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Health risk assessment of the heavy metals at wastewater discharge points of textile industries in Tongi, Shitalakkhya, and Dhaleshwari, Bangladesh

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ABSTRACT

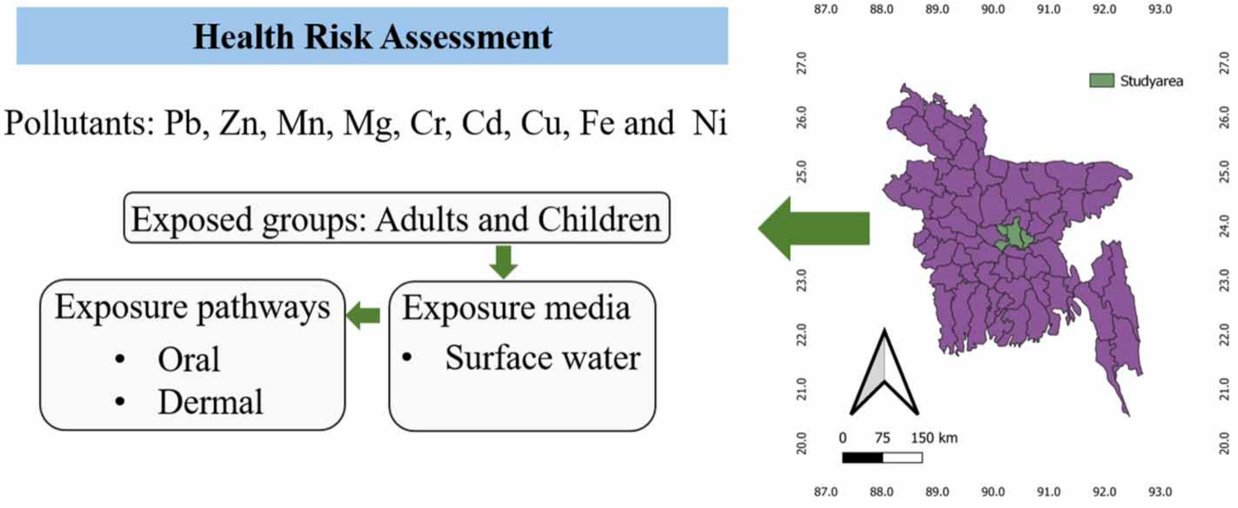
Pollution of industry-adjacent surface water bodies has become a major threat to the environment in Bangladesh. This study examined the health risks of concentrated heavy metals in Tongi, Shitalakkhya, and Dhaleshwari, which receive effluents from wastewater treatment plants. Samples were analyzed for heavy metals such as lead, cadmium, iron, magnesium, manganese, zinc, copper, chromium, and nickel. At all the locations, only Zn, Cu, and Ni did not exceed the Bangladesh standard for drinking water. The health risk was estimated using the hazard quotient (HQ) technique. There was a threat of health risks resulting from the exposure through ingestion, with Pb, Cd, Fe, Mg, and Cr being the main contributors. The orders of decreasing values of mean HQ were $Mg > Pb > Fe > Cr > Cd$, $Mg > Fe > Pb > Cr > Cd$, and $Cr > Mg > Pb > Fe > Cd$ via oral intake for both adults and children at Tongi, Shitalakkhya, and Dhaleshwari, respectively. For dermal intake, the mean HQ for only chromium at Dhaleshwari exceeded the limit for both groups. The results emphasize the need for enhancement, proper operation, and maintenance of wastewater treatment facilities in order to meet the discharge quality standard.

Key words: hazard quotient, health risk assessment, heavy metals, non-carcinogenic risk, water pollution, water quality

HIGHLIGHTS

- The river waters in Bangladesh are heavily polluted due to textile wastewater discharge.
- Heavy metals such as Pb, Cd, Fe, Mg, and Cr are the main contributors.
- The HQ values of Pb, Cd, Cr, Fe, and Mg are higher than 1 for both oral and dermal intake in all sampling locations of the study.
- The results indicate a significant level of health risk and a poor state of the wastewater treatment systems employed in the textile industries.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Increasing anthropogenic activities, rapid industrialization, population explosion, and climate change have led to a decline in the quality of surface water worldwide, and this has eventually led to the accumulation of contaminants in water systems (Wu *et al.* 2017). In response to diminishing freshwater resources, countries have constructed wastewater treatment facilities to recycle wastewater for reuse (Anderson 2003; Elimelech 2006). A wide range of sectors, including agriculture, use untreated and partially treated wastewater especially in developing nations (Scott *et al.* 2004).

Heavy metals (HMs) could be divided into two broad groups: essential metals which include Mg, Mn, Fe, Cu, Zn, and non-essential metals which include Cr, Co, Ni, As, Cd, and Pb (Moloi *et al.* 2020). They are discharged from various industrial sources and accumulated in soils after not being properly managed. Unmonitored effluents from several industrial establishments find their way to agricultural lands and waterways. The contaminants in wastewater enter the environment through the use of wastewater treatment byproducts which are used for several purposes, especially for agricultural purposes (Snyman *et al.* 2006). Agricultural lands that are irrigated by wastewater are heavily contaminated with toxic metals because of the high concentration of toxic metals in these effluents (Mapanda *et al.* 2005).

The practice of wastewater irrigation has long been used in arid areas, including China (Li *et al.* 2009), India, France, and Germany (Dere *et al.* 2006; Ingwersen & Streck 2006). Irrigating agricultural land with wastewater presents both opportunities and challenges. Water irrigation with excessive metals in agricultural soil can not only pollute soil but can also pose a risk for food contamination. Most people are exposed via diet, though inhalation can be important in some contaminated sites (Tripathi *et al.* 1997). In soil that has been irrigated with wastewater, trace metals could accumulate easily in the crops, which could pose a health risk (Ahmad *et al.* 2016; Zia *et al.* 2017). The long-term use of untreated municipal wastewater results in the accumulation of potentially toxic metals in the soil and eventually the uptake and accumulation by the plants also increase (Sarwar *et al.* 2020). Despite being illegal in most countries, water shortages have forced many nations worldwide to use untreated wastewater for irrigation (Jaramillo & Restrepo 2017; Zhang & Shen 2019).

A study showed that Cd and Cu have higher transfer quotients, as compared to Pb and Fe, and the order of transfer of these metals is $Cd > Cu > Pb > Fe$ (Khan *et al.* 2008). The poisoning of plants and animals is a threat posed by HMs, which can interfere with important biochemical systems. History has documented the adverse health effects of various chemical elements. The physicians in ancient Greece and Rome were able to discern the signs of acute lead and arsenic poisoning. The fast growth of urbanization, industrialization, and agriculture is responsible for the problem of HM pollution in the soil (Liu *et al.* 2020). Soil contaminated with metals has a concentration that is often higher than those needed as nutrients or background levels, causing plants to uptake the metals and deposition at unacceptably high levels. In addition, HM causes problems for microbes, plants, and humans (Akoumianakis *et al.* 2008).

There are several health impacts on people caused by drinking or swimming in polluted water such as gastroenteritis or stomach flu and dermal diseases (Turbow *et al.* 2003). Unsafe drinking water is the reason for 1.3 million deaths in 2015 worldwide (Landrigan *et al.* 2018). Not only drinking or swimming, but the consumption of HMs accumulated in fish and crops is also responsible for health hazards (Khan *et al.* 2008). This claim is bolstered by the evidence of HM bioaccumulation in fish and vegetables in several studies (Kawser Ahmed *et al.* 2016; Rashid *et al.* 2017). We now know more about the physiological effects of toxic elements on the body such as endocrine disruption, cancer, damage to the kidney, and disorders in the immunology of the body, and even death as a result of human exposure to those elements (Khan *et al.* 2009). A high risk of HM exposure through dermal contact has also been shown in recent studies. The risk depends on the exposed body surface area and the duration of the activity (Zhao *et al.* 2019).

The study of chemical toxicity and its impact on the environment and on human health has gained more and more attention (Bahadir *et al.* 2013). A number of research works have been conducted on assessing the HM contamination in different sediment and soil, however, there is a paucity of research on the health risks of HMs through the consumption of drinking water in and around Dhaka. Therefore, it is essential to estimate the risk posed by contaminated water from inappropriate wastewater treatment processes. Human health risks can be assessed by comparing the HMs present in the wastewater to the standard level. Hence, the study aims at identifying the concentration of HM in the water at the discharge points where the wastewater from the effluent treatment plants (ETPs) of textile dyeing factories are released, comparing the HM concentration present in the wastewater to the standard level set by national/international bodies and assessing the health risk posed by HMs in the contaminated waters.

2. MATERIALS AND METHODS

2.1. Sampling sites

Water samples were collected from Tongi Khal (canal), Shitalakkhya river, and Dhalesdhwari river, situated in and around Dhaka, Narayanganj, and Gazipur (Figure 1). Two distinct points (one point for upstream and one point for downstream of the discharges) were selected for carrying out the surface water sampling at each of the three sampling sites. Both points were near the industrial establishments where the wastewater was discharged. More than 200 large and small factories are situated around Tongi canal out of which 48 run without an ETP (Halder & Sarker 2021). According to the Bangladesh Bureau of Statistics, there are 2,409 industry units present in Narayanganj (Narayanganj – Banglapedia n.d.). The wastewater coming from these industry units eventually ends up at the Tongi canal and Shitalakhya river. The coordinates of sampling locations are presented in Table 1.

The water supply of Dhaka, Narayanganj, and Gazipur cities are largely reliant on Turag, Shitalakhya, and Balu Rivers. The treated and untreated wastewater are discharged in these rivers and thus the specific sampling sites were chosen to assess the health risk to the people. The Water Supply and Sewerage Authority (WASA) uses a conventional water treatment system to treat drinking water for the people living in the cities, and it is distributed through a pipeline system. The conventional water treatment steps include coagulation, flocculation, sedimentation, filtration, and disinfection (with chlorine). The water discharged at Tongi canal eventually goes to either the Turag River or Balu River since the canal is connected to both, hence increasing the risk of polluted water getting into the water distribution system.

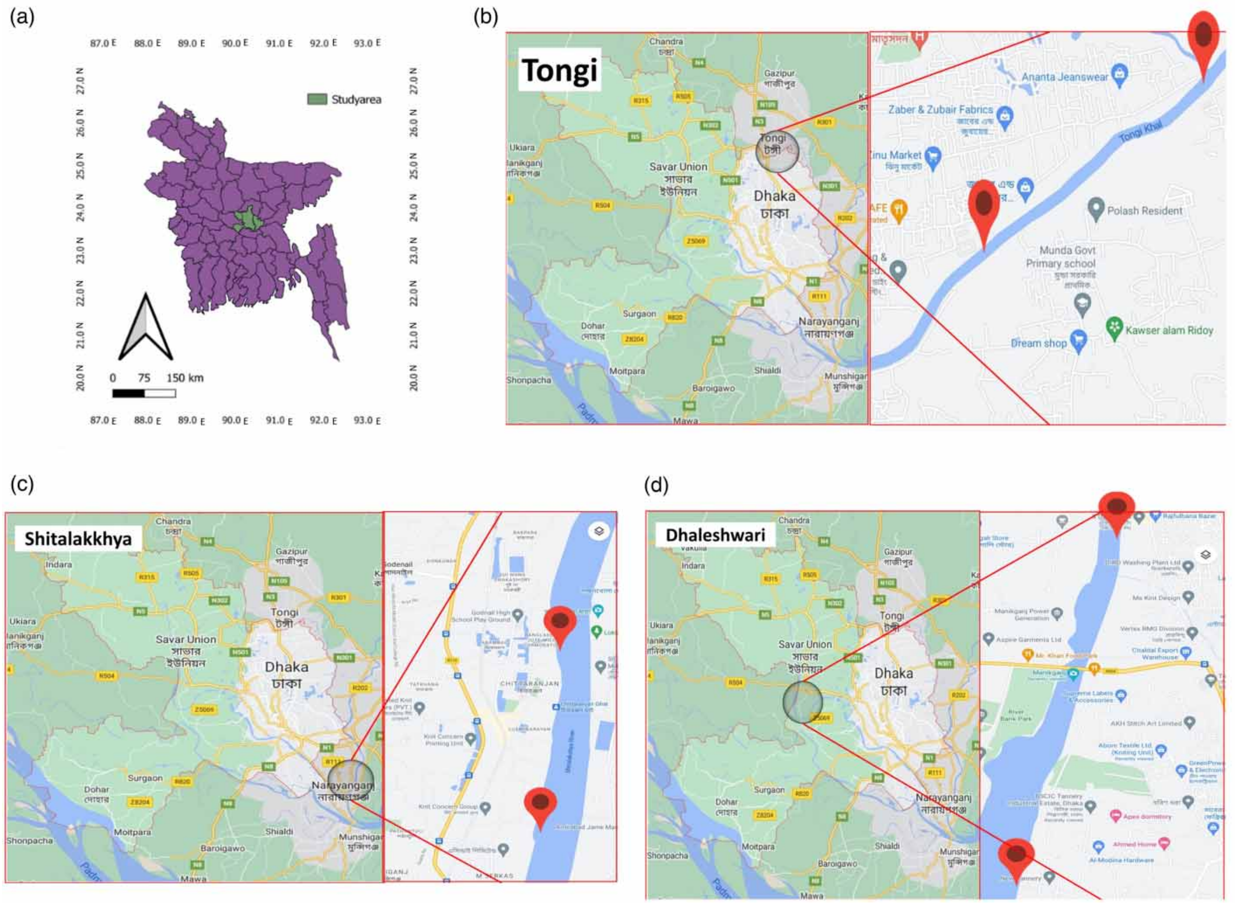


Figure 1 | (a) Study area map and the sampling points at (b) Tongi canal, (c) Shitalakkhya river, and (d) Dhaleshwari river.

Table 1 | Sampling location coordinates

Sampling location	Longitude (North)	Latitude (East)
Tongi 1	23.891853	90.425595
Tongi 2	23.898485	90.435387
Shitalakkhya 1	23.640275	90.517347
Shitalakkhya 2	23.652919	90.518745
Dhaleshwari 1	23.781484	90.240344
Dhaleshwari 2	23.808962	90.247538

2.2. Sample collection and preparation

A total of 30 water samples, 10 samples from each of the three locations (five samples from upstream and five samples from downstream) – Tongi canal, Shitalakhya river, and Dhaleshwari river – were collected from December 2021 to January 2022 which is basically the winter or dry season in the country. Each sample represented a volume of 400 mL collected in 500-mL plastic containers. The water samples were transported inside an ice box and stored at 4 °C until metal analysis could be performed. The water samples were filtered using a filter paper into 100 mL of prewashed plastic bottles before being analyzed for the presence of HMs. Analytical-grade HCl was then used to bring the pH of the water to 3.5. The samples were then stored at room temperature until analysis. The preparation was necessary for the water samples so that the activity of the microorganism did not change the concentration of HMs.

2.3. Sample analysis

The metal concentrations found in the samples were compared with the national standards for drinking water, as outlined in the ECR 1997 Bangladesh Standard for drinking water (ECR 1997). Other reference levels such as WHO drinking water standards could have been used. Nevertheless, since the sampling locations are situated in Bangladesh, the Bangladeshi standard was taken into consideration. The concentrations of the HMs were compared only to the drinking water standards of Bangladesh as the selected water bodies are used for water supply to Dhaka city and surrounding areas.

All the water samples were analyzed by an atomic absorption spectrophotometer (AAS) with an air/acetylene flame for the presence of HM concentrations (Pb, Cd, Cr, Cu, Ni, Fe, Zn, Mg, and Mn). The samples were examined using hollow cathode lamps. There was a 5.0 mA of light current. The instrument's detection limit for chromium was 0.01 mg/L, for zinc was 0.04 mg/L, for iron was 0.10 mg/L, for lead was 0.02 mg/L, for copper was 0.01 mg/L, for nickel was 0.01 mg/L, for cadmium was 0.02 mg/L, for manganese was 0.10 mg/L, and for magnesium was 0.10 mg/L (Table 2).

The calibration curve was obtained using standard samples containing 0.1, 0.5, and 1.0 mg/L for Cd; 0.2, 0.4, 0.8, and 1.0 mg/L for Cr; 0.2, 0.4, 0.8, 1.0, and 2.0 mg/L for Cu; 0.1, 0.2, 0.4, 0.8, and 1.0 mg/L for Mn; 0.5, 1.0, and 2.0 mg/L for Ni; 1.0, 2.0, 4.0, 5.00 mg/L for Fe; 0.5, 1.0, 1.5, and 2.0 mg/L for Mg; 0.2, 0.4, 0.8 and 1.0 mg/L for Pb. The wavelength

Table 2 | Details of the atomic absorption spectrophotometer (AAS) used for sample analysis

Heavy metal	Detection limit (mg/L)	Wavelength (nm)	Slit length (nm)
Cr	0.01	357.9	0.7
Zn	0.04	213.9	0.7
Fe	0.1	248.3	0.2
Pb	0.02	283.3	0.7
Cu	0.01	324.8	0.7
Ni	0.01	232	0.2
Cd	0.02	228.8	0.7
Mn	0.01	279.5	0.2
Mg	0.1	285.2	0.7

and the slit length were 357.9 and 0.7 nm, 213.9 and 0.7 nm, 248.3 and 0.2 nm, 283.3 and 0.7 nm, 324.8 and 0.7 nm, 232.0 and 0.2 nm, 228.8 and 0.7 nm, 279.5 and 0.2 nm, 285.2 and 0.7 nm for Cr, Zn, Fe, Pb, Cu, Ni, Cd, Mn, and Mg, respectively (Table 2).

Statistical analysis (mean and standard deviation), figures, and plots were performed and generated using R Studio (version 2021.09.2 + 382) and MS Excel. In order to process geographical data and make related figures, QGIS version 3.22 was used.

2.4. Human health risk assessment

This study applied the health risk assessment method proposed by the United States Environmental Protection Agency (US EPA). Drinking, skin contact, and inhalation are the general ways of human exposure to HMs. Based on these three pathways, the health risks of HMs can be estimated (Jiang *et al.* 2020; Xu *et al.* 2021).

The process of assessing human health risks involves four steps: risk identification, exposure assessment, dose/response assessment, and risk characterization (National Research 1983). In basic terms, it describes the potential adverse health effects associated with exposure to a specific set of environmental matrices (USEPA 1997). Non-carcinogenic human health risk was assessed according to a hazard quotient (*HQ*) (USEPA 1989).

$$HQ = \frac{CDI}{RfD} \tag{1}$$

where *RfD* (mg/kg/day) is the reference dose of HMs as suggested by the US EPA. *CDI* means the chronic daily intake of HMs (mg/kg/day), and is calculated as follows:

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{2}$$

In Equation (2), *C* represents the concentration of HMs in water in mg/L and *IR* represents the ingestion rate of water in L/day, the limit of which is 3.53 L/day for adults (Milton *et al.* 2006) and 1.0 L/day for children. According to USEPA 1989, the exposure duration (*ED*) is 70 years for adults and 6 years for children and exposure frequency (*EF*) is, in days/year, 365 days for both adults and children. The average body weight is expressed by *BW* which is 50 kg for adults and 15 kg for children (USEPA 1989; NIPORT 2013). Finally, *AT* means the average time. *AT* equals the value of 365 times ED.

The Equation (2) could be simplified to the following:

$$CDI = \frac{C \times IR \times 365 \times ED}{BW \times ED \times 365} \tag{3}$$

Both EDs and EFs in the equation cross each other.

Finally, Equation (1) becomes:

$$HQ = \frac{CDI}{RfD} = \frac{C \times IR}{BW \times RfD} \tag{4}$$

For both oral and dermal intake, the equation and variables other than the reference dose remain the same. For oral intake, the refence value is denoted by RfD_o and for dermal intake the refence value is denoted by RfD_d.

If the HQ estimates values above 1, then there is a potential for non-carcinogenic risk, whereas the value which is less than 1 implies that there is no potential for non-carcinogenic risk (Al-Saleh & Abduljabbar 2017).

3. RESULTS AND DISCUSSION

3.1. Characteristics of wastewater at the discharge points

Various levels of HMs were detected in the water samples collected from the discharge points around Dhaka (Figure 2). In Figure 2, the values of the HM concentrations are presented in log scale as the values cover a very large range. Most wastewater treatment facilities in Bangladesh have been reported to be insufficient (Sharmin 2016). Partially treated and untreated wastewater from industries is the main cause of HMs in river water (Aktar & Moonajilin 2017). Different types of textile

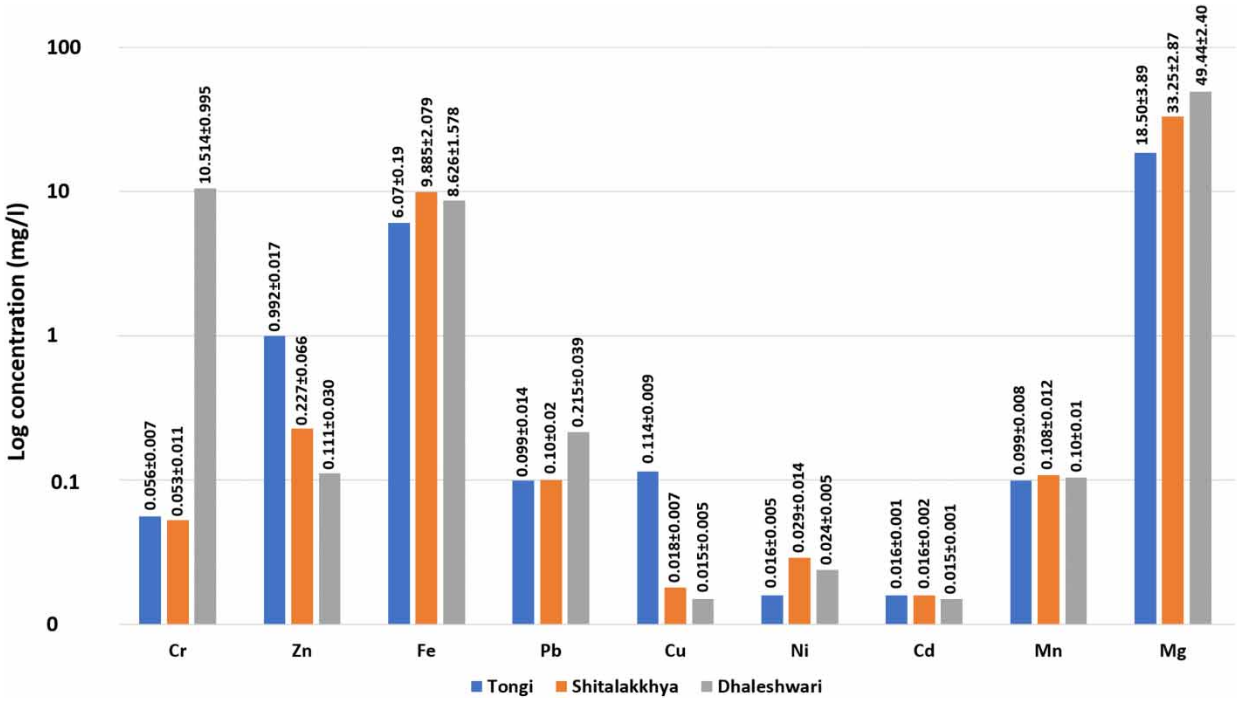


Figure 2 | Mean concentration (in log scale with standard deviation) of the HMs in the samples from Tongi canal, Shitalakkhya river, and Dhaleshwari river.

industry account (and the leather industry in the case of Dhaleshwari river) for the observed variation in wastewater HM content. The textile and garment industry's washing and dyeing sections are one of the world's most polluting sources. The chemicals and auxiliaries used in the textile dyeing industry contain a high number of HMs. HMs such as chromium (Cr), nickel (Ni), zinc (Zn), lead (Pb), copper (Cu), and cadmium (Cd) are used in color pigments in production (Bhardwaj *et al.* 2014).

The mean abundance of metals in Tongi was in the following order Mg > Fe > Zn > Cu > Pb > Mn > Cr > Ni > Cd. Also, the order of metals observed in Shitalakkhya follows: Mg > Fe > Zn > Mn > Pb > Cr > Ni > Cu > Cd. In Dhaleshwari, the order was Mg > Cr > Fe > Pb > Zn > Mn > Ni > Cu > Cd. pH of the samples collected from the Tongi canal was between 7.6 and 8.4, while the range for Shitalakkhya was 7.7–8.3 and for Dhaleshwari it was 7.6–9.4.

3.2. Presence of HM concentrations

The average concentrations of HMs at Tongi canal (discharge point of wastewater of textile industries situated at Tongi BSCIC) were higher than the standard limit (Table 3) except for zinc (0.992 mg/L), copper (0.114 mg/L), nickel (0.016 mg/L), manganese (0.099 mg/L), and magnesium (18.50 mg/L). These metals were well under the limit for drinking water set by the Environmental Conservation Rules, Bangladesh, 1997 (ECR 1997). The surface water of Tongi canal was found to be heavily polluted during the data collection phase by a high concentration of Pb, Cd, Cr, Fe. The mean concentrations of these metals were, respectively, 0.099, 0.016, 0.056, and 6.07 mg/L (Table 3). Different types of industries including metal industries, jute, pharmaceutical, and food manufacturing along with textile industries are available in Tongi (Rahman *et al.* 2012) which are the major sources of pollution in th Turag river and Tongi canal.

The range of concentration of lead was between 0.08 and 0.12 mg/L where the standard limit is 0.05 mg/L. The concentration of cadmium was found to be in the range of 0.014–0.018 mg/L. The standard cadmium concentration for drinking water is 0.005 mg/L. The concentrations of chromium varied between 0.042 and 0.063 mg/L. Based on the concentration and length of exposure, these metals may pose an acute or chronic risk to ecological and human systems. For nickel, the minimum concentration was found to be 0.01 mg/L while the maximum was 0.02 mg/L. The concentrations of zinc were found to be much lower than the standard. The range was 0.97–1.02 mg/L. The lowest concentration of iron in the samples was

Table 3 | Concentrations of HMs at discharge points

		Concentration (mg/L)											
		Upstream					Downstream						
Location	Heavy metal	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Mean ± Standard Deviation	Permissible Limit (ECR'97[a])
Tongi	**Cr**	0.061	0.058	0.063	0.042	0.059	0.062	0.06	0.049	0.049	0.058	0.056 ± 0.007	0.05
	Zn	0.99	0.97	0.98	0.99	1.01	1.02	0.98	0.97	1	1.01	0.992 ± 0.017	5
	Fe	5.92	6.27	6.15	5.63	6.2	5.99	6.17	5.95	6.27	6.15	6.07 ± 0.19	1
	Pb	0.09	0.12	0.1	0.12	0.08	0.09	0.11	0.11	0.09	0.08	0.099 ± 0.014	0.05
	Cu	0.11	0.12	0.12	0.11	0.1	0.13	0.12	0.11	0.1	0.12	0.114 ± 0.009	1
	Ni	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.016 ± 0.005	0.1
	Cd	0.018	0.014	0.016	0.015	0.015	0.014	0.018	0.016	0.017	0.016	0.016 ± 0.001	0.005
	Mn	0.09	0.1	0.11	0.09	0.09	0.1	0.1	0.11	0.09	0.11	0.099 ± 0.008	0.1
	Mg	11.4	23.5	17.8	15.43	21.22	15.18	14.9	21.89	22.4	21.32	18.50 ± 3.89	30–35
Shitalakhya	**Cr**	0.051	0.044	0.067	0.037	0.059	0.051	0.064	0.067	0.047	0.039	0.053 ± 0.011	0.05
	Zn	0.18	0.18	0.14	0.33	0.23	0.14	0.33	0.28	0.22	0.24	0.227 ± 0.066	5
	Fe	5.28	12.65	8.97	10.11	9.35	11.57	9.65	10.88	12.33	8.06	9.885 ± 2.079	1
	Pb	0.07	0.1	0.09	0.12	0.1	0.14	0.11	0.09	0.1	0.08	0.10 ± 0.02	0.05
	Cu	0.01	0.02	0.01	0.03	0.01	0.02	0.02	0.01	0.03	0.02	0.018 ± 0.007	1
	Ni	0.02	0.01	0.03	0.02	0.05	0.03	0.04	0.03	0.01	0.05	0.029 ± 0.014	0.1
	Cd	0.019	0.016	0.016	0.015	0.014	0.014	0.019	0.016	0.015	0.015	0.016 ± 0.002	0.005
	Mn	0.12	0.1	0.12	0.09	0.1	0.11	0.09	0.12	0.12	0.11	0.108 ± 0.012	0.1
	Mg	28.2	39.5	34	32.81	30.6	32.78	31.99	32.54	35.77	34.3	33.25 ± 2.87	30–35
Dhaleshwari	**Cr**	9.29	12.03	10.8	9.35	11.53	10.24	9.56	9.81	10.55	11.98	10.514 ± 0.995	0.05
	Zn	0.18	0.09	0.11	0.08	0.1	0.09	0.11	0.15	0.08	0.12	0.111 ± 0.030	5
	Fe	7.66	10.23	6.18	7.88	10.04	8.46	11.28	6.79	7.8	9.94	8.626 ± 1.578	1
	Pb	0.15	0.27	0.21	0.19	0.24	0.25	0.27	0.17	0.19	0.21	0.215 ± 0.039	0.05
	Cu	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.015 ± 0.005	1
	Ni	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.024 ± 0.005	0.1
	Cd	0.014	0.014	0.015	0.016	0.015	0.016	0.015	0.014	0.014	0.014	0.015 ± 0.001	0.005
	Mn	0.1	0.1	0.11	0.12	0.1	0.12	0.09	0.1	0.11	0.09	0.10 ± 0.01	0.1
	Mg	45.7	52.4	48.5	48.78	51.97	49.5	51.61	46.43	52.33	47.21	49.44 ± 2.40	30–35

[a] Drinking water quality standard by the Environment Conservation Rules, 1997 (ECR 1997).

5.63 mg/L while the highest was 6.27 mg/L. The range of magnesium present in the samples was 11.4–23.5 mg/L, which was clearly under the standard limit (Table 3).

The summary of the water quality parameters of the discharge point at Shitalakhya river is presented in Table 3 and Figure 2. The amount of cadmium (up to 0.019 mg/L) was higher than the standard limit. According to a report by Biswas *et al.* 2015, the average concentration of cadmium was found to be 0.01 mg/L in Shitalakkhya, which is similar to the present study. Very high lead (up to 0.14 mg/L), chromium (up to 0.067 mg/L), iron (up to 12.65 mg/L), manganese (up to 0.12 mg/L), and magnesium (up to 39.5 mg/L) were also recorded in water samples. A comparison of the water quality of the Shitalakhya river with the Bangladesh National Standard (ECR 1997) shows that these water quality parameters did not meet the standards. However, the concentrations of nickel (0.01–0.04 mg/L), zinc (0.14–0.33 mg/L), and copper (0.01–0.03 mg/L) found in the surface water of Shitalakhya river were well below the permissible limit.

Table 3 and Figure 2 also depict that the concentrations of chromium were significantly higher than the permissible limit in Dhaleshwari. The minimum and maximum values were 9.29 and 12.03 mg/L with a mean of 10.514 mg/L. The high amount of chromium is the result of untreated wastewater discharged from the tanneries situated just beside the river. After the tanneries had been shifted from Old Dhaka to Savar (beside Dhaleshwari) the concentration of chromium got much higher. Chromium is profoundly reported in the leather industry because of the immoderate use of chromium sulfate salts in leather processing (Rastogi *et al.* 2008). The study by Hasan *et al.* 2020 has also shown similar levels of chromium in Dhaleshwari. In addition to the high Cr value, very high lead (0.15–0.27 mg/L), cadmium (0.014–0.16 mg/L), iron (6.18–11.28 mg/L), and magnesium (45.7–52.33 mg/L) were recorded in water samples as well. These water quality parameters surely exceeded the standard limits set by ECR (1997). However, the concentration of nickel (0.02–0.03 mg/L), zinc (0.08–0.18 mg/L), and copper (0.01–0.02 mg/L) found in the surface water of Shitalakhya river were well below the permissible limit. The mean concentration of Mn (0.104 mg/L) slightly exceeded the limit.

Not only in Bangladesh, but the HM concentrations are higher than the standard limit at wastewater discharge points around the world especially in developing countries. The Cr content in New Calabar river water in Nigeria, which is also used as a wastewater discharge point, was much higher than Tongi canal and Shitalakkhya river (Table 7). However, its Cr concentration (1.78 mg/L) was exceeded by the mean concentration of the same metal in the Dhaleshwari river. The concentrations of Zn, Fe, Pb, Cu, Ni, and Cd were 1.69, 1.44, 1.34, 1.23, 2.57, and 0.25 mg/L, respectively (Edori & Kpee 2018). Comparing the present study results with prior studies in Iraq, it is seen that the zinc and copper content of Tongi, Shitalakhya, and Dhaleshwari fall within the range of study reported for the Diyala-Sirwan river. This river is used for effluent discharge points. However, iron (0.02–0.134 mg/L), magnesium (22.7–30.61 mg/L), and manganese (0.005–0.066 mg/L) content were lower (Issa & Alshatteri 2021) than the present study area (Table 7). In a study in Southern Ethiopia, Tikur Wuha River, 0.12 mg/L of lead, 0.132 mg/L of nickel, and 0.02 mg/L of cadmium were found at the discharge point of the textile industry (Mekuyie 2014). In a similar study in Challawa river, Kano, Nigeria, the concentrations of the HMs were 2.297, 2.986, 9.408, 1.051, 1.290, and 2.054 mg/L for Cr, Zn, Fe, Pb, Cu, and Mn, respectively (Dan'Azumi & Bichi 2010). The river is a potential industrial wastewater discharge point. All this indicates a high degree of pollution at wastewater discharge points around the globe.

3.3. Calculating the health risk

In the discharge points (Tongi khal, Shitalakkhya, and Dhaleshwari), Pb, Cd, Ni, Cr, Zn, Cu, Fe, Mn, and Mg of the surface water were found to be copious. Hence, their health risk due to the continuing consumption should be measured. Both oral and dermal intake of water was taken into consideration for adults' and children's health risk assessment. Table 4 shows the reference dose oral and reference dose dermal set by USEPA 2011. However, the health risks of manganese and magnesium for dermal intake were not determined. The summarized results of the analysis carried out in this study are presented in Table 5.

3.3.1. Oral intake

At Tongi canal, for adults, the mean HQ values presented in Table 5, for lead, cadmium, nickel, chromium, zinc, copper, iron, manganese, and magnesium are 1.75, 1.12, 0.06, 1.32, 0.23, 0.20, 1.43, 0.05, and 9.33, respectively. For children, depicted in Table 5, the mean values were 1.25, 0.22, 1.35, 1.65, 0.19, 0.05, 1.06, 0.05, and 8.81, respectively.

In the samples from the Shitalakkhya river, the HQ values for children are lower than for adults. For children, the mean hazard quotients of the samples for Cr, Zn, Fe, Pb, Cu, Ni, Cd, Mn, and Mg were 1.17, 0.05, 2.20, 1.67, 0.03, 0.10, 1.06, 0.05,

Table 4 | Reference dose oral (RfD_o) and reference dose dermal (RfD_d) for the estimation of health risk

Metals	RfD_o	RfD_d	Reference
Pb	0.004	60	USEPA (2011)
Cd	0.001	0.025	
Ni	0.02	0.42	
Cr	0.003	0.0075	
Zn	0.3	200	
Cu	0.04	8	
Fe	0.3	140	
Mn	0.14	–	
Mg	0.14	–	

Table 5 | Mean hazard quotient of the water samples for oral intake

Location	Category	Cr	Zn	Fe	Pb	Cu	Ni	Cd	Mn	Mg
Tongi Canal	Adults	1.32	0.23	1.43	1.75	0.20	0.06	1.12	0.05	9.33
	Children	1.25	0.22	1.35	1.65	0.19	0.05	1.06	0.05	8.81
Shitalakkhya	Adults	1.24	0.05	2.33	1.77	0.03	0.10	1.12	0.05	16.77
	Children	1.17	0.05	2.20	1.67	0.03	0.10	1.06	0.05	15.83
Dhaleshwari	Adults	247.43	0.03	2.03	3.79	0.03	0.08	1.04	0.05	24.93
	Children	233.64	0.02	1.92	3.58	0.03	0.08	0.98	0.05	23.54

and 15.83, respectively (Table 5). The respective maximum and minimum values were 0.82 and 1.49 for chromium, 0.03 and 0.07 for zinc, 1.17 and 2.81 for iron, 1.17 and 2.33 for lead, 0.02 and 0.05 for copper, 0.03 and 0.17 for nickel, 0.93 and 1.27 for cadmium, 0.04 and 0.06 for manganese, and 13.43 and 18.81 for magnesium (Figure 3). Figure 3 illustrates there is no significant variation in HQ among the three locations for Cd and Mn. In the case of Zn, Cu, and Cr, a good amount of variation can be seen. For adults, the highest and lowest values of HQ were 0.87 and 1.58 for chromium with a mean of 1.24, 0.03, and 0.08 for zinc with a mean of 0.05, 1.24, and 2.98 for iron with a mean of 2.33, 1.24, and 2.47 for the lead with a mean of 1.77, 0.02, and 0.05 for copper with a mean of 0.03, 0.04, and 0.18 for nickel with a mean of 0.10, 0.99, and 1.34 for cadmium with a mean of 1.12, 0.05, and 0.06 for manganese with a mean of 0.05, 15.43 and 19.92 for magnesium with a mean of 16.77 for adults (Figure 4 and Table 5). Figure 4 shows a similar trend as Figure 3 with no significant variation in HQ for Cd and Mn and a good amount of variation for Zn, Cu, and Cr.

The mean HQ of magnesium (min. 23.05, max. 26.42, mean 24.93), lead (min. 2.65, max. 4.77, mean 3.79), iron (min. 1.45, max. 2.65, mean 2.03), chromium (min. 218.62, max. 283.11, mean 247.43), and cadmium (min. 0.99, max. 1.13, mean 1.04) were more than 1 for adults (Figure 4 and Table 5), which are indications of high risk for health in Dhaleshwari. Illustrated in Figure 4, there is not much variation in HQ among the three locations for Cd and Mn as opposed to Zn, Pb, Mg, Cu, and Cr.

The ranges for HQ of copper, zinc, manganese, and nickel for adults were 0.02–0.04, 0.02–0.04, 0.05–0.06, 0.07–0.11 (Figure 4) with mean values of 0.03, 0.03, 0.05, and 0.08, respectively (Table 5). Also, for children, the mean values were 233.64 for Cr, 0.02 for Zn, 1.92 for Fe, 3.58 for Pb, 0.03 for Cu, 0.08 for Ni, 0.98 for Cd, 0.05 for Mn, and 23.54 for Mg (Table 5).

The mean HQ values were decreased in the following order: Mg > Pb > Fe > Cr > Cd > Zn > Cu > Ni > Mn, Mg > Fe > Pb > Cr > Cd > Ni > Mn > Zn > Cu, and Cr > Mg > Pb > Fe > Cd > Ni > Mn > Cu > Zn via oral ingestion routes for both adults and children at Tongi canal, Shitalakkhya, and Dhaleshwari, respectively. Figures 3 and 4 show that the HQ values of Cr, Pb, Fe, Cd, and Mg were well above the limit in all sites which indicates there is an exceedance of the non-cancer health guideline. There is a significant health risk to the consumer associated with the consumption of water from these locations. Cr, Fe, Cd, Mg, and Pb are regularly found in textile dyeing and tannery effluents (Juel *et al.* 2016; Velusamy

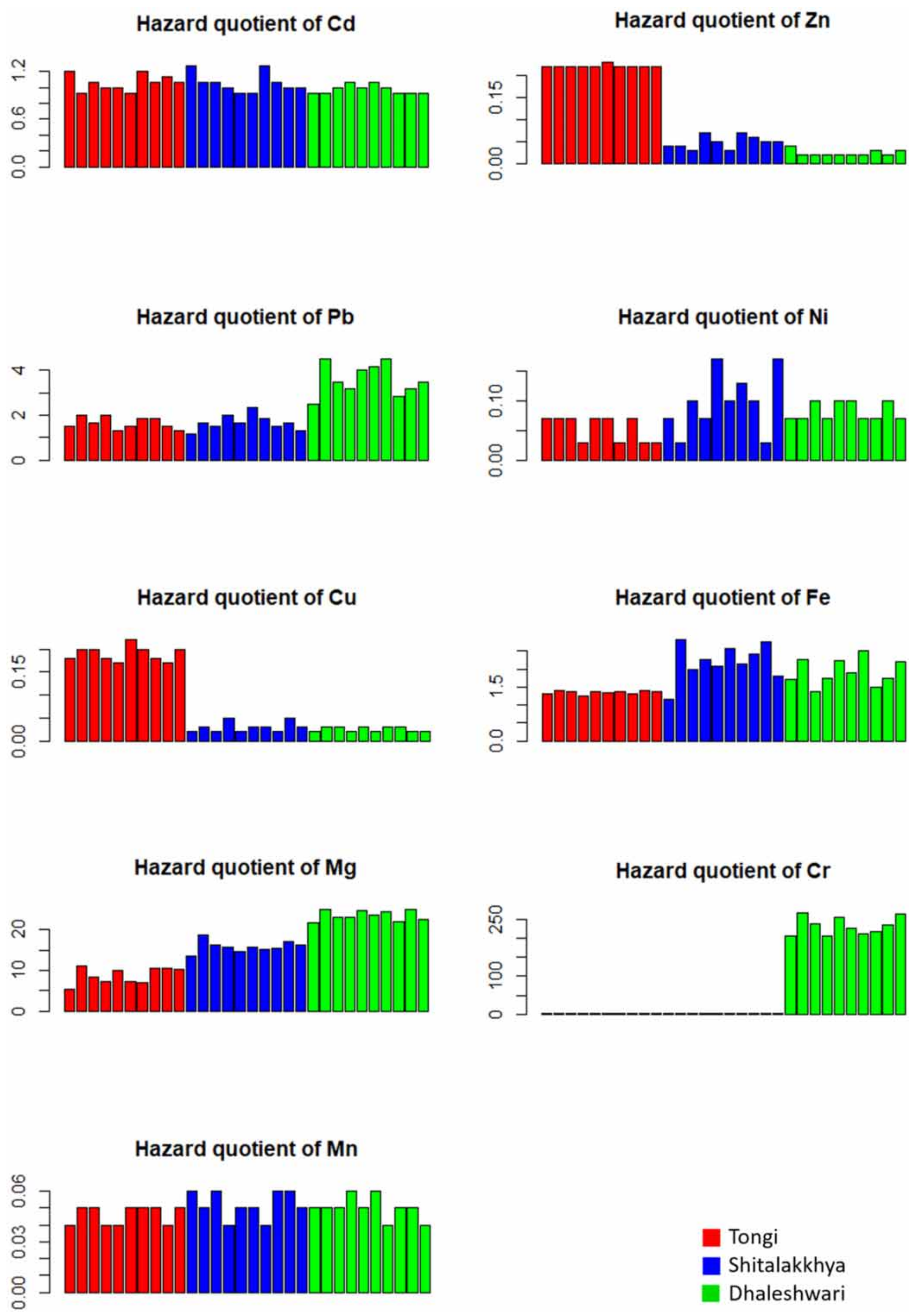


Figure 3 | HQ (oral) for children of each sample.

et al. 2021). The sampling locations were near industrial establishments. About 200 factories are situated in the vicinity of Tongi canal and 2,409 industry units are present in Narayanganj (Narayanganj – Banglapedia n.d.; Halder & Sarker 2021).

The mean HQ values for Zn, Cu, Ni, and Mn were less than 1 ($HQ < 1$) for adults, (Tables 5) at all three locations, suggesting that these elements pose little or no threat to adults over long-term exposure.

In Tongi and Shitalakkhya, the mean HQ values of zinc, copper, nickel, and manganese for children were less than 1 (Table 5), suggesting no potential non-carcinogenic health concerns among children. In Dhaleshwari along with these HMs, the mean HQ value for cadmium was also less than 1 for children.

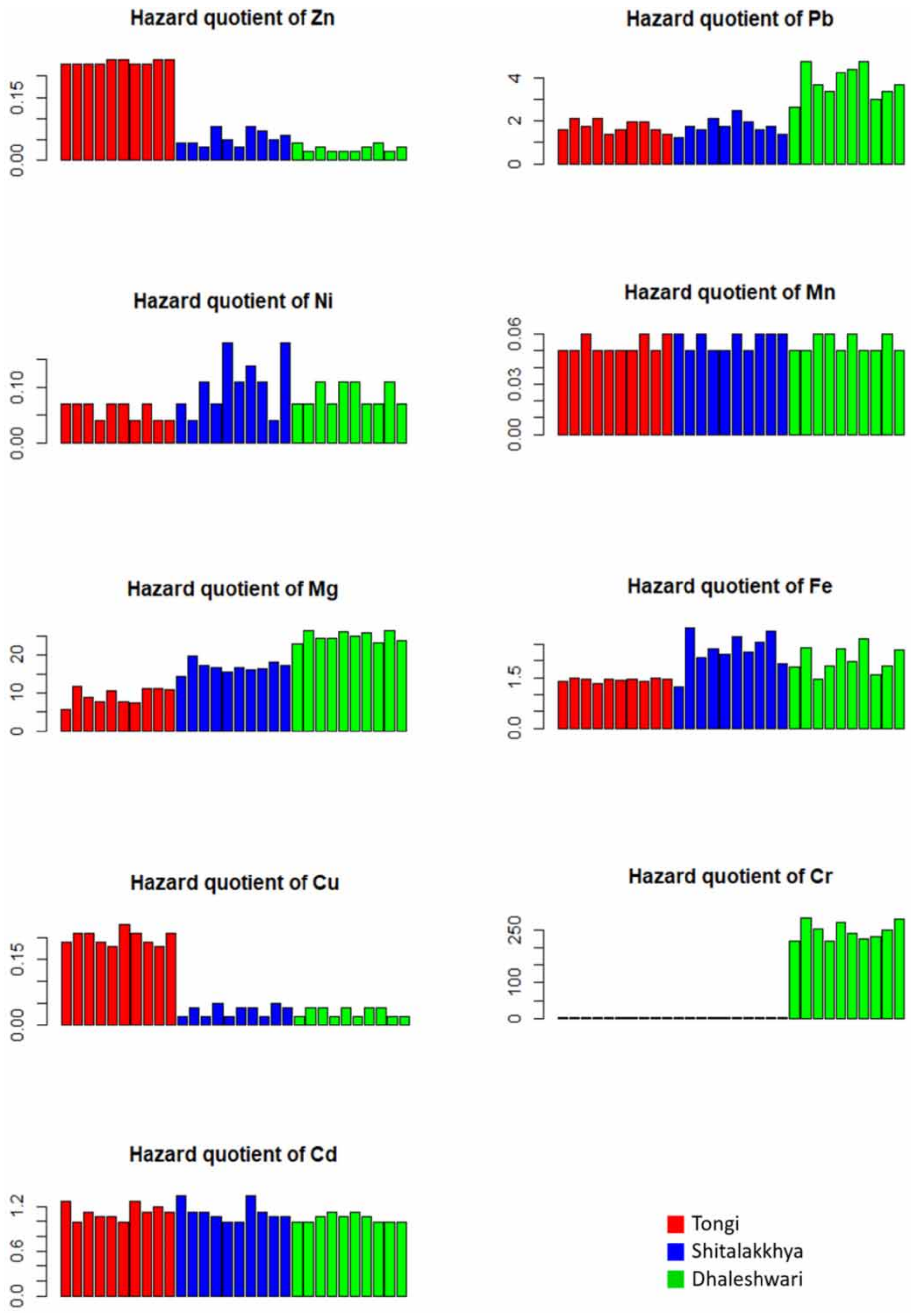


Figure 4 | HQ (oral) for adults of each sample.

It was observed that all HQ values of Cr (Figures 3 and 4) for both groups were higher than the acceptable limit because of its high concentration in the sampling locations. In Dhaleshwari, the concentration is significantly higher than the other two sites. This is due to the reason that there is a big tannery industry established in the study area (Rahman *et al.* 2020), which is continuously releasing effluents enriched with Cr.

In this study, water ingestion accounted for the majority of the average daily dose, which suggests that human exposure to HMs through the consumption of water is the important route for exposure. This result agrees with the study conducted by Alidadi *et al.* (2019), in which they reported that the most important HMs exposure pathway in drinking water happens to be the ingestion route.

3.3.2. Dermal intake

For dermal intake in all three locations, all the mean HQ values were less than 1 for both adults and children (Table 6) except for chromium at Dhaleshwari. The level of chromium present in the water of Dhaleshwari poses a significant threat to adults and children for dermal intake (HQ > 1).

The mean hazard quotient of Zn, Pb, and Cu for dermal intake was 0.001 or less. Iron and nickel had a mean HQ of 0.005 or less while Cd had a mean of 0.04. All these values are less than the threshold value 1. In Dhaleshwari, the mean HQ of Cr were between 93 and 99 which was significantly higher than the threshold. However, in Tongi and Shitalakkhya the mean was around 0.5 (Table 6).

3.4. Health risk posed by the HMs

A summary of HQ values for Cr, Zn, Fe, Pb, Cu, Ni, Mn, Mg and Cd metals in drinking water through ingestion and dermal contact with adults and children are presented in Figures 3 and 4, Tables 5 and 6. As seen from the data, the HQ values of Cr, Fe, Pb, Cd, and Mg through ingestion exposure exceeded the threshold of HQ for adults as well as children. The high HQ values of Pb, Cd, Cr, Fe, and Mg (HQ > 1) for oral intake indicate that people – both children and adults – have a significant level of health risk from drinking these sources of water over a lifetime.

Due to swimming in and continuously drinking water from these rivers and canals, inhabitants in that adjacent area are prone to suffer from several health issues, such as vomiting, diarrhea, abdominal pain, injury to the skin, and gastrointestinal problems (Turbow *et al.* 2003). In addition, respiratory tract infections, damage to the liver, cardiovascular, hematopoietic, and nervous system problems, diabetes, reproductive problems, hair loss, and neurological problems result from the

Table 6 | Mean hazard quotient of the water samples for dermal intake

Location	Category	Cr	Zn	Fe	Pb	Cu	Ni	Cd
Tongi Canal	Adults	0.53	<0.001	0.003	<0.001	0.001	0.003	0.04
	Children	0.50	<0.001	0.003	<0.001	0.001	0.003	0.04
Shitalakkhya	Adults	0.50	<0.001	0.005	<0.001	<0.001	0.005	0.04
	Children	0.47	<0.001	0.005	<0.001	<0.001	0.005	0.04
Dhaleshwari	Adults	98.97	<0.001	0.004	<0.001	<0.001	0.004	0.04
	Children	93.46	<0.001	0.004	<0.001	<0.001	0.003	0.04

Table 7 | Comparison of present study findings with previous studies

Location	Cr Mean/ range (in mg/L)	Zn Mean/ range (in mg/L)	Fe Mean/ range (in mg/L)	Pb Mean/ range (in mg/L)	Cu Mean/ range (in mg/L)	Ni Mean/ range (in mg/L)	Cd Mean/ range (in mg/L)	Mn Mean/ range (in mg/L)	Mg Mean/ range (in mg/L)	Reference
Tongi	0.056	0.992	6.07	0.099	0.114	0.016	0.016	0.099	18.5	This study
Shitalakkhya	0.053	0.227	9.885	0.1	0.018	0.029	0.016	0.108	33.25	This study
Dhaleshwari	10.514	0.111	8.626	0.215	0.015	0.024	0.015	0.104	49.44	This study
Diyala-Sirwan river, Iraq	–	0.005–0.022	0.02–0.134	–	0.006–0.032	0.004–0.005	–	0.005–0.066	22.7–30.61	Issa & Alshatteri (2021)
Iwofe Jetty, New Calabar River, Southern Nigeria	1.78	1.69	1.44	1.34	1.23	2.57	0.25	–	–	Edori & Kpee (2018)
Tikur Wuha River, Southern Ethiopia	–	–	–	0.12	–	0.132	0.02	–	–	Mekuyie (2014)
Challawa river, Kano, Nigeria	2.297	2.986	9.408	1.051	1.290	–	–	2.054	–	Dan'Azumi & Bichi (2010)

consumption of water containing toxic metals (Chakraborty *et al.* 2022). The people living in Dhaka city, since the water distribution system of Dhaka Water Supply and Sewerage Authority relies on these water sources, are also at high risk. The results of the present study point to the need for enhancement, proper operation, and maintenance of wastewater treatment facilities to meet the standard quality for wastewater discharge.

4. CONCLUSION

The overall results of this study indicate a high level of HMs (Pb, Mg, Cr, Cd, and Fe) pollution in rivers and canals located in and around Dhaka, Narayanganj, and Gazipur due to the discharge of little or untreated wastewater from the wastewater treatment plants (WWTPs) of textile factories. The sources of HM contamination in aquatic systems mainly come from the chemicals used in the textile dyeing and printing process. The concentrations of zinc, nickel, and copper in the water samples fell within the Bangladeshi water standard for drinking water. The level of manganese in the samples slightly exceeded the permissible limit in some cases. Health risk assessment of the HMs in the discharge points indicated that there could be a risk of non-cancer effects upon exposure to contaminated water samples. Hence, there is a dire need for the relevant stakeholders to address the poor state of the water treatment systems in the textile industries and thus mitigate HM pollution in the aquatic systems of the cities – Dhaka, Narayanganj, and Gazipur.

This study is not free of limitations. One of them is the duration of sample collection. The regime was just between December 2021 and January 2022. The winter or dry season was chosen due to the convenience of sample collection. During the winter, the water quality of the discharge points deteriorates because of high discharge and less flow of water in the rivers or canals. Most of the variables applied in this study for evaluating the health risk were derived from the USEPA guideline. The values of the variables may not be appropriate for the individuals living in Bangladesh. Along with that, only HM toxicity was considered to assess the health risk, but waterbodies in the study areas may also contain other toxic chemicals. Thus, the level of risk from drinking water in the study area may be higher than this work reports. Furthermore, there are more textile wastewater discharge points in various parts of Bangladesh. The study area of this research was limited to only the central part (Dhaka and adjacent two districts). In addition to these, no hazard index was measured. Future studies should consider other wastewater discharge points in Bangladesh and calculate the hazard index to get a bigger picture of the HM contamination in the rivers in the country.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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