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REVIEW ARTICLE

A comprehensive review of heavy metal pollution in the coastal areas of Bangladesh: abundance, bioaccumulation, health implications, and challenges

Md.Refat Jahan Rakib[1] · Md. Asrafur Rahman[1] · Amarachi Paschaline Onyena[2] · Rakesh Kumar[3] · Aniruddha Sarker[4] · M. Belal Hossain[1,5] · Abu Reza Md. Towfiqul Islam[6] · Md. Saiful Islam[7] · Md. Mostafizur Rahman[8] · Yeasmin Nahar Jolly[9] · Abubakr M. Idris[10,11] · Mir Mohammad Ali[12] · Muhammad Bilal[13] · Xian Sun[14]

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Abstract
The coastal zone of Bangladesh, with a population density of 1278 people per square kilometer, is under serious threat due to heavy metal pollution. To date, many studies have been conducted on the heavy metal contamination in soils, water, aquatic animals, and plants in the coastal zone of Bangladesh; however, the available information is dispersed. In this study, previous findings on the contamination levels, distributions, risks, and sources of heavy metals in sediments and organisms were summarized for the first time to present the overall status of heavy metal pollution along coastal regions. Earlier research found that the concentrations of various heavy metals (HMs), particularly Co, Cd, Pb, Cu, Cr, Mn, Fe, and Ni in water, sediment, and fish in most coastal locations, were above their permissible limits. High concentrations of HMs were observed in sediments and water, like Cr of 55 mg/kg and 86.93 mg/l in the ship-breaking areas and Karnaphuli River, respectively, in coastal regions of Bangladesh. Heavy metals severely contaminated the Karnaphuli River estuary and ship-breaking area on the Sitakundu coast, where sediments were the ultimate sink of high concentrations of metals. Sedentary or bottom-dwelling organisms like gastropods and shrimp had higher levels of heavy metals than other organisms. As a result, the modified PRISMA review method was used to look at the critical research gap about heavy metal pollution in Bangladesh's coastal areas by analyzing the current research trends and bottlenecks.

Keywords Heavy metals · Sediment · Ecological risk · Coastal Bangladesh · Environmental remediation

Introduction

Heavy metals (HMs) are inorganic contaminants found worldwide (Ray et al. 2013; Rahman et al. 2015; Elsagh, 2019, 2021; Rakib et al. 2021a; Islam et al. 2021a). Heavy metal (HM) contamination in soil and marine ecosystems is becoming a growing global environmental concern (Sharma et al. 2020). Since most of the HMs are non-biodegradable and have a long residence time in the food chain and marine biota, they constitute a risk to the environmental matrices and human health (Ametepey et al. 2018; Islam et al. 2020). Some soluble forms of HMs are particularly toxic, and their accumulation in natural systems is extremely hazardous, even at low concentrations (Adeniyi and Afolabi, 2002). The coastal zone covers 47,201 km^2, 32% of the total land mass of Bangladesh, where 37 to 38 million people live (Fig. 1) (Islam 2004; Sarwar 2005). Bangladesh's coastline is noted as a zone of vulnerability and a potential sink of unknown resources (Khan et al. 2017; Islam et al. 2021b). Consequently, HMs in the coastal environment can harm aquatic creatures, and their widespread bioavailability can lead to bioaccumulation in the food chain, which can also be harmful to human health.

The Bay of Bengal's coastal area is affected by tidal uncertainties in water levels up to 150 km from the coast. With a population density of 1278 people per square kilometer, Bangladesh is one of the world's most heavily populated countries. Chemical pollution is considered a potential threat to harm biodiversity and risk to the aquatic biota of the Bay of Bengal's environment (Rakib et al. 2022, 2021a; Rakib

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✉ Md.Refat Jahan Rakib
rifatjahanrakib@gmail.com

Extended author information available on the last page of the article

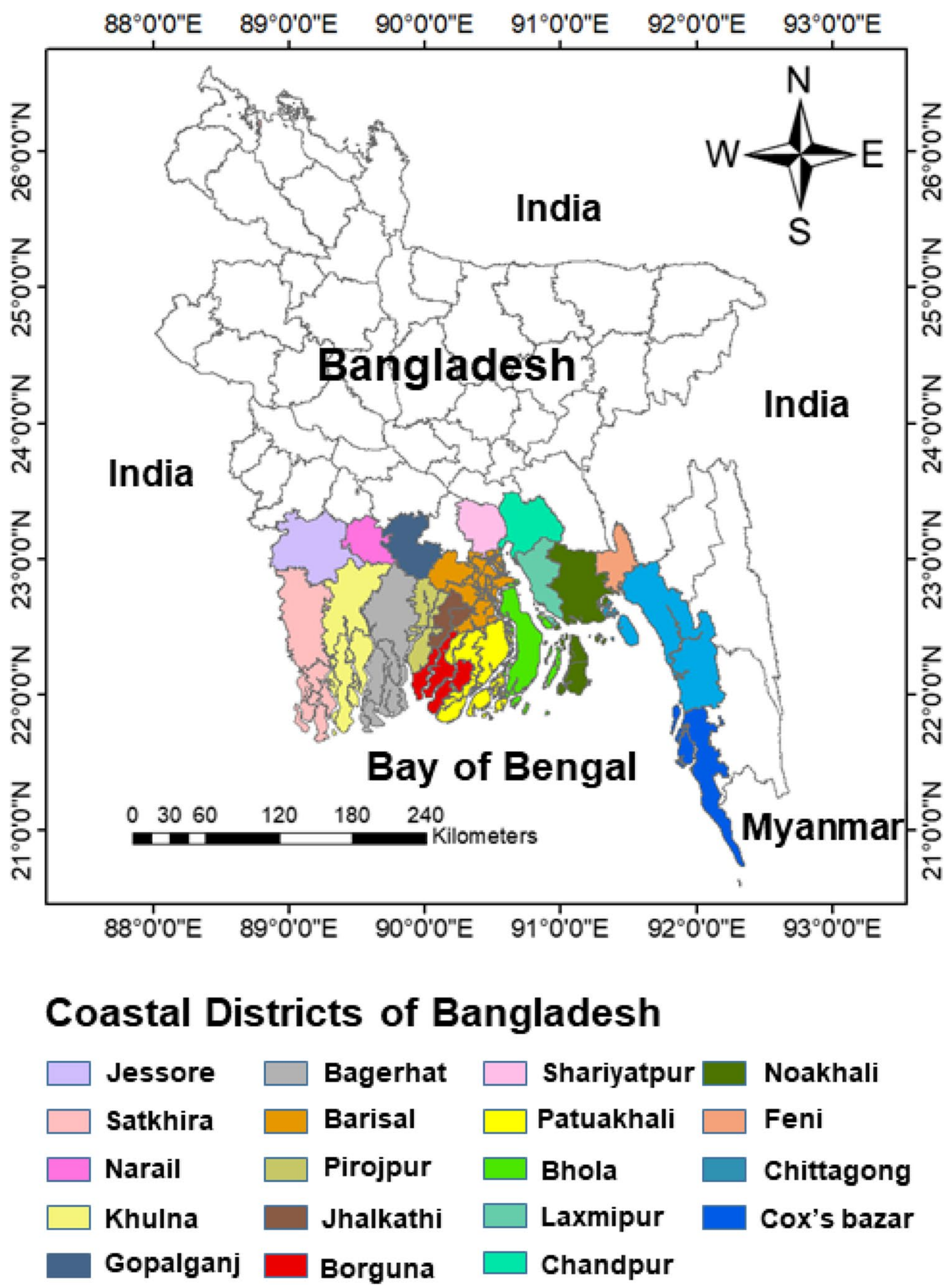

Fig. 1 Map showing the study area (coastal regions of Bangladesh). This figure is modified from the Bangladesh gazette–derived online archive with prior permission only for research purposes

et al. 2021f; Rahman et al. 2021; Siddique et al. 2021). In almost all of the Bay of Bengal's coastal countries, a large portion of the pollutants come from major rivers and minor sources. Furthermore, sewage significantly influences the Bay of Bengal coastal waterways (Rakib et al. 2022, 2021b; Sarma et al. 2020), which is intensified by the low economy of coastal states. Due to cheap and facile settlements, coastal businesses appear to discharge waste directly into rivers, estuaries, and the sea with negligible or no treatment. The countries of Bay of Bengal basin strive diligently to conserve the river estuary and the sea. Helmer and Hespanhol (1997) proposed worldwide rules for eliminating oil and garbage from aquatic areas and scientifically validated fishing guidelines. In Bangladesh, cyclones, storm surges, floods, erosion, soil salinity, and other severe natural disasters are common. Therefore, Karnaphuli, Sangu, Matamuhuri, Bakkhali, Naf, Payra, Pasur, and Rupsha are the major polluted rivers and lakes of Bangladesh (Siddiquee et al. 2012; Shil et al. 2017; Sabbir et al. 2018; Hossain et al. 2019; Proshad et al. 2019; Uddin et al. 2020).

HMs can be found in trace amounts in the natural environment, but anthropogenic stressors can increase their concentrations (Sultan and Shazili, 2010; Tchounwou et al. 2012; Gautam et al. 2014; Outa et al. 2020; Longo et al. 2013; Kabir et al. 2021). Marine ecosystems are natural hotspots for HM pollution, which can have significant environmental consequences due to bio-magnification in food chains (Mishra et al. 2019). Toxic HMs are present in substantial concentrations in effluents discharged onto the Bangladesh shore, posing environmental risks (National Research Council, 2001; Aghadadashi et al. 2019; Uddin et al. 2015; Chen et al. 2005). Because of their widespread use in industrial applications, HMs have recently become ubiquitous in every environmental component of Bangladesh (Sarker et al. 2021). Industrial waste dumped into rivers contributes to river pollution, creating havoc on the marine environment and causing ecological imbalances, ultimately threatening the food chain (Ametepey et al. 2018). HMs are discharged into coastal water by various activities, including fertilizers, pulp and paper, metal, cement, pharmaceuticals, food processing, chemical, textile, petroleum, lubricant factories, and many others (Rahman 2006; Rashid et al. 2015; Aktar and Moonajilin, 2017; Sarma et al. 2020). Additional pollution sources include gas production plants, shipbreaking yards, and untreated trash from the port, metropolis, and neighboring businesses. Regrettably, tannery, textile, mining, electroplating, dyeing, photography, printing, and pharmaceutical effluents are released directly into Bangladeshi rivers (Baki et al. 2018; Bakshi and Panigrahi 2022).

According to Rashid et al. (2015), the Bay of Bengal and the Karnaphuli River are extremely polluted near the Chittagong Port channel due to the discharge of oil and chemical waste from ships. The most prevalent types of litter seen in coastal waters are plastic bottles and other disposable materials (Rakib et al. 2021a; 2022). According to the previous study, the rapid and uncontrolled expansion of shrimp farming has become a major source of concern. The use of antibiotics and other chemicals in shrimp farms pollutes the water and harms other aquatic life. Annually, 620 tons of urea is used in shrimp farming in Cox's Bazar. Therefore, water pollution in Bangladeshi rivers has been the subject of numerous research works. It also produces 15 tons of garbage per day, which ends up in the marine ecosystems (Rahman 2006). Das et al. (2002) determined the quantities of various trace metals (Cr, Mn, Zn, Ni, Cu, Pb, and Fe) in water from the Karnaphuli River estuary and concluded that the estuary had been polluted by sewage from domestic sources, land washout, river runoff, and unplanned maritime activities. Sharif et al. (1994) report that higher concentrations of radioactive trace elements in river sediment could be caused by people putting phosphate fertilizer from nearby agricultural lands and wastes into the estuarine zone.

In Bangladesh, coastal factories discharge wastewater directly into the sea without treatment, causing significant harm to marine ecology and aquatic life, as well as the health of coastal residents exposed to this environment for an extended period (Khan et al. 2017; Sarker et al. 2021) (Fig. 1).

The anomalous values of physical and chemical parameters reveal their impact more clearly (Ametepey et al. 2018; Vajravelu et al. 2018). Due to this process, fish, crustaceans, and other aquatic biota in polluted coastal waters become contaminated. Consumption of marine fish and other seafood from such waters poses long-term harm to human health. Around five million people work in the commercial fishing industry along the coast. Fish and crustaceans are the primary protein sources and a source of revenue or livelihood for coastal inhabitants (Rehman et al. 2018). Organs, such as the kidneys, liver, lungs, brain, and bones, can be damaged by chronic HM exposure (Tchounwou et al. 2012; Rehman et al. 2018). Although there have been a few attempts at documenting HM research in Bangladesh's coastal area, no critical and thorough compilation of such studies has been done. Therefore, this study performs a comprehensive literature analysis in order to systematically assess the HM contamination scenario in Bangladesh, with an emphasis on coastal water, sediment, fish, macrophytes, HM pollution, and their effects on the coastal environment.

Methodology

A detailed assessment of previously published research and review papers on HM contamination, including books and university theses, was gathered through critical and exhaustive library compilation. The investigations focused on several elements of HM contamination and their pathways in the atmosphere, sediment, water, soil, and their health effects on living creatures. The search terms included "*Heavy metals in sediments,*" "*Heavy metals exposure,*" "*Heavy metals in coastal water of Bangladesh,*" "*Trace elements in water,*" "*Heavy metals transport in sediments,*" "*Heavy metals in river sediment,*" "*Heavy metals from industrial processes in Bangladesh,*" "*Heavy metal contamination in fishes,*" "*Heavy metals in food,*" "*Pathways of heavy metals,*" "*Heavy metals in the food chain,*" "*Heavy metals remediation,*" and "*Heavy metal effects on human health.*" A total of 219 research publications on HMs and their exposure-related studies were gathered through this method from internationally recognized sources, such as Science Direct, Web of Science, Scopus, Springer, Bangladesh Journals Online (Bangla JOL), and other national libraries, such as the Environment and Social Development Organization, Bangladesh Bureau of Statistics, Ministry of Environment, Forest and Climate Change, and World Health Organization (WHO).

For extracting the existing findings and study gaps on HM pollution in coastal Bangladesh, a particular accept-delete technique following the chronology of critical review (e.g., PRISMA) was used (Moher et al. 2009). After the associated abstracts were sorted out, full-text articles or reports were examined to identify fully or partially connected research to the study's aims through skimming and spotting. Figure 2 shows the features of peer-reviewed articles, including the number of studies and their methodology. After that, research that did not match the current study's goal was eliminated, leaving the most suitable studies for the current review. The objectives of selected studies were categorized. Figure 2 depicts an overview of the literature selection process. Finally, the findings were then processed and analyzed using the trans-technique to compare HM concentrations from various sources.

Heavy metal sources in the coastal areas

Natural and anthropogenic sources of HMs in the environment are significant factors. Natural sources that contribute to the HM contamination in the surrounding sinks include volcanoes, mineral degradation, forest fires, and evaporation from soil and water surfaces (Fig. 3). In contrast, much of the country is flooded during the monsoon season; severe floods occur when rivers rise above their normal levels; tropical storms (hurricanes) and storm surges; droughts; riverbank erosion; earthquakes; and maybe tsunamis are all possible sources of HM accumulation in the environment (Parvin et al. 2016; Alam, 2019; Rakib et al. 2021c; Ali et al. 2021, 2022). As opposed to natural sources, anthropogenic sources are widely regarded as the primary causes of increasing HM contamination. Anthropogenic sources can be classified into two categories: (1) releases from the intentional extraction and use of HMs, such as HM mining, leather production, electroplating production, and the manufacture of HM-containing products, and (2) releases from waste incineration, landfills, and other metallurgical activities.

Current scenario of HM levels in different ecosystem components of Bangladesh

HM contamination in sediments

Riverine ecosystems comprise diverse habitats and circumstances, and sediment is a significant and dynamic

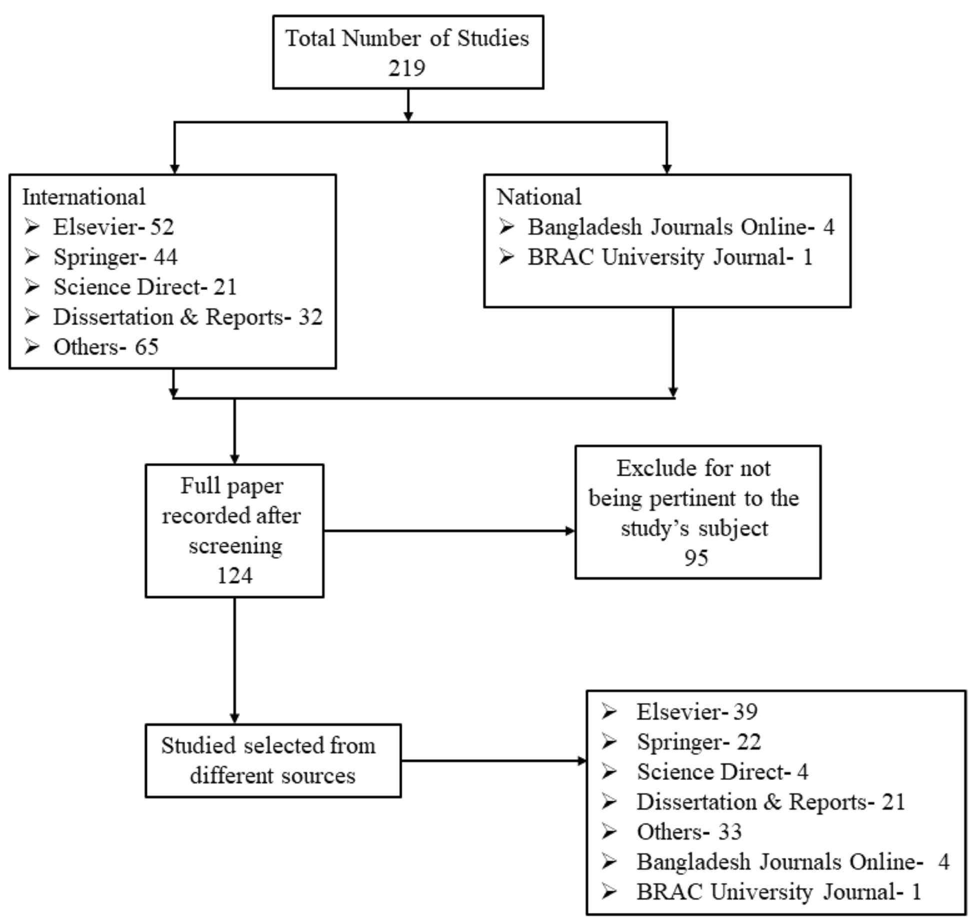

Fig. 2 PRISMA flow diagram indicating the articles collection, screening, exclusion, and inclusion process

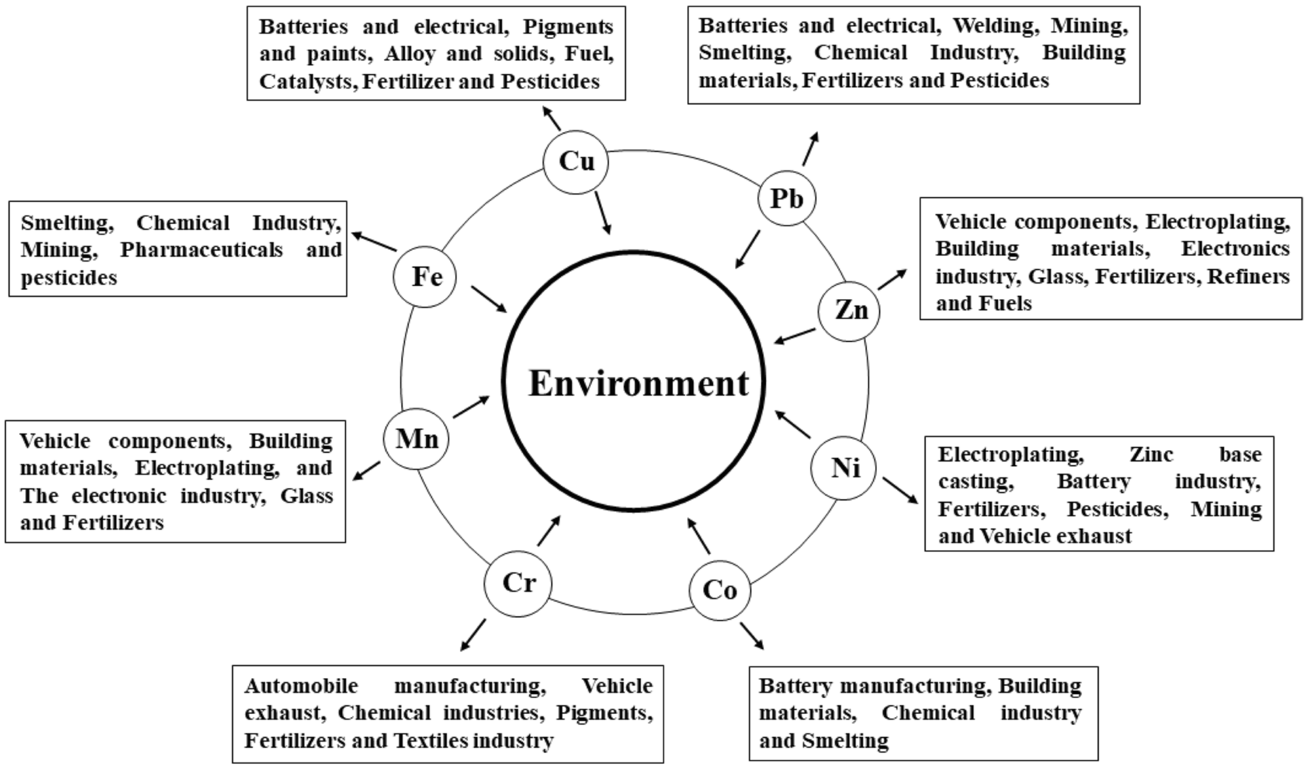

Fig. 3 Sources of HMs in coastal area

component. Sediments are frequently used to assess environmental and geochemical contamination levels (Uluturhan et al. 2011; Islam and Habibullah-Al-Mamun, 2017; Mohiuddin et al. 2016; Islam et al. 2015b). HMs are present in sediment in a variety of chemical configurations and undergo major speciation changes as they transit through the river system due to dissolution, precipitation, sorption, and complicated activities (Mohiuddin et al. 2012; Islam et al. 2018a, b, c). As metals accumulate in bottom deposits, HM concentrations in sediment are substantially higher than in the water column (He et al. 2009; Sultan and Shazili, 2009; Nobi et al. 2010; Rezayi et al. 2011; Saha and Hossain, 2011; Hossain et al. 2021). Liquid effluent disposal, traffic emissions, terrestrial runoff, brick kilns, and leachates carrying chemicals from a variety of urban, industrial, and agricultural activities can all contaminate sediments in riverine ecosystems (Ahmad et al. 2010; Chen et al. 2012; Shikazono et al. 2012; Myers et al. 2013; Mohiuddin et al. 2015; Varol and Şen 2012).

Municipal wastes, industrial effluents, chemical fertilizers, and pesticides are all major sources of HMs in sediment (Chen et al. 2005), and river water is also a source of sediment contamination. Coastal farming pollution from HMs and metalloids can significantly influence food safety and human health (Martin and Griswold 2009; Islam et al. 2018c; Wang et al. 2019). Untreated industrial effluents directly incorporate HMs and metalloids into neighboring water and sediment in coastal locations (Rahman et al. 2012). Several investigations on farmland near the coastline area industrial zone revealed an increase in contaminated sewage water (Singh et al. 2004; Rahman et al. 2012; Hasnine et al. 2017).

Table 1 depicts various HM concentration in coastal sediment of Bangladesh. In some coastal areas of Bangladesh, mining significantly impacts soil due to HMs. Coal, coal ash, and coal-fired boilers have substantial environmental consequences (Habib et al. 2019). Other important sources of sediment HM pollution in Bangladesh have also been identified. HMs are released in considerable quantities by industrial and urban effluents, resulting in high levels of HMs in sediment and water. Cadmium contamination was discovered in sediment from Chittagong and Bogra, owing to rampant industrialization and urbanization in recent decades (Begum et al. 2014; Martín et al. 2015; Alamgir et al. 2015). Large concentrations of chromium, copper, nickel, zinc, arsenic, cadmium, lead and cadmium were detected in some polluted coastal areas of Bangladesh (Raknuzzaman et al. 2016) as compared to Kutubdia Island, Cox's Bazar Chittagong, where chromium concentrations were not detected (Doulah et al. 2017), while the ship-breaking area of Bangladesh in

Table 1 Concentration of HMs in sediments in Bangladesh coast (mg/kg)

Coast	Sampling site	Station/sampling time/site number	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chandpur	Dakatia river	3 stations	23,580 ± 321.86	23.99 ± 4.76	3.7 ± 1.70	67.19 ± 1.56	N/A	N/A	31.09 ± 1.61	265.73 ± 25.22	Hasan et al. 2015
Chittagong	Halda River	2 stations	N/A	5.90	8.80	79.58	15.97	4.92	8.84	139.5	Bhuyan and Bakar, 2017
Chittagong	Bakkhali River estuary, Cox's Bazar	4 stations	N/A	34.92 ± 6.74	27.14 ± 5.09	100.84 ± 5.62	N/A	N/A	N/A	N/A	Siddiquee et al. 2012
Chittagong	Karnaphuli River coast	4 stations	3279 ± 504.31	45.79 ± 16.61	26.705 ± 10.33	105.137 ± 14.92	N/A	N/A	N/A	N/A	Siddique and Akter 2012
Chittagong	Karnaphuli River estuary	Chaktai Khal	6471.43	71.19	40.84	156.86 1	BDL	284.86	444.57	984.43	Sultana et al. 2015
Chittagong	Industrial and municipal wastes in Chittagong	5 stations	N/A	37.8 ± 9.36	65.4 ± 12.58	247.2 ± 51.89	N/A	N/A	N/A	421.2 ± 146.75	Alam et al. 2012
Chittagong	Meghna River near Narsingdi District	Boro Bazar, Boiddamar Char	737–2385	BDL	6.98	BDL	BDL	0.86	1.27–6.81	BDL	Bhuyan et al. 2017
Chittagong	Karnaphuli river	Upstream the Pollution Source (UPS)	20,900 ± 2656.46	19.46 ± 1.10	14.44 ± 1.63	N/A	25.39 ± 3.94	N/A	25.23 ± 2.18	N/A	Mamun et al. 2013
Chittagong	Karnaphuli river	Summer	N/A	N/A	38.33 ± 12.74	N/A	N/A	N/A	70.06 ± 30.93	N/A	Ali et al. 2016
		Winter	N/A	N/A	49.04 ± 15.06	N/A	N/A	N/A	92.11 ± 33.16		
Chittagong	Karnaphuli River	5 stations	832.40 ± 160.28	1.22 ± 0.78	4.96 ± 0.60	16.30 ± 6.82	N/A	N/A	0.76 ± 0.12	15.30 ± 72.95	Islam et al. 2013
Chittagong	Karnaphuli River estuary	5 stations	N/A	25.916 ± 6.28	24.20 ± 0.57	65.53 ± 5.69	38.26 ± 3.44	N/A	87.41 ± 9.18	N/A	Wang et al. 2016
Chittagong	Karnaphuli River		832.40 ± 160	1.22 ± 0.78	4.96 ± 0.60	16.30 ± 6.82	N/A	N/A	0.76 ± 0.12	15.30 ± 72.9	Bhuyan and Islam 2017
Chittagong	Chittagong City	21 stations	N/A	32.63 ± 23.15	7.33 ± 3.22	139.3 ± 98.06	860.33 ± 724.31	N/A	N/A	160.79 ± 151.39	Alamgir et al. 2015
Chittagong	Karnaphuli River	3 stations	29,871 ± 2261.002	N/A	N/A	84.67 ± 6.66	N/A	16.67 ± 0.58	68.67 ± 4.73	717 ± 40.73	Das et al. 2002
Chittagong	Sonadia Island, Cox's Bazar	10 stations	15,127.07 ± 1564.15	18.08 ± 1.99	9.032 ± 1.24	38.75 ± 14.46	16.03 ± 8.29	70.84 ± 14.50	N/A	390.73 ± 53.66	Kabir et al. 2018

Table 1 (continued)

Coast	Sampling site	Station/sampling time/site number	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chittagong	Sangu River estuary	12 stations	N/A	29.24 ± 10.78	19.58 ± 7.02	88.97 ± 58.98	32.75 ± 16.09	N/A	25.15 ± 5.21	N/A	Hossain et al. 2019
Bangladesh	Polluted coastal areas of Bangladesh	6 sampling site	N/A	18.44 ± 10.17	27.24 ± 14.81	40.13 ± 12.83	27.62 ± 6.84	N/A	29.28 ± 14.13	N/A	Raknuzzaman et al. 2016
Chittagong	Kutubdia Island, Cox's Bazar	Sub surface sediments	39,587.32 ± 0.4616	30.28 ± 0.36	15.85 ± 1.04	11.07 ± 3.63	42.65 ± 0.85	N/A	N/A	1027.05 ± 0.89	Doulah et al. 2017
		Surface sediments	37,941.99 ± 0.6775	27.11 ± 0.59	17.69 ± 2.36	9.10 ± 11.48	45.74 ± 1.86	N/A	N/A	985.85 ± 3.01	
Chittagong	Feni River estuary	Wet season	N/A	N/A	0.67–17.03	N/A	13.54–45.71	14.48–45.84	17.77–46.09	23.46–48.73	Islam et al. 2018b
		Dry season	N/A	N/A	0.36–14.04	N/A	8.56–41.86	11.11–42.84	13.91–41.74	17.92–46.01	
Chittagong	Ship-breaking area of Bangladesh	5 Stations	22,575.18 ± 15,783.7	24.33 ± 14.16	71.41 ± 60.02	94.152 ± 45.76	27.308 ± 16.55	N/A	55.064 ± 31.85	4.38 ± 2.97	Barua et al. 2017
Chittagong	Karnaphuli River mouth up to north-east coast of the Bay of Bengal	12 stations	5272.13 ± 600.02	32.91 ± 4.24	23.18 ± 1.81	33.54 ± 1.04	N/A	N/A	78.09 ± 2.84	556.10 ± 8.12	Khan and Khan, 2003
Chittagong	Ship-breaking industries in the Chittagong region	Minimum	1250 ± 1.00	BDL	BDL	33.25 ± 0.47	16.30 ± 0.15	5.75 ± 0.01	0.6 ± 0.00	BDL	Ahmed et al. 2013
		Maximum	10,057 ± 1.30	295.65 ± 1.15	137.05 ± 1.00	305.10 ± 1.51	162.2 ± 1.00	24.45 ± 0.08	65.2 ± 0.61	158.90 ± 0.91	
Chittagong	Ship breaking site in Sitakunda	15 stations	N/A	0.267 ± 0.192	55.936 ± 18.708	70.715 ± 19.454	N/A	N/A	106.806 ± 47.651	20.089 ± 4.033	Aktaruzzaman et al. 2014
Chittagong	Ship break area, Sitakunda, Chittagong	7 stations	62,990–75,210	15.4–21.95	65.5–116.9	124.3–176.4	BDL	N/A	7.95–19.22	N/A	Rahman et al. 2019
Chittagong	Ship breaking yards in Sitakunda	Paddy field	61.72 ± 25.00	39.13 ± 47.55	316.98 ± 47.28	91.44 ± 11.40	75.70 ± 24.4	N/A	54.40 ± 8.30	N/A	Chowdhury and Rasid 2021
		Vegetable field	1712.00 ± 56.00	120.32 ± 38.76	528.81 ± 182.42	127.72 ± 47.44	77.78 ± 4.20	N/A	94.50 ± 6.00	N/A	
		vegetable garden	2103.00 ± 436.00	426.52 ± 315.79	1388.25 ± 980.00	154.03 ± 64.41	89.50 ± 60.0	N/A	80.20 ± 56.00	N/A	

Table 1 (continued)

Coast	Sampling site	Station/sampling time/site number	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Pasur River estuary	Mongla	6 sampling site	16500-31900	11.48-29.25	5.33-18.42	26.25-71.93	18.80-45.00	7.30-16.40	2.80-31.90	265-698	Rahman et al. 2011
Pasur River	N/A	N/A	4.16 ± 0.45	N/A	N/A	69.8 ± 14.8	N/A	14.9 ± 0.2	72.5 ± 8.1	649 ± 99	Hossain et al. 2016
Pasur River	N/A	N/A	19,006.067	6.333	1.035		20.053		18.907		Shil et al. 2017
Mongla port	N/A	N/A	3736.90 ± 322.17	19.55 ± 6.49	10.40 ± 1.49	66.76 ± 18.32	N/A	N/A	N/A	258.08 ± 51.61	Rayhan Khan et al. 2019
Sundarban	N/A	N/A	173,890 ± 9880	10.5 ± 1.7	19.3 ± 1.0	73.6 ± 2.2	76.1 ± 18.8	31.3 ± 5.6	15.7 ± 3.4	436.8 ± 14.7	Awal et al. 2009
Sundarban (Shyamnagar Upazila, Satkhira)	N/A	N/A	51,912	478	2226	154	230	N/A	1499	3584	Arafin et al. 2019
Sundarban	N/A	N/A	3.81 ± 0.51	22.3 ± 3.83	15.8 ± 3.11	67.7 ± 12.3	28.6 ± 4.49	13.9 ± 1.67	67.0 ± 10.6	634 ± 132	Islam et al. 2017
Sundarban	N/A	N/A	42, 172.17	44.69	25.61	74.09	207.31	N/A	5287	740.95	Kumar et al. 2016
Rupsha River	N/A	Summer	N/A	48.28 ± 17.7	22.90 ± 12.1	N/A	2.72 ± 1.7	34.47 ± 27.7	N/A	18.71 ± 6.1	Proshad et al. 2019
	N/A	Winter	N/A	89.32 ± 32.9	42.23 ± 22.4	N/A	4.83 ± 3.0	50.33 ± 40.4	N/A	31.81 ± 10.4	

Chittagong recorded values of 55.064 mg/kg (Barua et al. 2017). Meghna River Delta and Dakatia River in Chandpur had Pb values greater than the permissible limit by the World Health Organization (Hasan et al. 2015; Bibi et al. 2006; Bhuyan et al. 2016). Therefore, human health implications subsist from continuous consumption of crops, water, and fishery consumptions from the area.

Heavy metals in coastal water of Bangladesh

HM contamination in sediments and water columns deteriorates water quality in developing countries like Bangladesh (Rakib et al. 2021d; Islam et al. 2021a, b, c; Ali et al. 2016; Kibria et al. 2016; Islam et al. 2015a, b; Ali et al. 2016; Kibria et al. 2016; Islam et al. 2015a, b; Khadseet al. 2008; Venugopal et al. 2009; Khadseet al. 2008). HMs have been identified at alarming levels in rivers, estuaries, seawater, and lakes in the previous decades, as shown in Table 2 (Majid et al. 2003; Begum et al. 2005; Fernandes et al. 2008; Hasan et al. 2015; Uddin et al. 2019).

Fe concentration in the Karrnaphuli River was 0.18 mg/l, which is below the allowed limit. Hasan et al. (2015) discovered Fe concentrations in the Dakatia river in Chandpur within the standard specification. Hossain et al. (2017a) determined significant concentrations in Chittagong City. The level of Pb found in the Kalurghat Industrial Area of Chittagong (0.194 mg/kg) was above the WHO (1993) and EU (1998) detection limits (Majid et al. 2003). The Karnaphuli River had high levels of 15.2 mg/l (Uddin et al. 2020). In the Kalurghat Industrial Area of Chittagong, the content of Cr (0.23 mg/l) was found to be much over the WHO (1993) and EU (1998) limits (0.05 mg/kg) (Majid et al. 2003). Lower Cr values were found by Hasan et al. (2015) and Shil et al. (2017). Ali et al. (2016) observed that the Karnaphuli River in Chittagong had greater Cr concentrations in the summer (69.56 mg/l) than in the winter (86.93 mg/l).

In the Rupsha and Pasur Rivers, cobalt concentrations were less than 0.1 mg/l (Samad et al. 2015; Sabbir et al. 2018; Shil et al. 2017). Co is good for health at lower concentrations but causes lung and heart problems and dermatitis by exposure to higher levels (ATSDR 2004). The Mn content in textile industry effluents in Chittagong was found (0.661 mg/l) (Ahmed and Nizamuddin, 2012), which was within the EU's permissible limit of 0.03 mg/l (Karim et al. 2018). The level of Ni discovered (0.3 mg/l) in the Meghna River in Chittagong (Bhuyan et al. 2017) surpassed the WHO (1993) and the EU (1998) permitted limit (0.02 mg/l). Ahmed and Nizamuddin (2012) found a Zn content of (3.315 mg/l), but Uddin et al. 2019 and Hasan et al. (2015) found values much below the WHO permitted limits of 3 mg/l in the Karnaphuli and Dakatia Rivers (1993). Cu concentrations (0.033 mg/l) were observed in the Dakatia River in Chandpur (Hasan et al. 2015), which are significantly below the WHO (1993) and EU (1998) acceptable limits (2.0 mg/kg). This concentration was substantially lower than Majid et al. (2003) found in Chittagong's Kalurghat Industrial Area.

Heavy metals in fishes of Bangladesh

Cadmium, lead, and other harmful metals can bio-accumulate and bio-magnify in seafood and then be passed on to mammals via the food chain (Islam et al. 2014; Martín et al. 2015; Chakraborty et al. 2016; Islam et al. 2015a, b; Ahmed et al. 2015). Ingestion of infected foods contaminated by chemical and microbiological risks causes man-made foodborne illnesses (Rahmani et al. 2018).

Fish and fishery products are an important part of a balanced diet (Galimberti et al. 2016). They comprise several key nutrients, such as omega 3 fatty acids, and are low in saturated fat and a cheap source of animal protein in developing countries (Miri et al. 2017; Fakhri et al. 2018). Bangladesh's beaches are potential hotspots for various biological species and economic trends, with rural residents engaging in commercial fishing activities. Since fish is the Bangladeshi people's primary source of animal protein, HMs present in the aquatic diet have become the major contaminant of this region, as various HM contamination summarized in Table 3. Owing to the rapid invasion of HMs into the aquatic environment by anthropogenic activities, industrial wastes, and metal effluent discharge, HMs have become the major contaminants in aquatic diets (Li et al. 2015). Untreated industrial wastes, unused battery particles, painting materials generated from Pb sources, gasoline from cargos, launch-steamer, motorized boat transportation routes, and improper home discharged wastes contribute to many HMs on the coast. Consumption of aquatic foods polluted with toxic chemicals poses major health complications around the globe (Gan et al. 2017; Liang et al. 2018). Thus, chemical contamination in food has long been regarded as one of the most serious threats to human health (Martin and Griswold 2009; Machado et al. 2017).

HMs enter the aquatic environment via natural and anthropogenic sources, posing major hazards to aquatic biota and humans (Saha et al. 2016a, 2016b; Fakhri et al. 2018). Absorption of particulate material particles in sediment–water interactions, ingestion of feed, ion exchange transversely into lipophilic tissues, and adsorption on tissue and skin surfaces are all ways that fish amass large levels of harmful metals (Ahmed et al. 2016). Metals absorbed in fish are transported to humans via the food chain and deposited in various tissues and vital organs (He et al. 2009; Fang et al. 2014; Chakraborty et al. 2016). Many food safety studies have been linked to the risk of consuming HM-contaminated

Table 2 Concentration of HMs in water in Bangladesh coast (mg/L)

Coast	Sampling site	Station/sampling time/site number	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chandpur	Dakatia River	3 stations	0.217 ± 0.096	0.033 ± 0.03	0.0063 ± 0.007	0.114 ± 0.10	N/A	N/A	0.003 ± 0.001	0.334 ± 0.322	Hasan et al. 2015
Chittagong	Kalurghat Industrial Area of Chittagong	5 stations	N/A	1.59 ± 1.00	0.194 ± 0.077	0.138 ± 0.08	N/A	N/A	0.234 ± 0.268	N/A	Majid et al. 2003
Chittagong	Halda River	2 stations	N/A	0.10	0.07	0.35	0.41	0.05	0.06	0.16	Bhuyan et al. 2017
Chittagong	Karnaphuli River	4 stations	20.025- 42.203	0.372- 0.973	0.405- 1.195	0.472—1.186	0.356- 0.865	N/A	0.421 -0.925	0.498—1.372	Das et al. 2002
Chittagong	Majhirghat	2 Stations	1.205 ± 0.1	0.022 ± 0.00	0.16 ± 0.00	N/A	0.032 ± 0.00	N/A	0.039 ± 0.02	N/A	Jothi et al. 2018
Chittagong	Karnaphuli river salt marsh pore water	4 Stations	4.635 ± 2.053	0.3175 ± 0.08	0.247 ± 0.084	0.655 ± 0.319	N/A	N/A	N/A	N/A	Siddique and Akter 2012
Chittagong	Meghna River near Narsingdi District	2 Stations	3.68	0.027	0.01	0.04	0.3	0.009	0.02	0.5	Bhuyan et al. 2017
Chittagong	Karnaphuli river	Upstream the Pollution Source (UPS)	0.6455 ± 0.0025	ND; not detected	0.158 ± 0.012	N/A	ND; not detected	N/A	ND; not detected	N/A	Mamun et al. 2013
		Pollution Source (PS)	1.821 ± 0.332	ND; not detected	0.224 ± 0.031	N/A	ND; not detected	N/A	ND; not detected	N/A	
Chittagong	Textile industry effluents	15 Stations	2.38 ± 0.79	0.138 ± 0.1	0.0396 ± 0.036	3.315 ± 2.07	0.095 ± 0.093	0.010 ± 0.01	0.045 ± 0.046	0.661 ± 1.464	Ahmed and Nizamuddin 2012
Chittagong	Chittagong City, Bangladesh	22 Stations	2.31 ± 3.99	0.868 ± 0.035	2.09 ± 0.275	Trace	Trace	Trace	0.639 ± 0.387	0.892 ± 0.768	Hossain et al. 2017a
Chittagong	Karnaphuli River	Summer	N/A	N/A	9.85 ± 4.75	N/A	N/A	N/A	69.56 ± 16.95	N/A	Ali et al. 2016
		Winter	N/A	N/A	16.83 ± 6.17	N/A	N/A	N/A	86.93 ± 17.39	N/A	
Chittagong	Karnaphuli River	5 Stations	2.06 ± 1.456	0.05 ± 0.028	0.14 ± 0.031	0.28 ± 0.139	N/A	N/A	0.25 ± 0.068	0.12 ± 0.043	Islam et al. 2013

Table 2 (continued)

Coast	Sampling site	Station/sampling time/site number	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chittagong	Karnaphuli River	Rainy Season	N/A	N/A	BDL	N/A	0.0278	N/A	0.0072	N/A	Dey et al. 2015
		Winter season	N/A	N/A	BDL	N/A	0.0276	N/A	0.0073	N/A	
Chittagong	Karnaphuli river	5 Stations	15.28117 ± 20.4775	0.0189 ± 0.02531	15.51733 ± 14.88124	0.07213 ± 0.06768	N/A	N/A	0.62 ± 0.2226	0.35483 ± 0.3057	Uddin et al. 2019
Chittagong	Karnaphuli river	10 Stations	2.797 ± 1.126	0.0161 ± 0.00	0.0028 ± 0.00	0.0275 ± 0.012	0.004 ± 0.00	N/A	0.1655 ± 0.00	0.088 ± 0.06	Jolly et al. 2019
Chittagong	Karnaphuli River	5 Stations	0.18 ± 0.24	N/A	N/A	0.036 ± 0.025	0.094 ± 0.027	N/A	N/A	0.03 ± 0.03	Karim et al. 2018
Chittagong	Karnaphuli River	N/A	2.06 ± 1.456	0.05 ± 0.028	0.14 ± 0.031	0.28 ± 0.139	0.01 ± 0.002	N/A	0.25 ± 0.068	0.12 ± 0.043	Bhuyan & Islam 2017
Chittagong	Sitakund Upazilla (Bhatiary to Kumira) Ship breaking area	Sea water	28.40 ± 59.19	0.17 ± 0.34	0.07 ± 0.12	0.52 ± 0.98	0.08 ± 0.18	N/A	0.04 ± 0.08	0.48 ± 0.78	Hasan et al. 2013
Chittagong	Ship breaking	15 stations	N/A	0.267 ± 0.192	0.477 ± 0.265	0.320 ± 0.282	N/A	N/A	0.511 ± 0.284	0.196 ± 0.122	Aktaruzzaman et al. 2014
Chittagong	Shipbreaking	Thirty (30)	26.21 ± 10.16	0.0875 ± 0.09	0.0265 ± 0.016	0.61 ± 0.37	0.03 ± 0.03	0.05 ± 0.04	0.2 ± 0.2	1.93 ± 1.02	Islam et al. 2013
Pasur River	N/A	N/A	0.27	0.02	N/A	0.01	< 0.01	< 0.01	0.02	NA	Shil et al. 2017

Table 3 Concentration of HMs in fishes in Bangladesh coast (mg/kg)

Coast	Sampling site	Station/sampling time/species	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chittagong	Chaktai Khal of Karnaphuli River estuary	*Scylla serrata*	333.67	58.12	3.79	100.14	13.19	BDL	N/A	123.95	Sultana et al. 2015
		Meretrix lyrata	1924.14	1819.96	3.7	28.16	12.97	18.27	N/A	54.11	
		Neocaridina davidi	3383	23.2	BDL	51.39	BDL	30.9	N/A	97.4	
Chittagong	Karnaphuli River	*Gonialosa manmina*	63.082	2.806	7.707	33.46	N/A	N/A	0.099	4.784	Islam et al. 2013
		Otolithoides pama	7.465	0.842	0.886	8.535	N/A	N/A	0.569	1.733	
		Rita rita	73.732	1.508	2.861	72.701	N/A	N/A	0.064	13.301	
		Pellonaditchela	8.703	1.093	1.094	15.794	N/A	N/A	0.429	1.078	
		Apocrptes bato	145.131	0.77	1.843	11.45	N/A	N/A	1.077	6.123	
Chittagong	4 fish markets in Chittagong	*Otolithoides pama*	55.77 ± 26.73	3.48 ± 0.66	1.63 ± 0.097	N/A	1.15 ± 0.064	N/A	4.71 ± 1.3	N/A	Jothi et al. 2018
		Harpadon nehereus	36.66 ± 1.97	2.45 ± 0.36	1.13 ± 0.75	N/A	1.32 ± 0.59	N/A	3.75 ± 0.59	N/A	
		Coiliaramcarati	100.03 ± 8.90	2.97 ± 1.61	2.65 ± 0.16	N/A	0.44 ± 0.384	N/A	12.61 ± 4.25	N/A	
Chittagong	Karnaphuli River	*Apocryptes bato* muscle	39.53 ± 10.48	0.58 ± 0.01	0.13 ± 0.07	N/A	0.12 ± 0.063	N/A	0.44 ± 0.31	N/A	Sumon et al. 2013
		Palaemon karnafuliensis muscle	22.67 ± 0.47	4.97 ± 1.59	0.04 ± 0.00	N/A	0.06 ± 0.025	N/A	0.825 ± 0.99	N/A	
		Cerithidea cingulata muscle	2095.75 ± 325.83	370.30 ± 512.18	1.27 ± 0.79	N/A	3.34 ± 1.72	N/A	4.27 ± 2.23	N/A	
Chittagong	Karnaphuli River	*Corica soborna*	82.4 ± 3.8	5.4 ± 0.5	< 0.001	70.6 ± 2.1	< 0.24	N/A	16.3 ± 1.1	14.1 ± 0.6	Jolly et al. 2019
		Otolithoides pama	51.9 ± 0.7	5.2 ± 1.3	< 0.001	35.0 ± 0.5	< 0.24	N/A	15.0 ± 0.0	15.7 ± 2.0	
		Apocryptes bato	84.9 ± 1.2	10.6 ± 0.8	< 0.001	40.1 ± 0.3	< 0.24	N/A	14.4 ± 0.7	16.3 ± 1.4	
		Macrobracium lamarre	196.5 ± 5.1	4.5 ± 0.2	< 0.001	30.6 ± 13.1	< 0.24	N/A	15.3 ± 0.5	16.2 ± 1.1	
		Neritaspengleriana	319.9 ± 10.6	3.4 ± 1.9	< 0.001	21.5 ± 1.0	< 0.24		14.0 ± 0.6	216.1 ± 0.3	
Chittagong	Karnaphuli River	*A. bato*	N/A	15.29 ± 3.82	15.22 ± 1.32	N/A	N/A	N/A	3.54 ± 0.54	N/A	Ahmed et al. 2019a
		P. chinensis	N/A	13.10 ± 2.49	14 ± 1.79	N/A	N/A	N/A	3.59 ± 0.55	N/A	
		I. parsia	N/A	9.50 ± 1.16	13.98 ± 1.93	N/A	N/A	N/A	3.30 ± 0.40	N/A	
		M. cephalus	N/A	11.48 ± 1.27	12.70 ± 1.72	N/A	N/A	N/A	3.14 ± 0.36	N/A	
		H. limbatus	N/A	12.52 ± 1.40	13.77 ± 1.54	N/A	N/A	N/A	3.52 ± 0.48	N/A	
		T. toli	N/A	10.72 ± 1.47	13.61 ± 0.82	N/A	N/A	N/A	3.11 ± 0.54	N/A	
Chittagong	Meghna River Estuary	*L. calcarifer*	N/A	6.62	4.63	N/A	N/A	N/A	1.19	N/A	Ahmed et al. 2019b
		S. silondia	N/A	6.26	4.42	N/A	N/A	N/A	0.95	N/A	
		C. garua	N/A	5.83	4.07	N/A	N/A	N/A	0.77	N/A	
		P. subviridis	N/A	4.94	3.77	N/A	N/A	N/A	0.67	N/A	
		O. pama	N/A	4.43	3.37	N/A	N/A	N/A	0.65	N/A	
		T. ilisa	N/A	4.06	3.33	N/A	N/A	N/A	0.64	N/A	
		R. corsula	N/A	3.83	2.91	N/A	N/A	N/A	0.62	N/A	
		A. coila	N/A	3.77	2.76	N/A	N/A	N/A	0.62	N/A	

Table 3 (continued)

Coast	Sampling site	Station/sampling time/species	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chittagong	Karnaphuli River		69.95 ± 5.96	1.40 ± 0.84	1.67 ± 0.89	20.79 ± 12.4	N/A	N/A	0.45 ± 0.25	3.77 ± 2.23	Bhuyan and Islam 2017
Chittagong	Karnaphuli river	10 stations/8 species									Ali et al. 2019
		Tenualosa ilisha									
		Summer	N/A	N/A	0.57	N/A	N/A	N/A	0.27	N/A	
		Winter	N/A	N/A	0.67	N/A	N/A	N/A	0.65	N/A	
		Gudusia chapra									
		Summer	N/A	N/A	0.74	N/A	N/A	N/A	0.71	N/A	
		Winter	N/A	N/A	0.82	N/A	N/A	N/A	0.84	N/A	
		Otolithoides pama									
		Summer	N/A	N/A	1.67	N/A	N/A	N/A	0.85	N/A	
		Winter	N/A	N/A	2.1	N/A	N/A	N/A	1.03	N/A	
		Setipinna phasa									
		Summer	N/A	N/A	0.91	N/A	N/A	N/A	0.7	N/A	
		Winter	N/A	N/A	0.95	N/A	N/A	N/A	0.85	N/A	
		Harpadon nehereus									
		Summer	N/A	N/A	1.56	N/A	N/A	N/A	0.97	N/A	
		Winter	N/A	N/A	2	N/A	N/A	N/A	1.02	N/A	
		Polynemus paradiseus									
		Summer	N/A	N/A	1.02	N/A	N/A	N/A	0.75	N/A	
		Winter	N/A	N/A	1.52	N/A	N/A	N/A	0.98	N/A	
		Sillaginopsispanijus									
		Summer	N/A	N/A	1.78	N/A	N/A	N/A	1.02	N/A	
		Winter	N/A	N/A	2.64	N/A	N/A	N/A	1.19	N/A	
		Pampus chinensis									
		Summer	N/A	N/A	0.74	N/A	N/A	N/A	0.75	N/A	
		Winter	N/A	N/A	0.95	N/A	N/A	N/A	0.81	N/A	

Table 3 (continued)

Coast	Sampling site	Station/sampling time/species	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chit-tagong	Moheskhali Cox's Bazar	*Perna viridis (L.)* Winter season	N/A	N/A	0.03	N/A	N/A	N/A	N/A	N/A	Islam et al. 2016
		Rainy season	N/A	N/A	0.03	N/A	N/A	N/A	N/A	N/A	
		Crassostrea Winter	N/A	N/A	0.05	N/A	N/A	N/A	N/A	N/A	
		Rainy	N/A	N/A	0.04	N/A	N/A	N/A	N/A	N/A	
		Sepia officinalis Winter	N/A	N/A	0.051	N/A	N/A	N/A	N/A	N/A	
		Rainy	N/A	N/A	0.045	N/A	N/A	N/A	N/A	N/A	
		Loligo edulis Winter	N/A	N/A	0.05	N/A	N/A	N/A	N/A	N/A	
		Rainy season	N/A	N/A	0.035	N/A	N/A	N/A	N/A	N/A	
Chit-tagong	Cox's Bazar District	Sun-dried *Stromateus cinereus*	N/A	1.15	8.43	24.93	N/A	N/A	5.85	N/A	Hossain et al. 2017b
		Sun-dried *Latescal carifer*		1.04	6.28	23.8	N/A	N/A	5.6	N/A	
Chit-tagong	Cox's Bazar District	Sundried *Harpadon nehereus*	N/A	2.21	8.281	55.38	N/A	N/A	8.38	N/A	Jamil et al. 2017
		Sun-dried *Trichiurus haumela*	N/A	1.401	5.465	19.95	N/A	N/A	6.969	N/A	
Chit-tagong	Cox's Bazar District	*H. neherius*	133.5 ± 1.14	19.3 ± 0.3	0.52 ± 0.02	59.2 ± 1.0	N/A	0.30 ± 0.02	7.06 ± 0.06	9.40 ± 0.31	Rakib et al. 2021e
		T. lepturus	191.6 ± 4.2	14.5 ± 0.5	0.28 ± 0.04	50.4 ± 0.8	N/A	0.30 ± 0.02	9.34 ± 0.07	0.33 ± 0.02	
		P. chinensis	178.2 ± 4.1	0.20 ± 0.12	0.001 ± 0.00	68.7 ± 0.8	N/A	0.31 ± 0.04	0.42 ± 0.03	0.32 ± 0.01	
		P. affinis	160.8 ± 1.6	17.7 ± 0.5	0.001 ± 0.00	63.5 ± 1.1	N/A	2.25 ± 0.48	3.55 ± 0.04	8.11 ± 0.07	
		A. mola	148.3 ± 1.1	34.7 ± 0.3	0.001 ± 0.00	43.5 ± 1.5	N/A	0.32 ± 0.04	5.46 ± 0.09	0.32 ± 0.01	
		P. microdon	148.0 ± 1.7	10.7 ± 0.2	0.001 ± 0.00	35.5 ± 0.7	N/A	4.32 ± 0.46	6.67 ± 0.05	1.36 ± 1.80	
		I. megaloptera	203.0 ± 11.0	63.3 ± 2.0	0.001 ± 0.00	63.7 ± 1.1	N/A	0.27 ± 0.01	9.35 ± 0.03	0.34 ± 0.04	
		C. dussumieri	172.6 ± 2.3	19.4 ± 0.5	0.001 ± 0.00	51.7 ± 1.4	N/A	1.69 ± 0.25	7.79 ± 0.03	7.45 ± 0.43	
		L. calcarifer	134.6 ± 4.9	19.7 ± 0.6	0.001 ± 0.00	46.3 ± 1.7	N/A	2.65 ± 0.73	7.39 ± 0.04	0.39 ± 0.07	
		G. chapra	179.0 ± 0.6	21.8 ± 0.7	0.001 ± 0.00	56.8 ± 0.3	N/A	0.29 ± 0.01	12.4 ± 0.0	7.85 ± 0.32	

Table 3 (continued)

Coast	Sampling site	Station/sampling time/species	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chittagong	Cox's Bazar, Saint martin	*Harpadon nehereus*	9.3841 ± 1.41	0.1031 ± 0.05	BDL	0.3084 ± 0.13	N/A	N/A	0.323 ± 0.09	0.0924 ± 0.01	Akter et al. 2019
		Amblypharyngodon mola	52.773 ± 823	0.0473 ± 0.01	BDL	0.1473 ± 0.04	N/A	N/A	0.3072 ± 0.05	0.1105 ± 0.07	
		Devario devario	20.2737 ± 3.86	0.2167 ± 0.110	BDL	1.3373 ± 0.09	N/A	N/A	0.7415 ± 0.01	0.3196 ± 0.12	
		Chandramara chandramara	10.004 ± 4.95	0.2632 ± 0.05	BDL	1.8146 ± 0.08	N/A	N/A	0.3657 ± 0.06	0.2259 ± 0.17	
		Nemipterus vigatus	18.9268 ± 2.57	0.185 ± 0.02	0.2571 ± 0.001	1.5708 ± 0.61	N/A	N/A	0.3702 ± 0.01	0.3905 ± 0.16	
		Trichiurus lepturus	65.9382 ± 9.35	0.1925 ± 0.06	BDL	0.1535 ± 0.05	N/A	N/A	0.5502 ± 0.13	0.4026 ± 0.153	
		Chepa	29.8327 ± 5.12	0.1608 ± 0.08	0.1605 ± 0.007	0.5774 ± 0.162	N/A	N/A	0.5255 ± 0.23	0.2884 ± 0.09	
		Stromateus chinensis	19.6859 ± 6.62	0.1571 ± 0.04	0.0277 ± 0.003	0.615 ± 0.164	N/A	N/A	8.5352 ± 2.75	0.3088 ± 0.162	
		Fatra	15.5554 ± 6.43	0.1664 ± 0.08	0.0277 ± 0.003	0.9106 ± 0.231	N/A	N/A	0.163 ± 0.08	0.2235 ± 0.05	
		Setipinna phasa	13.056 ± 2.72	0.1981 ± 0.02	0.0277 ± 0.009	1.7525 ± 0.94	N/A	N/A	0.1788 ± 0.04	0.2042 ± 0.031	
Chittagong	Cox's Bazar	*Stromateus cinereus*	N/A	1.82	1.62	N/A	N/A	N/A	0	N/A	Mansur et al. 2018
		Lates calcarifer	N/A	2.41	4.16	N/A	N/A	N/A	3.63	N/A	
		Trichiurus haumela	N/A	4.53	16.04	N/A	N/A	N/A	7.94	N/A	
		Harpodon nehereus	N/A	3.41	1.78	N/A	N/A	N/A	12.46	N/A	
		Hilsa ilisha	N/A	4.43	4.87	N/A	N/A	N/A	8.14	N/A	

Table 3 (continued)

Coast	Sampling site	Station/sampling time/species	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Chittagong	Saint Martin Island	Marine fish	N/A	N/A	N/A	N/A	N/A	N/A		N/A	Baki et al. 2018
		L. fasciatus	1.189 ± 0.28	< 0.2	0.11 ± 0.07	3.92 ± 0.16	N/A	N/A	< 0.05	0.60 ± 0.09	
		R. kanagurta	30.0297 ± 1.85	2.23 ± 0.48	1.74 ± 1.41	9.21 ± 0.14	N/A	N/A	< 0.05	0.74 ± 0.10	
		H. nigresceus	18.97 ± 0.82	0.74 ± 0.28	8.92 ± 0.51	12.10 ± 0.16	N/A	N/A	0.34 ± 0.01	< 0.2	
		P. cuneatus	11.91 ± 2.33	0.44 ± 0.14	< 0.06	3.34 ± 0.01	N/A	N/A	0.19 ± 0.00	< 0.2	
		P. annulare	165.2 ± 29.9	< 0.2	< 0.06	4.08 ± 0.05	N/A	N/A	1.87 ± 0.00	< 0.2	
		S. rubrum	5.40 ± 2.83	< 0.2	4.02 ± 0.94	6.93 ± 0.15	N/A	N/A	< 0.05	0.60 ± 0.12	
		L. Atkinson	46.35 ± 2.46	0.3 ± 0.09	< 0.06	7.55 ± 0.45	N/A	N/A	0.40 ± 0.00	< 0.2	
		T. jerboa	15.58 ± 2.0	1.17 ± 0.39	< 0.06	5.91 ± 0.21	N/A	N/A	0.40 ± 0.01	< 0.2	
		Shrimp					N/A	N/A			
		P. sculptilis (M)	18.713 ± 2.63	5.049 ± 0.07	0.690 ± 1.56	13.5 ± 0.43	N/A	N/A	< 0.08	< 0.2	
		P. sculptilis (S)	272.7 ± 1.90	16.2 ± 1.55	9.474 ± 2.84	43.26 ± 0.38	N/A	N/A	< 0.08	20.1 ± 16.2	
		Lobster					N/A	N/A			
		P. versicolor (M)	9.466 ± 2.77	13.398 ± 0.45	< 0.3	22.413 ± 0.35	N/A	N/A	< 0.08	< 0.2	
		P. versicolor (S)	128.4 ± 5.00	5.7 ± 0.55	< 0.3	27.48 ± 0.49	N/A	N/A	0.980 ± 0.00	3.3 ± 0.56	
		Crabs					N/A	N/A			
		P. sanguinolentus(M)	29.558 ± 1.71	17.205 ± 0.53	< 0.06	47.367 ± 0.37	N/A	N/A	0.063 ± 0.00	89.706 ± 1.26	
		P. sanguinolentus (S)	117.2 ± 2.93	23.0 ± 0.71	< 0.06	7.02 ± 1.74	N/A	N/A	0.456 ± 0.00	117.6 ± 0.35	
		T. crenata(M)	168.82 ± 1.68	30.735 ± 0.36	< 0.06	61.921 ± 0.43	N/A	N/A	1.412 ± 0.04	10.147 ± 0.2	
		T. crenata (S)	72.4 ± 0.65	22.6 ± 0.97	< 0.06	39.44 ± 0.23	N/A	N/A	0.334 ± 0.00	1.4 ± 0.75	
		M. victor (M)	69.952 ± 2.5	11.394 ± 0.44	< 0.06	22.601 ± 0.2	N/A	N/A	0.623 ± 0.008	6.490 ± 3.48	
		M. victor (S)	360 ± 5.4	15.9 ± 0.50	< 0.06	52.47 ± 0.62	N/A	N/A	1.119 ± 0.01	18.9 ± 7.69	

Table 3 (continued)

Coast	Sampling site	Station/sampling time/species	Fe	Cu	Pb	Zn	Ni	Co	Cr	Mn	References
Bangladesh	Coastal area of Bangladesh	Cox's Bazar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Raknuzzaman et al. 2016
		Fish (*Tenualosa ilisha, Pampus argentius, Cynoglossus lingua*)	N/A	14 ± 16.2	0.63 ± 0.46	138 ± 87.3	0.56 ± 0.57	N/A	2.2 ± 1.80	N/A	
		Shrimp (*Penaeus indicus*)	N/A	13 ± 1.1	0.38 ± 0.12	131 ± 3.60	1.3 ± 0.06	N/A	1.1 ± 0.04	N/A	
		Crabs (*Scylla serrata*)	N/A	400 ± 28.8	67.84 ± 6.87	1480 ± 24.3	43 ± 15.3	N/A	29 ± 12	N/A	
		Chittagong port	N/A					N/A		N/A	
		Fish (*Tenualosa ilisha, Pampus argentius, Cynoglossus lingua*)	N/A	5.9 ± 6.7	0.51 ± 0.34	53 ± 27.3	0.51 ± 0.48	N/A	1.1 ± 1.2	N/A	
		Shrimp (*Penaeus indicus*)	N/A	22 ± 3.0	0.31 ± 0.17	107 ± 1.4	1.4 ± 0.4	N/A	1.0 ± 0.3	N/A	
		Crabs (*Scylla serrata*)	N/A	305 ± 4.7	78.54 ± 12.12	902 ± 14.3	34 ± 9.12	N/A	14 ± 3.0	N/A	
		Sundarbans	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
		Fish (*Tenualosa ilisha, Pampus argentius, Cynoglossus lingua*)	N/A	1.3 ± 1.07	0.07 ± 0.09	31 ± 9.2	0.1 ± 0.04	N/A	0.15 ± 0.05	N/A	
		Shrimp (*Penaeus indicus*)	N/A	63 ± 20.0	0.10 ± 0.09	53 ± 11.2	0.49 ± 0.10	N/A	0.34 ± 0.20	N/A	
		Crabs (*Scylla serrata*)	N/A	80 ± 12.5	0.49 ± 0.18	157 ± 13.9	1.4 ± 0.4	N/A	0.48 ± 0.18	N/A	
		Meghna estuary, Bhola	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
		Fish (*Tenualosa ilisha, Pampus argentius, Cynoglossus lingua*)	N/A	1.6 ± 0.44	0.25 ± 0.19	34 ± 8.8	0.28 ± 0.11	N/A	0.32 ± 0.16	N/A	
		Shrimp (*Penaeus indicus*)	N/A	52 ± 14.00	0.13 ± 0.05	114 ± 8.6	0.77 ± 0.11	N/A	0.17 ± 0.06	N/A	
		Crabs (*Scylla serrata*)	N/A	111 ± 1.73	0.24 ± 0.06	137 ± 6.0	0.81 ± 0.12	N/A	0.29 ± 0.10	N/A	

foods (Saha and Zaman, 2013; Patra et al. 2019), particularly concerning metal accumulation in fish (Traina et al. 2019; Erdorul and Ateş, 2006). Thus, it is critical to comprehend the source of the potential human health risk associated with the ingestion of popular fish species in Bangladesh.

The presence of metal concentrations in fish implies environmental contamination that threatens human health. Table 3 shows the concentrations of HMs in several fish species. From the Karnaphuli River in Chittagong (Jolly et al. 2019), HM hierarchy in *Otolithoides pama* was Fe > Zn > Mn > Cr, but the same species reported Fe > Cr > Cu > Pb > Ni from four fish markets in Chittagong (Jolly et al. 2019; Jothi et al. 2018). *Scylla serrata* was found to have a mean concentration of Cu, 58.12 mg/kg in the Chaktai Khal of the Karnaphuli River estuary (Sultana et al. 2015), which was greater than the Bangladesh food safety guideline and beyond the international food safety guideline values. *Meretrix lyrata* recorded 1819.96 mg/kg from the same research region in the same way. Copper is essential for optimal health, especially in the synthesis of hemoglobin and several essential enzymes; nevertheless, excessive Cu intake might affect liver and kidney function (Baki et al. 2018).

In comparison to the research of Ahmed et al. (2019b) from the Meghna River estuary, Sultana et al. (2015) revealed that the Cu contents in the Karnaphuli River estuary were higher. According to FSANZ (2008), the maximum permissible limit (MPL) of lead impurities in fish is 0.5 mg/kg. Mean Pb concentrations of 3.79 mg/kg in *S. serrata* were above the safety recommendations, although another species (i.e., *O. pama)* had lower values than the international guidelines. Islam et al. (2013) studied some selected fish species from the Karnaphuli River and reported decreasing trends for Pb concentration: *Gonialosa manmina* (7.707 mg/kg) > *Rita rita* (2.861 mg/kg) > *Apocrptes bato* (1.843 mg/kg) > *Pellonaditchela* (1.094 mg/kg) > *Otolithoides pama* (0.886 mg/kg), as shown in Table 3. The highest Pb concentration level (7.707 mg/kg) was found in *G. manmina*, while the lowest Pb concentration level (0.886 mg/kg) was found in *O. pama*. The average Pb concentration of several species was greater than the Turkish Food Codes (TFC 2002) and Ministry of Food and Livestock (MOFL 2014) permitted values. The mean concentration was similar to that reported by Ahmed et al. (2019b) in the Meghna River estuary, where the highest Pb concentration was 4.63 mg/kg for *L. calcarifer* (Table 3). The majority of the fish sampled from the Karnaphuli River had Pb levels of less than 12.70 mg/kg (Ahmed et al. 2019a).

Otolithoides pama, Harpadon nehereus, and *Coiliaramcarati* were collected from four fish markets in Chittagong and recorded Cr concentrations of 4.71 mg/kg, 3.75 mg/kg, and 12.61 mg/kg, respectively (Jothi et al. 2018). The whole species were higher than the guideline value of 1.0 mg/kg set by MOFL (2014) and the recommended value of 0.15 mg/kg set by FAO (1984). These fish species exceed the recommendations and can damage the liver and kidney (ATSDR, 2004). Results of Jothi et al. (2018) were higher than that of Sumon et al. (2013), where all the fish species sampled from the Karnaphuli River recorded Cr values < 1 mg/kg except in *Cerithidea cingulata* (4.27 mg/kg), as shown in Table 3. Chromium (Cr) has a dynamic role in lipid and glucose metabolism when present in the diet (Saha et al. 2016a, b; Velusamy et al. 2014). However, Cr overdose can lead to acute respiratory problems (Ahmed et al. 2016) and damage the liver, lungs, and kidneys (Alipour et al. 2015). The differences in bioaccumulation capacity, element extraction, concentration, and accumulation time from point and non-point sources could explain the variation in HM concentrations in fish species (Zhonget al. 2018). The number of HMs in a fish's body is also influenced by the habitat, metabolic capacity, and dietary patterns (Singh et al. 2007).

Heavy metals in plants

Long-term deposition of HMs in soils results in higher accumulation of metals in plants due to sediment-plant direct interactions. Only two studies have been conducted so far on the concentration of metals in 11 plant species (Hossain et al. 2020; Rakib et al. 2021f). Of the plant species, saltmarsh species had higher levels of metals than seaweed species (Table 4), and saltmarsh species collected from ship-breaking areas (Sitakundu coast) reflected a higher concentration of HMs. Pb and Fe concentrations were found to be higher than the sediment quality guideline. Similar results were reported by Shammi et al. (2021) for Fe, Mn, Zn, Co, Cu, Pb, etc. in plant leaves, observed in suburban industrial regions of Dhaka, Bangladesh. Therefore, there is a need to closely monitor the great danger posed by the bioaccumulation of these HMs in plants via contaminated sediments.

Heavy metals and health implications

Metals like Fe, Cu, Pb, Zn, Ni, Co, Cr, and Mn are all naturally occurring elements. Low concentrations of these metals have no discernible effect on the human body. Despite this, large quantities of these metals in the food chain pose a health risk to humans. Intake (drinking or eating) or inhalation (breathing) are the most common ways in which humans are exposed to these metals (National Research Council, 2001; Martin and Griswold 2009). These HMs are primarily accumulated in the bodies of plants and fish. Ingestion of HMs, including dietary items, has long-term consequences for human organs. Memory loss, drowsiness, stomach discomfort, elevated blood cholesterol levels, tube dysfunction, endometrial cancer, musculoskeletal issues, and other disorders affect people (Fig. 4).

Table 4 Accumulation of metals (mg/kg) in tissues of seaweed and saltmarsh macrophytes from coastal area, Bangladesh

Species name	Organ	Co	Cu	Fe	Zn	Rb	Sr	Mn	Pb	Cr	As	References
Porteresia sp.	Leaves	0.97 ± 0.32	13.1 ± 1.45	2380.2 ± 1089.61	9.18 ± 1.60	7.61 ± 4.31	7.33 ± 4.73	235.67 ± 119.71	12.17 ± 4.75	N/A	N/A	Hossain et al. 2020
	Shoots	0.85 ± 0.29	13.42 ± 2.19	588.27 ± 412.83	6.73 ± 1.07	2.92 ± 0.62	4.25 ± 1.25	742.73 ± 1292.16	12.3 ± 3.43	N/A	N/A	
	Roots	1.27 ± 0.54	13.22 ± 2.42	2245.78 ± 1205.75	8.9 ± 4.02	6.3 ± 2.97	7.78 ± 4.77	172.32 ± 24.71	15.15 ± 7.72	N/A	N/A	
Hypnea musciformis	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.59 ± 0.01	0.57 ± 0.08	0.60 ± 0.25	Rakib et al. 2021f
Hypnea pannosa	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.62 ± 0.02	0.33 ± 0.07	1.60 ± 0.43	
Jania rubens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.71 ± 0.01	1.94 ± 0.08	0.76 ± 0.06	
Gelidium pusillum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.50 ± 0.15	3.64 ± 0.06	1.68 ± 0.14	
Padina tetrastromatica	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.24 ± 0.10	0.45 ± 0.03	11.89 ± 0.35	
Sargassum oligocystum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.63 ± 0.11	1.90 ± 0.09	10.57 ± 0.10	
Padina boryana	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.40 ± 0.04	0.69 ± 0.13	1.70 ± 0.14	
Caulerpa racemosa	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.77 ± 0.06	0.57 ± 0.03	2.27 ± 0.14	
Enteromorpha intestinalis	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.76 ± 0.12	0.64 ± 0.05	0.84 ± 0.05	
Ulva compressa	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.95 ± 0.05	0.72 ± 0.04	1.72 ± 0.07	

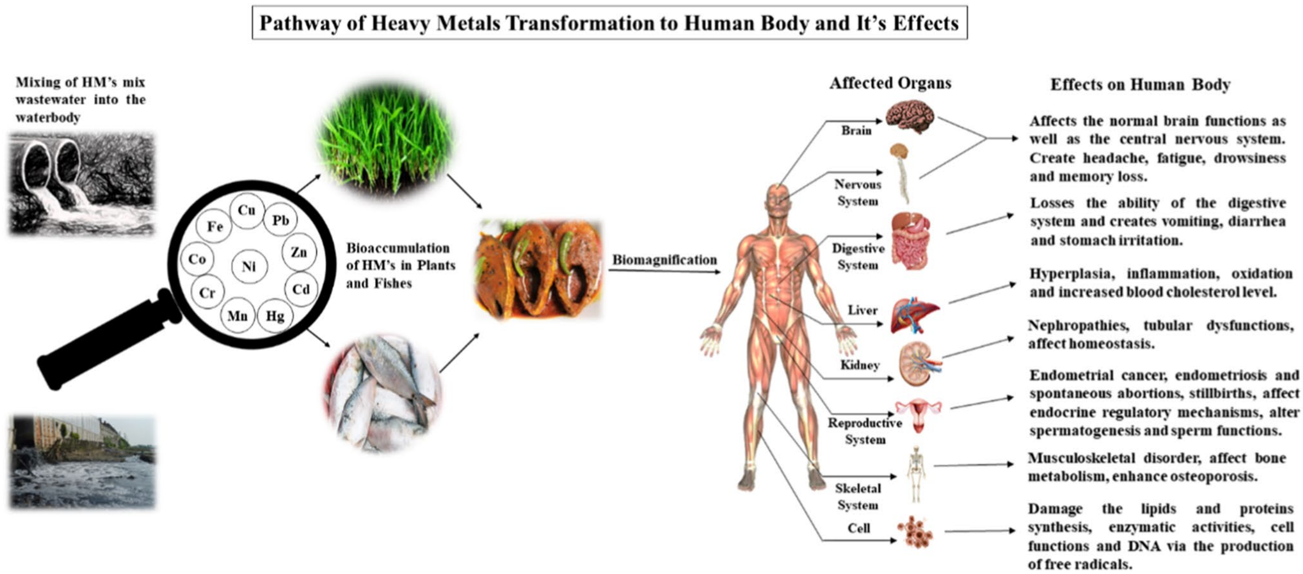

Fig. 4 Pathway of heavy metals' transformation to human body and its effect

Remediation of HM contaminations

This study shows that the absence of contamination is prevalent in the area, types, and degree of contamination in water, sediment, and fish. Indeed, HM contamination in Bangladesh's soil, water, sediment, and fisheries from the ongoing anthropogenic activities is a serious environmental issue worldwide (Bhuyan and Islam 2017). This raises a slew of difficulties for the global ecology and human health. Metal accumulation assessments in various fish species are required to understand the probability of metal transmission to the human body (Gu et al. 2015; Nor Hasyimah et al. 2011). Studying human health risk indices can guide responsible environmental stakeholders in making decisions and acting. These alone may not be enough to alienate the pollution of the ecosystem. Human health risks can be averted through remediation and control of possible pollution routes. Therefore, as HMs and human health risks keep on increasing in the Bangladesh coastal environments and their capacity of accumulating in the tissues or organs of living species over many years, specialists in the ongoing years have used plants and microorganisms for bioremediation in contaminated environmental sites (Lim et al. 2008; Rakib et al. 2021e; Ibañez et al. 2016). Plants have the natural capacity to decontaminate inorganic and organic pollutants; genetically modified species have been developed to carefully decontaminate polluted sites (Macek et al. 2008; Novakova et al. 2009).

Metabolomics has been applied in the ecotoxicology field to identify and describe the interactions of organisms with their environment (Viant, 2008; Samuelsson and Larsson, 2008). Hines et al. (2007) showed that direct field sampling is better for environmental metabolomics because it can minimize metabolic variability and observe stress-induced phenotypic changes that could be masked by stabilizing the organism in laboratory conditions. Omics technologies have been used to better understand the relationship between biomarkers, pollutants, and their adverse effects (Garcia-Reyero and Perkins 2011).

Nanoremediation seems to be a promising pollution control and management technique (El-Ramady et al. 2017). It allows for remediation in deeper soils and sediments, making it well-suited to other methods like bioremediation and serving as a growing decontamination tool (Huang et al. 2016). In polycyclic aromatic hydrocarbon (PAH) decontamination, nanoremediation has been investigated to improve restorative sites in real field conditions/settings (Kuppusamy et al. 2017). The method might be used to decontaminate HMs, and using green nanotechnology in Bangladesh's contaminated environment could completely identify contaminants and transform them into non-toxic forms. Green nanoremediation is the combination of phytoremediation with nanoparticles (Shalaby et al. 2016; Martínez-Fernández et al. 2017), microorganisms (Patil et al. 2016; Davis et al. 2017), or zoonoremediation (Belal and El-Ramady, 2016; Patil et al. 2016; Davis et al. 2017).

Challenges and perspectives

In Bangladesh, HM contamination is attracting serious attention in the field of environmental pollution. The contamination pathways of HMs in sediment, water, fish, and plants, on the other hand, are still poorly understood and will require greater focus in the future. Contamination methods must be thoroughly studied to detect the load of toxic substances that can enter our diet and become biomagnified. Physiological, genetic, and biotechnological techniques based on sediment, water, fish, and plant treatments can help organisms and genes tolerate HM consumption more effectively. Even though ambient surroundings contain a combination of pollutants, current techniques are mostly focused on a single pollutant. The long-term remediation of HM contamination in Bangladesh is a major concern. Integration of advanced remedial methodologies is still in its early stages of research. Yadav et al. (2017) found that certain proteins and natural chelators are overproduced in transgenic plant cells. This means that foreign genes can be inserted into plant genomes to help plants adapt to high HM concentrations and hyper-accumulators.

The careful combination of bioremediation and nanoremediation techniques is one of the most promising choices for removing chemical and biological contaminants, along with HMs, from wastewater or coastal waters. Future development and full-scale implementation of these remedial approaches HMs, confront numerous hurdles, necessitating further comprehensive research. Intensive field studies with process optimization and improvements in the suitability of materials/methods in specific environments must be carried out effectively to reduce HM contamination in the food chain and ensure sustainability and broad applicability for future generations and resources.

Conclusions and recommendations

The prevalence of HMs in Bangladesh's coastal areas and the associated risks posed to human and ecosystem health were critically reviewed in this review work. Based on the comprehensive review results, it is apparent that the coastal ecosystems of Bangladesh are becoming severely polluted due to high accumulation of metals in water, sediment, fish, and plants, along with associated public and ecological health threats. The Karnaphuli estuary is the most polluted habitat on the Bangladesh coast, and soils are extensively polluted with metals serving as the ultimate sinks. The analyses of some previous findings also demonstrated the high carcinogenic and non-carcinogenic risks that HM pollution poses to the public, especially children. Though surface water and soil parent materials and erosions contribute less than anthropogenic sources. Primary sources for HMs in soils were wastewater, hazardous solid wastes, and agricultural inputs. Various innovative remediation strategies have already been used to minimize HMs contamination in the Bangladeshi environment. However, there is currently a lack of sustainable and modern HM abatement solutions. The following recommendations should be implemented: a unified maximum tolerable limit (MTL); regular monitoring of HM-contaminated water, sediments, and soils; integrated policy implications for effective management of polluted sites; and synchronization of global abatement strategies for long-term HMs remediation toward environmental sustainability. The current issues in Bangladesh and the potential for increased HMs pollution in the coastal region call for a thorough review in the future, based on the sustainable strategy that has been suggested.

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R.K.: Writing-review and editing. A. S., M.B.H., A. R. M. T.I., M. S. I., M. M. R., Y. N. J., A. M. I., M.M.A., M.B., X.S: Writing-review and editing.

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Authors and Affiliations

Md.Refat Jahan Rakib[1] · Md. Asrafur Rahman[1] · Amarachi Paschaline Onyena[2] · Rakesh Kumar[3] · Aniruddha Sarker[4] · M. Belal Hossain[1,5] · Abu Reza Md. Towfiqul Islam[6] · Md. Saiful Islam[7] · Md. Mostafizur Rahman[8] · Yeasmin Nahar Jolly[9] · Abubakr M. Idris[10,11] · Mir Mohammad Ali[12] · Muhammad Bilal[13] · Xian Sun[14]

[1] Department of Fisheries and Marine Science, Faculty of Science, Noakhali Science and Technology University, Noakhali, Bangladesh

[2] Department of Marine Environment and Pollution Control, Nigeria Maritime University Okerenkoko, Warri, Delta State, Nigeria

[3] School of Ecology and Environment Studies, Nalanda University, Rajgir, 803116 Bihar, India

[4] School of Applied Biosciences, College of Agriculture and Life Sciences, Kyungpook National University, Daegu 41566, Republic of Korea

[5] School of Engineering and Built Environment, Griffith University, Brisbane, QLD, Australia

[6] Department of Disaster Management, Begum Rokeya University, Rangpur 5400, Bangladesh

[7] Department of Soil Science, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh

[8] Laboratory of Environmental Health and Ecotoxicology, Department of Environmental Sciences, Jahangirnagar University, Dhaka 1342, Bangladesh

[9] Atmospheric and Environmental Chemistry Laboratory, Chemistry Division Atomic Energy Centre, Dhaka 1000, Bangladesh

[10] Department of Chemistry, College of Science, King Khalid University, Abha 62529, Saudi Arabia

[11] Research Center for Advanced Materials Science (RCAMS), King Khalid University, Abha 62529, Saudi Arabia

[12] Department of Aquaculture, Bangla Agricultural University, Sher-e, Dhaka-1207, Bangladesh

[13] School of Life Science and Food Engineering, Huaiyin Institute of Technology, Huaian, China

[14] Zhuhai Key Laboratory of Marine Bioresources and Environment, Guangdong Provincial Key Laboratory of Marine Resources and Coastal Engineering, School of Marine Sciences, Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Sun Yat-Sen University, Guangzhou 510275, China