HUMAN HEALTH RISK ASSESSMENT FROM THE CONTAMINANTS OF MAHANANDA RIVER WATER AND ITS ADJACENT GROUNDWATER IN BANGLADESH

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Abstract

This study aims to assess the physicochemical parameters of the surface water of the Mahananda River and the concentration of the nutrients of the Mahananda River water and the adjacent groundwater. Among physicochemical parameters, pH, Dissolved Oxygen (DO), and Total Dissolved Solids (TDS) were measured on 18 sampling sites of the river, while Sulfate (SO_4^{2-}), Orthophosphate (PO_4^{3-}), Arsenic (As), and Manganese (Mn) concentrations were measured on 17 equidistant sampling sites of the river and the adjacent groundwater. The mean pH value was 8.50 with a standard deviation (SD) of 0.30. DO and TDS were 9.56 mgL^{-1} (SD 1.67) and 127.62 mgL^{-1} (SD 24.76), respectively. The mean SO_4^{2-} concentration was found to be 5.38 mgL^{-1} (SD 12.00) for groundwater and 2.29 mgL^{-1} (SD 1.96) for surface water, while the mean PO_4^{3-} concentration was 1.17 mgL^{-1} (SD 0.78) and 0.63 mgL^{-1} (SD 0.15) for groundwater and surface water respectively. The contamination of As was found to be as high as 100 μgL^{-1} in the groundwater while within 25 μgL^{-1} in the surface water. Mn concentration was high at almost all the points, with a mean value of 1.64 mgL^{-1} (SD 0.90) and 0.54 mgL^{-1} (SD 0.23) for the groundwater and surface water, respectively. The carcinogenic risk from As and non-carcinogenic risk from both As and Mn was estimated for adults and children. The carcinogenic risks were found to be high for both surface water and groundwater, while non-carcinogenic risks were found high for surface water and very high for groundwater. In both cases, children were found more vulnerable than adults.

Keywords: *Arsenic, Carcinogenic Risk, Groundwater, Mahananda River, Manganese, Non-Carcinogenic Risk.*

Introduction

Mahananda is one of the major transboundary rivers between Bangladesh and India. It originates from the Himalayas. Several hilly streams meet at Gyan Sangam and form the Mahananda River. From the origin, it flows about 31 km to reach to Bangladesh and India border adjacent to the Banglabandha-Fulbari land port. About 1.5 km up from this point, the river experienced a major diversion by the Fulbari barrage, where the river meets the Teesta irrigation canal of India and flows further downstream with the same canal name up to Nitaiganj. The mainstream of the river with the remaining streamflow flows as the border river for about 20 km. It then flows through India for 225 km and finally falls on the Ganges near the Farakka barrage. Prior to the falls on the Ganges, a part of the river bifurcated and flowed about 71 km to reach the Bholahat upazila of Chapainawabganj district of Bangladesh. The following 16 km river flow from Bholahat upazila sadar to Baruipara of Gomostapur upazila is again a border river and finally enters Bangladesh at this point. Mahananda River travels about 76 km and falls to the Padma River at Sultanganj of the Godagari upazila of Rajshahi. The total catchment area of the river from its origin to Sultanganj is 20600 km^2, where 11530 km^2 is in India, and 9070 km^2 is in Bangladesh (Ghosh *et al.*, 2022).

The Mahananda River in Bangladesh, crosses Gomastapur, Shibganj, and Chapainawabganj Sadar upazilas. The river has two tributaries in Bangladesh, one on the left bank at Gomostapur, Punarbhaba River, and the other on the right bank at Chapainawabganj Sadar, Pagla River. According to the Bangladesh Water Development Board (BWDB) data, the river's minimum water level declined from 1977 to 2017. BWDB data also suggest that the adjacent groundwater level follows the same trend, and the southern part has a lower groundwater level than the northern part (RRI, 2019). The river contributes to the irrigation of above 10000 hectares of cropland. People near the river use its water for bathing, washing, and household work. According to the Bangladesh Population and Housing Census 2011, about 8.3% of the district's population uses tap water for drinking purposes, while 88.2% uses groundwater and 3.5% other water sources, including surface water (BBS, 2014). They also use this water for cooking.

As is found on Earth naturally. There are both organic and inorganic forms of As in the environment. The organic form is much less harmful than the inorganic form. Inorganic As is highly toxic and found at high levels in the groundwater of many countries, including Bangladesh. Ingestion of As-rich groundwater poses the greatest threat to human health. Inorganic As is a significant contaminant in drinking water and is a confirmed carcinogen (Farzan *et al.*, 2013). Long-term exposure to a high level of inorganic As causes skin, lung, and bladder cancer, pigmentation changes, skin lesions, and hard patches on the palms and soles. In addition to skin cancer, long-term exposure to As may also cause cancers of the bladder and lungs (Tolins *et al.*, 2014). The other effects of As on human health include developmental effects, diabetes, pulmonary disease, and cardiovascular disease (Ravenscroft *et al.*, 2009).

Mn is an essential element for humans. Both under and over-exposure to Mn can cause adverse health effects. Although Mn deficiency is rare, overexposure to Mn is very common globally since it is found in various foods and natural water (USEPA, 1984; Hurley and Keen, 1987). Chronic inhalation of high Mn has been found to have adverse neurological effects on humans. It can cause weakness, anorexia, muscle pain, apathy, slow speech, monotonous tone of voice, emotionless masklike facial expression, and slow, clumsy movement of the limbs (Canavan *et al.*, 1934; Cook *et al.*, 1974; Roels *et al.*, 1999; ATSDR, 2012). Long-term high intake of Mn from drinking water also causes neurotoxicity, and the concentration of Mn is proportional to neurotoxicity (Kondakis *et al.*, 1989).

Both oral and dermal contact with these metals can cause health risks. Thus, it is important to determine the health risk

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of both carcinogenic and non-carcinogenic manner of these contaminants to estimate the health hazard. Assessing the health risk of environmental pollutants is known as human health risk assessment (Momot and Synzynys, 2005). The assessment's main component includes identifying hazards, dose-response relationships, exposure assessment, and risk characterization (Wu *et al.*, 2010). It is a useful way to show the degree of health risk caused by various contaminants (Bortey-Sam *et al.*, 2015).

Tuinhof and Kemper (2011) studied "Mitigation of As Contamination in Drinking Water Supplies of Bangladesh." They studied the severity of As contamination in groundwater at Chapai Nawabganj town was investigated thoroughly, and a scheme was designed to supply As-free water to the townspeople. Islam *et al.* (2014) studied the accumulation of heavy metals in two urban rivers and found a high concentration of accumulation in all the fish species. Akter *et al.* (2021) Conducted a study on the human health risk assessment of groundwater As, Fe, and Mn contamination at the Dhamrai upazila of Bangladesh. Ali *et al.* (2022) studied the heavy metal toxicity of the Bhairab river and reported various heavy metals exceed the permissible limit. Kubra *et al.* (2022) reported the high carcinogenic risks from the sediments of Rupsa River. Several other studies have been conducted to assess human health risks through oral and dermal routes by heavy metals in water (Zhang *et al.*, 2019; Ramazanova *et al.*, 2022). Kormoker *et al.* (2023) studied the physicochemical and heavy metal concentrations of the Buriganga River and reported high carcinogenic and non-carcinogenic risks for both children and adults with a higher vulnerability of children. There has been no report on the human health risk analysis of the Mahananda River. Hence, this study aims to assess the human health risk from the Mahananda River water and its adjacent groundwater.

Methodology

Study Area

The whole reach of the Mahananda River in the Chapainawabganj district of Bangladesh was considered the study area as this is the only part of the river where it flows completely through Bangladesh. The extent of the studying of physicochemical parameters was 86 km, from Bazratek (24°57.025'N, 88°13.953'E), Bholahat, the furthest a civilian can go to the Bangladesh-India border to Sultanganj Ghat (24°29.663'N, 88°18.381'E), Godagari, Rajshahi, where it falls to the Padma River. The extent of the studying of nutrients and elements was 76 km, the total reach of the Mahananda River through Bangladesh, from Baruipara (24°52.639'N, 88°15.490'N), Gomostapur, Chapainawabganj, where the river ultimately enters the Bangladesh territory to Sultanganj (24°29.598'N, 88°18.384'N), where it falls to Padma River.

Sampling Points

Physicochemical parameters were analyzed at 18 points of the Mahananda River, whereas, nutrient and elemental analysis was done at 17 equidistant points of the Mahananda River and adjacent groundwater samples. The groundwater samples were analyzed at the nearest available tube well of the river sampling points. The surface water sampling points for physicochemical parameters are shown in **Fig. 1** and **Table 1**, while nutrients and elemental analysis points are shown in **Fig. 2** and **Table 2**.

Water Quality

All the parameters were determined in situ at the sampling site. The physicochemical parameters such as pH, DO, and TDS were measured only for river water by direct probe method using a portable HACH hq30d multiparameter meter. The Analysis of As was carried out by using a HACH low-range As testing kit method. Mn, SO_4^{2-}, and PO_4^{3-} were determined by the HACH DR 900 portable colorimeter. USEPA Periodate Oxidation Method was used for the determination of Mn concentrations (USEPA, 1979) with a detection limit of 0.1 to 20.0 mgL^{-1}, USEPA SulfaVer 4 Method was used for the determination of SO_4^{2-} concentrations (USEPA a) with a detection limit of 2.0 to 70.0 mgL^{-1}. USEPA PhosVer 3 (Ascorbic Acid) Method was used to determine PO_4^{3-} concentrations (USEPA b) with a detection limit of 0.02 to 2.5 mgL^{-1}.

Health Risk Assessment

Ingestion of water for drinking and cooking purposes and dermal contact during bathing and washing were taken as the intake routes for human health risk assessment. The intake rate of metal through the ingestion route (I_o) was calculated by Eq. (1) (USEPA, 1989):

$$I_o = \frac{C_w \times IR \times EF \times ED}{BW \times AT} \quad \text{Eq. (1)}$$

where C_w is the metal concentration at the exposure site (mgL^{-1}); IR is the ingestion rate (L/day); EF is the exposure frequency (day/ year); ED is the exposure duration (years); BW is the average body weight (kg); AT is the averaging time (day). The intake rate of metal through dermal contact (I_d) was calculated by Eq. (2) (USEPA, 1989):

$$I_d = \frac{C_w \times SSA \times k_p \times CF \times ET \times EF \times ED}{BW \times AT} \quad \text{Eq. (2)}$$

where SSA is the skin surface area (cm^2); k_p is the permeability coefficient specific for each metal (cm.h^{-1}); CF is the respective conversion factor (L.cm^{-3}); ET is the exposure time (h/event); Oral and dermal intakes are expressed as mg.kg^{-1} of body weight/day.

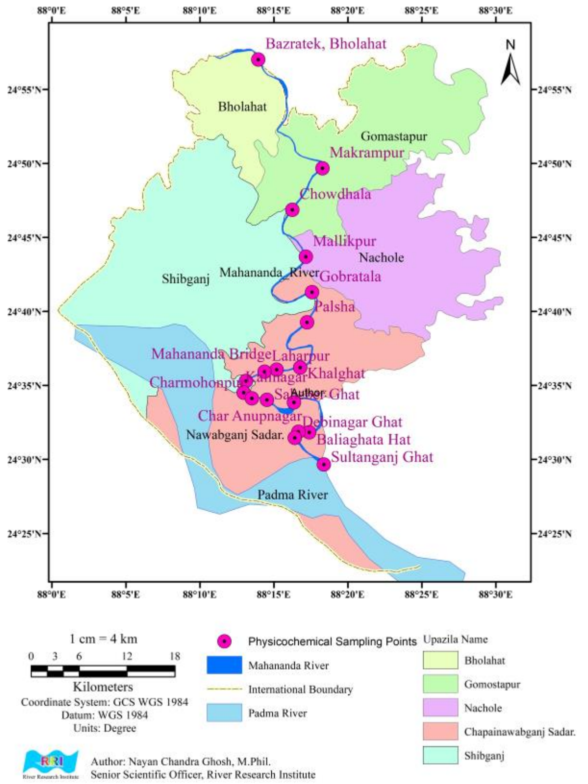

Fig. 1. Surface water sampling points for the analysis of physicochemical parameters.

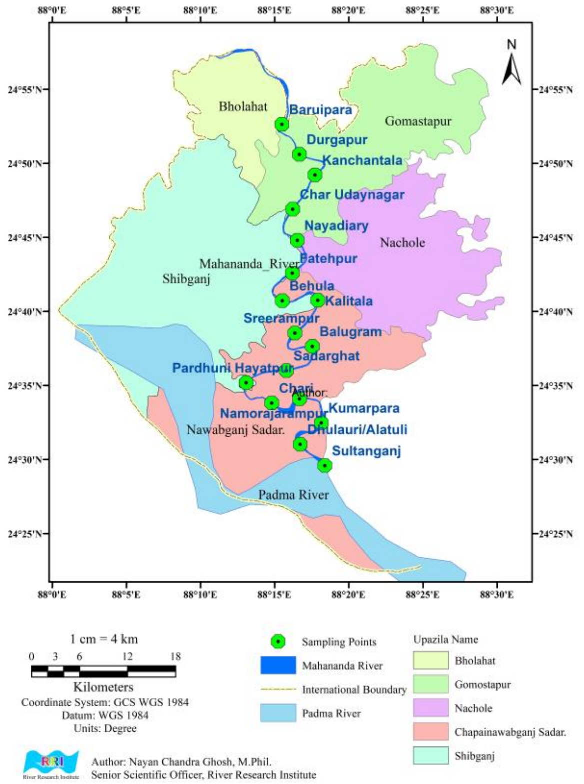

Fig. 2. Surface water sampling points for the analysis of nutrients and elements.

Table 1. Coordinates of the surface water sampling points for the analysis of physicochemical parameters.

Name	Latitude	Longitude
Bazratek, Volahat	24°57.025'N	88°13.953'E
Makrampur	24°49.673'N	88°18.295'E
Chowdhala	24°46.869'N	88°16.257'E
Mallikpur	24°43.700'N	88°17.171'E
Gobratala	24°41.304'N	88°17.593'E
Palsha	24°39.265'N	88°17.247'E
Khalghat	24°36.217'N	88°16.785'E
Mahananda Bridge	24°36.067'N	88°15.196'E
Laharpur	24°35.937'N	88°14.377'E
Ansarer Ghat	24°35.301'N	88°13.119'E
Kalinagar	24°34.514'N	88°12.967'E
Charmohonpur	24°34.137'N	88°13.526'E
Saheber Ghat	24°34.034'N	88°14.538'E
Rajarampur Ghat	24°33.858'N	88°16.361'E
Baliaghata Hat	24°31.836'N	88°17.397'E
Char Anupnagar	24°31.878'N	88°16.668'E
Debinagar Ghat	24°31.466'N	88°16.422'E
Sultanganj Ghat	24°29.663'N	88°18.381'E

Table 2. Coordinates of the surface water sampling points for the analysis of nutrients and elements.

Name	Latitude	Longitude
Baruipara	24°52.639'N	88°15.490'E
Durgapur	24°50.615'N	88°16.673'E
Kanchantala	24°49.218'N	88°17.724'E
Char Udaynagar	24°46.906'N	88°16.219'E
Nayadiary	24°44.809'N	88°16.532'E
Fatehpur	24°42.595'N	88°16.192'E
Behula	24°40.735'N	88°15.515'E
Kalitala	24°40.760'N	88°17.911'E
Sreerampur	24°38.547'N	88°16.366'E
Balugram	24°37.642'N	88°17.547'E
Sadarghat	24°36.008'N	88°15.792'E
Pardhuni Hayatpur	24°35.191'N	88°13.076'E
Chari	24°33.817'N	88°14.809'E
Namorajarampur	24°34.105'N	88°16.680'E
Kumarpara	24°32.479'N	88°18.151'E
Dhulauri/Alatuli	24°31.032'N	88°16.721'E
Sultanganj	24°29.598'N	88°18.384'E

Risk assessment: carcinogenic risk

The carcinogenic risk caused by a specific heavy metal was estimated by Eq. (3) (USEPA, 1989):

$$Risk = I \times SF \quad \text{Eq. (3)}$$

where SF is the slope factor of the carcinogenic heavy metal (kg. day/mg).

Since two exposure routes were considered in this study, the total cancer risk caused by As through oral and dermal exposures was estimated using Eq. (4) (USEPA, 1989):

$$Risk = \sum_{i=1}^{n}\sum_{j=1}^{m} I \times SF \quad \text{Eq. (4)}$$

The threshold range for carcinogenic risk was taken as 10^{-6} as it was determined for a single carcinogenic element (Tepanosyan *et al.*, 2017).

Risk assessment: non-carcinogenic risk

The non-carcinogenic risk was characterized by the hazard quotient (*HQ*) and estimated by Eq. (5) (USEPA, 1989):

$$HQ = I/RfD \quad \text{Eq. (5)}$$

where RfD is the respective metal's reference dose (mg.kg^{-1}. Day^{-1}).

The total non-carcinogenic risk caused by both metals through both exposure routes was characterized as the hazard index (*HI*) and estimated as the sum of obtained hazard quotients (USEPA, 1989) by Eq. (6):

$$HI = \sum_{i=1}^{n}\sum_{j=1}^{m} HQ \quad \text{Eq. (6)}$$

The threshold value for non-carcinogenic risk was taken as 1.00 (LaGrega *et al.*, 2010).

The parameters used to assess the carcinogenic and non-carcinogenic risk assessment for both adults and children are presented in **Table 3**.

Table 3. Risk assessment parameters.

Parameters	Value (Adult)	Value (Child)	
IR	2	1	(Akter *et al.*, 2021)
EF	365	365	(USEPA, 1989)
ED	74.3	10	(BBS, 2014; Akter *et al.*, 2021)
BW	70	25	(Akter *et al.*, 2021)
AT	27120	3650	(USEPA, 2011)
SSA	18000	13000	(USEPA, 2011)
k_p	0.001	0.001	(USEPA, 2004)
CF	0.001	0.001	(Turdiyeva and Lee, 2023)
ET	0.58	1.00	(USEPA, 2004
SF oral	1.5	1.5	(USEPA IRIS, 2019; RAIS, 2022; OEHHA, 2018)
SF dermal	1.58	1.58	(USEPA, 2004)
RfD oral (As)	0.0003	0.0003	(USEPA IRIS, 2019; RAIS, 2022)
RfD dermal (As)	0.000285	0.000285	(USEPA, 2004)
RfD oral (Mn)	0.024	0.024	(USEPA, 2004; USEPA IRIS, 2019; RAIS, 2022)
RfD dermal (Mn)	0.00096	0.00096	(USEPA, 2004)

Results and Discussions

The pH value of the Mahananda River was in the standard range (6.5-8.5) of the DoE (ECR, 2023) in most places, but at the river's entrance to Bangladesh has a slight overvalue. The mean pH value was 8.50 (SD 0.30), while the maximum value was 9.39. A similar value was reported on the Bangladesh part of the Mahananda River (Anonna *et al.*, 2022), but a less value was reported on the Indian territory of the Mahananda River (Rangarajan *et al.*, 2019).

The DO and TDS values were found in good complement to the DoE standards (≥6 mgL^{-1} and 1000 mgL^{-1} respectively) (ECR, 2023) throughout the reach of the river. The mean DO was found to be 9.56 mgL^{-1} (SD 1.67) with a maximum value of 11.71 mgL^{-1} at the Chowdhala point. A DO value of less than 7 mgL^{-1} was reported at the Indian part of the Mahananda River (Rangarajan *et al.*, 2019). The TDS value was found to be 127.62 mgL^{-1} (SD 24.76), with an increasing trend as the river flows downstream. Similar data values on the Bangladesh part of the Mahananda River were reported (Anonna *et al.*, 2022). The rising trend of TDS can be attributed to the influence of the Punarbhaba and Pagla rivers and the urbanization on the banks of the river. The graphical representation of pH, DO, and TDS is shown in **Fig. 3.**

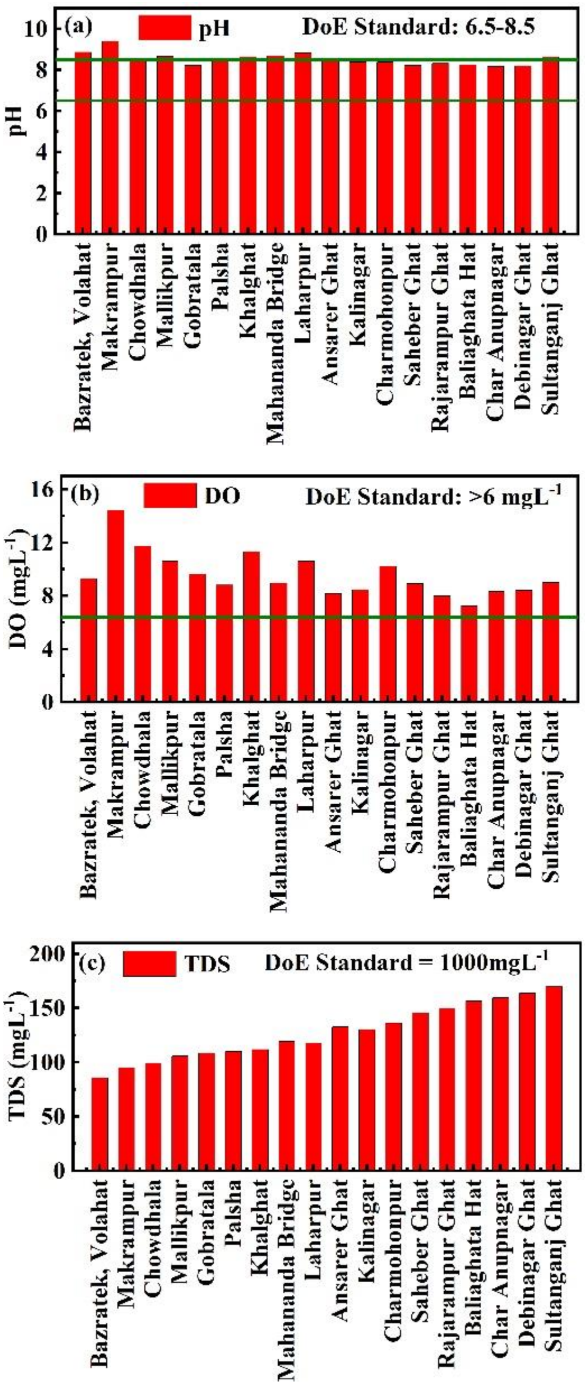

Fig. 3. Distribution of (a) pH, (b) DO, and (c) TDS through the reach of the Mahananda River.

The SO_4^{2-} concentration of both surface water and groundwater of total reach of the Mahananda River is within the standard concentration <250 mgL^{-1} for drinking water by DoE (ECR, 2023), as shown in **Fig. 4.** The maximum concentration of 49 mgL^{-1} of SO_4^{2-} was found in the groundwater of Chari point, and the minimum concentration <2 mgL^{-1}, the lowest measuring range of the testing method, was found in the sampling points of 1-7, 9, 10, and 14. On the other hand, in the surface water, only points 4 and 6 have the Below Measuring Range (BMR) of SO_4^{2-} concentration. The mean SO_4^{2-} concentration in the groundwater was found to be 5.38 mgL^{-1} (SD 12.00), while for surface water, it was 2.29 mgL^{-1} (SD 1.96). The deviation of data shows that the distribution of SO_4^{2-} concentration in groundwater is more scattered than the surface water. A higher SO_4^{2-} concentration in the surface water was reported in (Anonna *et al*., 2022).

Phosphorous in the form of PO_4^{3-} has been found in all the points of sampling points of the Mahananda River and its adjacent groundwater, as shown in **Fig. 5.** The maximum concentration of 2.7 mgL^{-1} PO_4^{3-} was found in the groundwater of the Durgapur point, and the minimum concentration was 0.27 mgL^{-1} at the Fatehpur point. For surface water, it was 0.91 mgL^{-1} at Kalitala point and 0.23 mgL^{-1} at Sultanganj for maximum and minimum concentration, respectively. The mean PO_4^{3-} concentration of the groundwater was 1.17 mgL^{-1} (SD 0.78), while for surface water, it was 0.63 mgL^{-1} (SD 0.15). The recorded data was within the safety limit of ECR 1997 of <6 mgL^{-1} for drinking water (ECR, 1997).

Mn was found high in concentration than the DoE standard of 0.1 mgL^{-1} (ECR, 2023) in all the ground and surface water samples except the samples of the Sadarghat surface water. The maximum concentration of 3.5 mgL^{-1} of Mn was found in the groundwater of Char Udaynagar, while the lowest of 0.4 mgL^{-1} was found at Kanchantala. The lowest concentration of Mn in the groundwater was four times the DoE standard of Mn for drinking water.

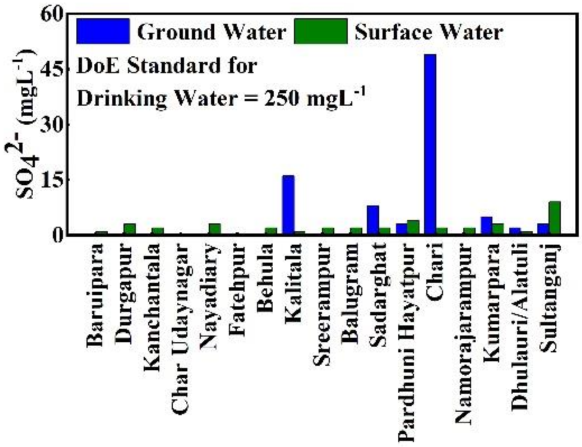

Fig. 4. Distribution of SO_4^{2-} concentration on Groundwater and surface water of Mahananda River.

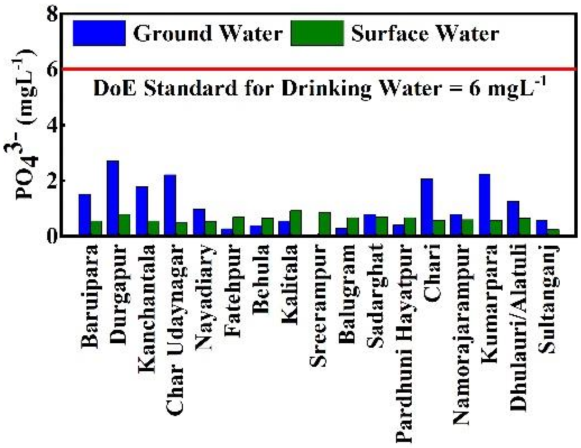

Fig. 5. Distribution of PO_4^{3-} concentration on Groundwater and surface water of Mahananda River.

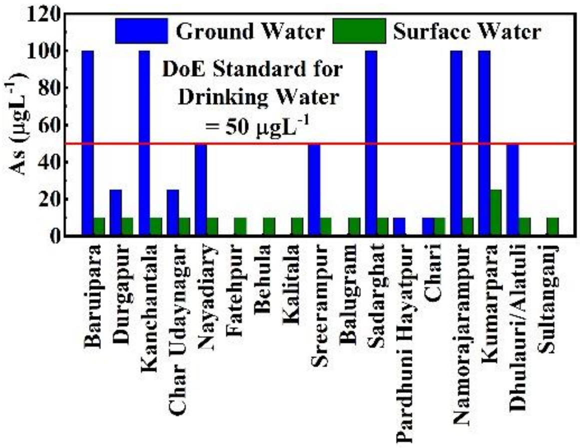

Fig. 6. The As concentration of groundwater and surface water of the reach of Mahananda River.

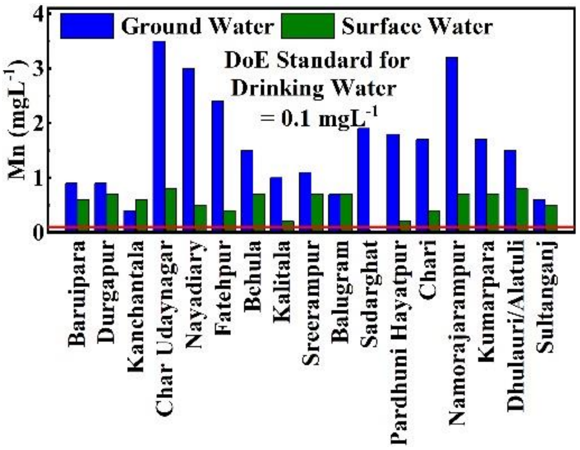

Fig. 7. The Mn concentration of groundwater and surface water in the reach of Mahananda River.

The surface water of the Mahananda River holds a maximum of 0.8 mgL^{-1} of Mn and a minimum of 0.2 mgL^{-1} except at one point. The mean concentration of Mn in groundwater and surface water of the Mahananda River is 1.64 mgL^{-1} (SD 0.90) and 0.54 mgL^{-1} (SD 0.23), respectively. The mean concentration of Mn in groundwater and surface water is higher than the allowable limit of DoE by about 16 and 5 times respectively. This phenomenon may also be attributed to the increasing withdrawal rate of groundwater.

Since As and Mn are higher in concentration than the DoE standard, both carcinogenic and non-carcinogenic health risks were determined from these contaminants and shown in **Table 4** and **Table 5**, respectively. The carcinogenic risk was determined for only As, and the non-carcinogenic risk was determined for both As and Mn. The risk was determined for both adults and children. And also for both maximum and mean concentrations of As and Mn.

The carcinogenic risk from the river water was estimated at 4.44×10^{-04} and 1.08×10^{-03} for mean and maximum concentration of As, respectively, for adults, while 6.26×10^{-04} and 1.52×10^{-03} for children. For groundwater, the value for adults are 1.83×10^{-03} and 4.31×10^{-03} and for children are 2.58×10^{-03} and 6.08×10^{-03} for mean and maximum concentration, respectively. From the result, it is evident that both the surface and groundwater possess high carcinogenic risks. Groundwater poses more risk than surface water; in both cases, children are more vulnerable than adults. A high carcinogenic risk from As was also reported in the groundwater of other parts of Bangladesh (Akter *et al.*, 2021).

The non-carcinogenic risks from surface water at mean concentration is 1.72 for adults and 2.59 for children, while at maximum concentration are 3.47 and 5.15 for adults and children, respectively. Thus, the non-carcinogenic risks are high for both adults and children. For groundwater, the risks are 6.25 and 9.33 for adults and children, respectively, at the mean concentration, while 14.29 and 21.25 are at the maximum concentration. The results show that at mean concentration, the risks are high for adults and children, while the risks are very high at the maximum concentrations of As and Mn in the groundwater. In all the cases, children possess more risks than adults. A similar assessment of risks has been reported in (Akter *et al.*, 2021; Turdiyeva and Lee, 2023; Mohammadi *et al.*, 2019).

Table 4. Carcinogenic risk of As from Mahananda River water and its adjacent groundwater.

Source of Water	Adult			Children		
	Oral	Dermal	Sum	Oral	Dermal	Sum
Surface Water (Mean Concentration)	4.41×10^{-04}	2.43×10^{-06}	**4.44×10^{-04}**	6.18×10^{-04}	8.46×10^{-06}	**6.26×10^{-04}**
Surface Water (Max. Concentration)	1.07×10^{-03}	5.89×10^{-06}	**1.08×10^{-03}**	1.50×10^{-03}	2.05×10^{-05}	**1.52×10^{-03}**
Groundwater (Mean Concentration)	1.82×10^{-03}	9.98×10^{-06}	**1.83×10^{-03}**	2.54×10^{-03}	3.48×10^{-05}	**2.58×10^{-03}**
Groundwater (Max. Concentration)	4.29×10^{-03}	2.36×10^{-05}	**4.31×10^{-03}**	6.00×10^{-03}	8.22×10^{-05}	**6.08×10^{-03}**

Table 5. Non-carcinogenic risk of As in Mahananda River water and its adjacent groundwater.

Source of Water	Metal	Adult			Children		
		Oral	Dermal	HQ Sum	Oral	Dermal	HQ Sum
Surface Water (Mean Concentration)	As	0.98	0.01	0.99	1.37	0.02	1.39
	Mn	0.65	0.08	0.73	0.91	0.29	1.20
	HI			**1.72**			**2.59**
Surface Water (Max. Concentration)	As	2.38	0.01	2.39	3.33	0.05	3.38
	Mn	0.95	0.12	1.08	1.33	0.43	1.77
	HI			**3.47**			**5.15**
Groundwater (Mean Concentration)	As	4.03	0.02	4.05	5.64	0.08	5.72
	Mn	1.95	0.25	2.20	2.73	0.88	3.61
	HI			**6.25**			**9.33**
Groundwater (Max. Concentration)	As	9.52	0.05	9.58	13.33	0.18	13.52
	Mn	4.17	0.54	4.71	5.83	1.90	7.73
	HI			**14.29**			**21.25**

Conclusions

The physicochemical parameters of the surface water were found within the allowable range of the DoE standard. SO_4^{2-} and PO_4^{3-} were also in the permissible range for surface water and groundwater. The As concentration of surface water was found within the allowable range, but it has been found high at several points for groundwater. Mn concentration was high at all the surface water and groundwater points except for one moment. The carcinogenic risk from As and non-carcinogenic risk from both As and Mn was estimated for adults and children. The estimation shows a high carcinogenic risk from surface water and groundwater, while non-carcinogenic risks were assessed as high from surface water and very high from groundwater. In both cases, children were found at more risk than adults. To alleviate the risks, this water should be filtered through an appropriate filter that can remove As and Mn for drinking. For other uses, surface water should give preference over groundwater as long as there is no treated water supply from authorities.

Recommendations

The study was limited by the availability and resources, both equipment and funds. A more comprehensive study with more contaminants, including heavy metal determination, would better estimate carcinogenic and non-carcinogenic human health risks.

Acknowledgment

The authors acknowledge the Government of the People's Republic of Bangladesh and the River Research Institute, Bangladesh, for funding the study.

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