doe.portal.gov.bd/sites/default/files/files/doe.portal.gov.bd/page/155eebe8_0092_4653_907d_421dc0890e6d/aian_sonkolon_ff-1-100.pdf)
43. US EPA. National primary drinking water regulations [Internet]. United States Environmental Protection Agency; 2009. Available: <http://water.epa.gov/drink/contaminants/index.cfm>
44. USGS. Saline water and salinity [Internet]. Water Science School; 2021. [Cited 2021 May 2]. Available: [https://www.usgs.gov/special-topic/water-science-school/science/saline-water-and-salinity?qt-science\\_center\\_objects=0#qt-science\\_center\\_objects](https://www.usgs.gov/special-topic/water-science-school/science/saline-water-and-salinity?qt-science_center_objects=0#qt-science_center_objects)
45. Naseh MRV, Noori R, Berndtsson R, Adamowski J, Sadatipour E. Groundwater pollution sources apportionment in the ghaen plain, Iran. *Int J Environ Res Public Health* [Internet]; 2018. [Cited 2021 May 2];15(1). Available: [pmc/articles/PMC5800271/](https://pubmed.ncbi.nlm.nih.gov/31146317/)
46. Tiwari AK, Pisciotto A, De Maio M. Evaluation of groundwater salinization and pollution level on Favignana Island, Italy. *Environ Pollut* [Internet]. 2019;249:969–81. [Cited 2021 May 2]; Available: <https://pubmed.ncbi.nlm.nih.gov/31146317/>
47. Wen X, Lu J, Wu J, Lin Y, Luo Y. Influence of coastal groundwater salinization on the distribution and risks of heavy metals. *Sci Total Environ* [Internet]. 2019;652:267–77. [Cited 2021 May 3]; Available: <https://pubmed.ncbi.nlm.nih.gov/30366327/>

© 2021 Akter et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*

*The peer review history for this paper can be accessed here:*  
<http://www.sdiarticle4.com/review-history/68771>