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Heavy Metal Exposure and Health Concerns in Bangladeshi Rivers: a Seasonal Comparison of the Buriganga, Shitalakhya, Meghna, Karnaphuli, and Padma Rivers' Water, Sediment, and Fish

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ABSTRACT

We determined the levels of nine heavy elements in water, sediment, and the edible tissues of three frequently eaten fish species collected from the five polluted rivers in different divisions of Bangladesh. These samples were randomly taken from five rivers and analyzed by Flame Atomic Absorption Spectroscopy. We found seasonal fluctuations in the hierarchy of mean concentration for different heavy metals in five rivers' fish, water, and sediments. In the water, the concentrations of Cd, Cr, Cu, Fe, Mn, Pb, Zn, Ni, and Hg ranged from 0.010-0.081, 0.016-5.531, 0.013-2.445, 0.860-22.924, 0.043-1.424, 0.015-0.933, 0.091-1.451, 0.012-2.888, and 0.010-0.032 mg/l where in the sediment the concentrations ranged from 0.1-1.47, 4.21-284.1, 0.12-28.46, 1860-14971.33, 122.1-480.8, 0.84-42.15, 2.14-210.35, 15.3-30.4, and 0.17-10.44 mg/kg. For fishes concentrations ranging from BDL-0.78, 0.04-86.45, 0.01-1.67, 4.19-102, 0.08-0.94, 0.01-0.99, 0.08-9.56, 0.01-4.56, and BDL-0.2 mg/kg were reported for the above metals order respectively. The highest concentration (mean) of Cr and Fe in waters and sediments was 1023 times and 13020.72 % higher than WHO's standard and Toxicity Reference Values (TRV), respectively. Besides, the bioaccumulation factors (BAF) of the selected elements for the studied fishes were found to be between 0.036-626.25, where the pollution load index (PLI) for the five rivers ranged from 0-0.95 and the concentration factor (CF) found between 0.02-4.03. Estimated daily Intake (EDI) as well as Target hazard quotients (THQs) analyses revealed potential risks for fish consumers, particularly the level of some metals exceeding the WHO/FAO's tolerable limit, which indicates that the rivers' water and fish are dangerous to humankind.

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INTRODUCTION

Heavy metal pollution is one of the most severe problems, which threaten water standard (Hossain *et al.* 2021; Islam *et al.* 2015). Such pollution happens in several circumstances, including expanding manufacturing workload, unhealthy agricultural practices, ongoing disposal of urban effluent, unnecessary transportation, etc. (Rajendran *et al.* 2022). Thus, water,

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soil, and food are contaminated rapidly and finally endanger the ecology, fish, and invertebrates (Nasrabadi *et al.* 2013). Bioaccumulation of contaminated materials and substances is hazardous for humans as well as different aquatic organisms (Rajendran *et al.* 2022; Khatun *et al.* 2021; Alhashemi *et al.* 2012a; Alhashemi *et al.* 2012b). The Sustainable Development Goals (SDG) and United Nations Agenda 2030 take a strong action on improving water quality globally by reducing anthropogenic activities (dumping, excavation, brick production, mining, material recycling, etc.) (Hossain *et al.* 2021; UN 2017).

Daily, a massive volume of hazardous effluent is deposited into lower land and water bodies in Bangladesh. Moreover, the Teesta and Brahmaputra rivers carry significant throw-outs in suspension from the neighboring people, which also influences heavy metal contamination. As a result, it puts the submerged aquatic life in grave peril (Braulik *et al.* 2021, Alhashemi *et al.* 2011).

The pollution of rivers has become a worth-mentioning crisis in emerging countries like Bangladesh. The waste products from hundreds of factories are dumped into adjacent rivers. Along with organic pollution, the dissolved oxygen of river water levels is reduced by the discharge of highly hazardous substances from battery industries, fabric industries, aluminum and steel mills, and tanneries. As a result, it hinders aquatic life, including the natural environment in tropical countries like Bangladesh (Hossain *et al.* 2021; Khatun *et al.* 2021; Yasasve *et al.* 2022; Alhashemi *et al.* 2012a).

The primary sewage from factories drains around Bangladesh's capital city, Dhaka, unraveled to Buriganga, Shitalakhya, and Meghna (Uddin *et al.* 2021). There are significant penalties for the careless disposal of business wastes, wasted liquors, including several chemicals used in manufacturing fabrics and leather (Uddin *et al.* 2023). Since 2017, the government has relocated all tanning factories to the Savar leather estate zone under a High Court ruling (Hossain *et al.* 2021). The Shitalakhya River receives considerable waste from textile and dyeing industries and is contaminated by lead and other waste from the battery industry. Besides, the Karnaphuli River in Chittagong is suffering from waste released by paper mills (Khatun *et al.* 2021). On the other hand, the Padma River in the Rajshahi division receives relatively less pollution threat than other rivers (Uddin *et al.* 2021). The rivers are used for different agricultural practices, household activities, transportation, natural and artificial fish culturing, etc. Again, many garment workers live on the banks of rivers, and those inhabitants rely entirely on polluted water for daily activities (Khatun *et al.* 2023).

Since 1960, heavy metals have been regarded as a crucial factor in analyzing ecological contamination (Lu *et al.* 2015). Due to their extreme levels of persistence, most trace metals are toxic to living beings (Hossain *et al.* 2021; Nasrabadi *et al.* 2013; Nasrabadi *et al.* 2015). Analysis of the amounts of heavy elements in the water and sediment is essential for establishing the general quality of the natural aquatic environment, including fauna, flora, invertebrates, vertebrates, etc. (Lu *et al.* 2015). Toxic metals exist in soil or water may penetrate into the food cycle via various pathways—a notable mode of transmission is the bioaccumulation of heavy metals in fishes. Inside the fish body, heavy metals are deposited in the cardiovascular system, liver, gills, and fish skeletons, which can alter fish's flavor (Hossain *et al.* 2021; Khatun *et al.* 2021; Alhashemi *et al.* 2012b). Consuming such fish poses risks to human health to a great extent (Karbassi *et al*. 2016). At greater pH levels, heavy metals separate and easily adsorbed on the outermost layer of sediment (Karbassi *et al.* 2016), furthermore the heavy metals are transmitted from the sediments to the above water when the dissolved oxygen level gets below seven (mg/l) (Li *et al.* 2013). The sediment is considered important for analysis as it is a significant dwelling place for many aquatic species (Duncan *et al.* 2018).

Climatic factors such as moisture, heat, rainfall, and others contribute to seasonal fluctuations in the heavy metals content (Hossain *et al.* 2021). Heavy rain typically lowers toxic metal concentration through leaching and runoff in tropical areas (Khatun *et al.* 2021). Seasonal variations in the accumulation of trace metals have also been recorded in the fresh water ecosystem of different rivers (Hossain *et al.* 2021; Khatun *et al.* 2021; Mohiuddin *et al.* 2012). For good research, it is also essential to consider the seasonal change for analyzing the presence of heavy metal. Polluted water may seriously threaten agricultural practices along the riverside (Nasrabadi *et al.* 2015, Nasrabadi *et al.* 2013). Until 2017, the waste of the tannery factories situated in the Hazaribagh area of Dhaka fell into the Buriganga River. Then, the government initiated action to relocate tanneries to a new tannery estate in Savar, which stands on the bank of the River Dhaleshwari attached to Buriganga. Tragically, the whole move has been postponed for more than two years. There is a centralized wastewater treatment facility in that region, and it is only partially in operational mode now (Hossain *et al.* 2021; Report, TBS. 2019). After the tannery relocation, only a few researchers have conducted studies on river water pollution by heavy metals and wastes from tanneries in freshwater ecosystems. It has become crucial to weigh the benefits of relocating tanneries and guarantee the excellent utilization of every resource to fulfill national requirements as per SDG, etc. The River Shitalakhya provides water to the Dhaka City Corporation and passes through the districts of Narayanganj and Gazipur. As it flows through these areas, a lot of untreated industrial waste is dumped from the nearby factories and industries, which are contaminating the river with heavy metals and garbage. The river's water is contaminated to a great extent that it is unsuitable for the survival of aquatic life (Rahman *et al.* 2020).

Several chemicals, including lead, sulfur compounds, petroleum, fuel, pigment, toxic elements, etc. are released to the rivers (Yahaya *et al.* 2009; Islam *et al.* 2012). Meghna River is also accompanied by pollution from multiple sources like batteries, dyeing, textile industries, and jute mills (Bhuyan *et al.* 2017). Wastewater from the Nasirabad and Kalurghat industrial areas discharges into surface drains and ultimately falls into the Karnaphuli River (Khatun *et al.* 2021). On the contrary, over 500 million people from Bangladesh, India, and Nepal live along the banks of the Padma River. At Bheramara point, various activities like agriculture, sand extraction, transportation, etc., occur throughout the year, which gradually triggers the degradation of water quality (Islam *et al.* 2014; Khalid *et al.* 2004).

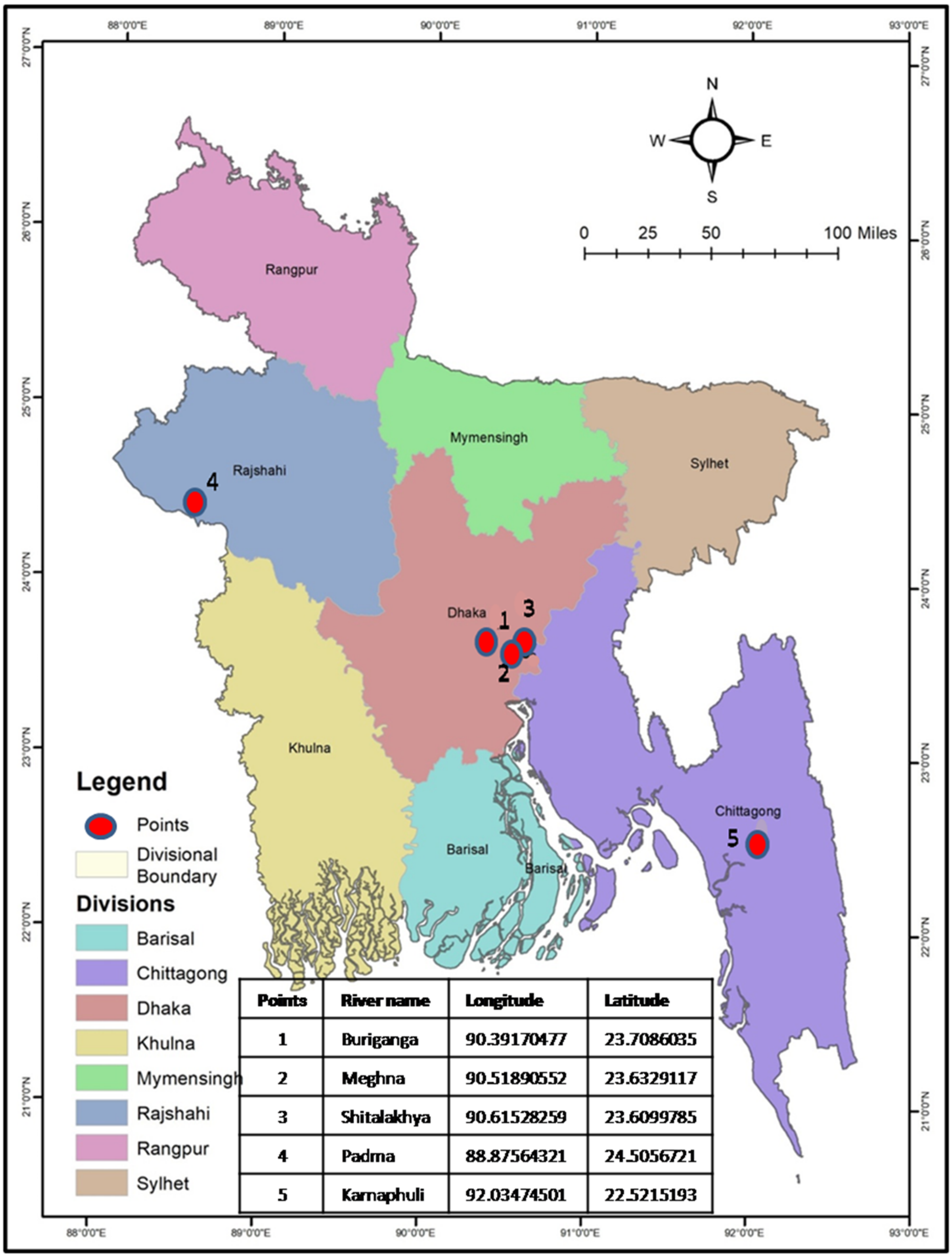
The study assessed the levels of heavy metals released into nearby rivers from the leather, dyeing, fabric, paper, and battery manufacturing industries in the areas of Dhaka, Rajshahi, and Chittagong divisions of Bangladesh. Additionally, this study also explored the seasonal variation of heavy elements in the aquatic ecosystem, including the selected rivers' fish, water, and sediment, to properly quantify pollution as well as associated health hazards.

MATERIALS AND METHOD

Description of the research area

Present research focuses on the five major rivers of Bangladesh, namely Buriganga, Meghna Shitalakhya, Padma, and Karnaphuli, located in Dhaka, Rajshahi, and Chittagong divisions, respectively. Dhaka Metropolitan (DMP; area = ~ 815 km^2) is in the country's geographic center and is listed 7th as the most densely populated city (Hossain *et al.* 2021). The Buriganga River is one of the most polluted in the whole globe. The southern edges of Dhaka town are traversed by this river, where the depth is 7.6 m with a maximum height of 18m (Kamal *et al.* 1999).

Shitalakhya River has a depth of 10 m. It mainly flows through the Narayanganj district and combines with the Meghna River at Munshiganj (Rahman *et al.* 2020). The Meghna, Padma, and Karnaphuli River are 408, 295, and 10 meters deep, respectively. They function as a river ghat for transit in the Narsingdi district, where boats are the primary transportation medium (Bhuyan *et al.* 2017). The Karnaphuli River is the main river of the Chittagong district, originating from the Lushai hills of India (Khatun *et al.* 2021).



Points	River name	Longitude	Latitude
1	Buriganga	90.39170477	23.7086035
2	Meghna	90.51890552	23.6329117
3	Shitalakhya	90.61528259	23.6099785
4	Padma	88.87564321	24.5056721
5	Karnaphuli	92.03474501	22.5215193

Fig. 1. Different sampling sites of the five most polluted selected rivers in Bangladesh

These rivers are employed as suitable disposal sites for industrial waste from nearby commercial belts, untreated wastewater from industries, rural residences, and wastewater from cities. Many enterprises, including tanneries, clothing, paper, pulps, distilleries, pesticides, carbide, and medicines, can operate in these rivers (Mohiuddin *et al.* 2012; Ahamad *et al.* 2020). Because of these artificial and ecological activities, the ecosystems along the river have deteriorated, causing heavy metals to accumulate in edible fish (Khatun *et al.* 2023; Lu *et al.* 2015).

Table 1. Basic biological parameters of three selected fish species (Baki *et al.* 2020).

Local name	Common name	Scientific name	Habit	Average TL (cm)	Average BW (g)
Shing	Stinging catfish	*Heteropneustes fossilis*	Omnivorous	17.68	14.72
Taki	Spotted Snake head	*Channa punctatus*	Carnivorous	13.7	9.9
Shol	Snakehead murrel	*Channa striata*	Carnivorous	60	60

Collection of samples

In 2022, the sample was collected from five rivers in three seasons: winter (January-February), summer (April-May), and rainy (July-August). For each river, all the samples were collected from one sampling location for a different season, making three samples per river for three seasons. To compare the seasonal change of metal content, 15 water and 15 sediment samples were taken separately from the sample area. The samples were then transferred to 100 mL polypropylene bottles. 1 mL of HNO_3 (99%) was kept to the polypropylene bottles to achieve a pH of 0.1 (Suresh *et al.* 2012). Sediment samples were collected by hand auger. Every sample was preserved at 4 °C till analysis. For this investigation, the three most popular fish species—*Heteropneustes fossilis*, *Channa striata*, and *Channa punctatus* were chosen (Table 1 provides sample specifications) and collected from 5 rivers in 3 different seasons, making total 45 fish samples. All samples were collected by nylon nets (local fishing nets) and sent to the lab quickly in sealed air plastic bags. After that, a previously cleaned stainless steel cutter was used to remove the inedible parts. The significant consumable portions, *i.e.*, muscular tissues, were then rinsed with deionized water. After that, a clean knife was used to cut the muscular tissues into smaller (3-6 cm) parts. Then, samples were preserved in a controlled environment at 4 °C till analysis.

Digestion of the sample and extraction of metals

The fish sample was digested using a microwave digestion machine, taking 2 ml of 30% Hydrogen peroxide (H_2O_2) and 5 ml of 70% HNO_3 (Nitric acid) as a digestion agent (Hossain *et al.* 2021). We followed a microwave digestion system for sediment samples reported by Mendil *et al.* (2010). At first, we digested 0.5 g sediment samples with 2 ml HNO_3 (70%) + 6 ml HCl (37%) in a microwave for 35 minutes at six steps (viz. 4 minutes at 250 W, 4 minutes at 100 W, 6 minutes at 250 W, 5 minutes at 400 W,8 minutes at 550 W, and lastly vent for 8 minutes). The filtered solution was then stored in polypropylene bottles (50 ml).

Working conditions, Standardization, and Quality Control

Constant monitoring for analysis, data input, technique verification, etc., was followed to ensure internal quality. Chemicals and reagents (Merck, commercially obtainable Fluka) were used during the analyses. Before each usage, the equipment was calibrated. The proficient analyst ensured external quality by managing the specimen, reagent, and apparatus with care. The typical heavy metal recoveries are between 93-97%, depending on the accuracy of the procedure. Four standards with various known contaminations were repeated two times for the calibration curve (Hossain *et al.* 2021). Working standards were created daily by serial dilution from the stock solution (1000 ppm, Fluka, Switzerland). Blanks, Duplicates, and Standard samples were run at certain intervals for proper Quality Control (QC). Blank solutions were randomly run in addition to the sample, and their contaminations were subsequently eliminated from the sample levels to estimate the actual metal content in each sample (Khatun *et al.* 2023).

Analysis techniques

The digested samples' Cd, Cr, Cu, Fe, Mn, Pb, Zn, Ni, and Hg content were determined using flame atomic absorption spectroscopy (Perkin Elmer PinAAcle 900H version). Cd, Cr, Cu, Fe, Mn, Pb, Zn, Ni, and Hg hollow cathode lamps were used in compliance with the manufacturer's instructions. Acetylene and 99.99% pure argon gas are used as the firing fuel for the burner.

Evaluation of heavy metals in sediment

Concentration factor (CF) and pollution load index (PLI) were estimated to ensure the accumulation of heavy metals in sediment. The average shale value of the outermost layer of the earth was utilized to calculate the contamination indices for this investigation (Turekian *et al.* 1961).

Pollution load index (PLI) and concentration factor (CF)

Sediment contamination is determined using the nine metals' combined pollution load index (PLI) technique (Suresh *et al.* 2012; Cenci *et al.* 2004). The pollution load index (PLI), which indicates how frequently contamination occurs in sediment and exceeds the baseline value, serves as a collective warning of the generalized hazard of heavy metals in a given specimen. The multiplication of the metals concentration factor (CF) by the n^{th} root yields the total PLI.

$$\mathrm{PLI} = \sqrt[n]{\left(CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n\right)} \tag{1}$$

The proportion of the concentration of each specific metal to its background values/natural abundance here serves as the metal concentration factor (background value = pre-industrial samples from the research region, Bangladesh).

$$\mathrm{CF}_{\mathrm{metals}} = \frac{C_{metal}}{C_{background}} \tag{2}$$

Taking the average shale value of the earth's crust as $C_{\mathrm{background}}$ and contamination of heavy metal for sediment as C_{metal} (Turekian *et al.* 1961), we've calculated the concentration factor (CF) of every heavy metal (ASV: Cd = 0.3, Cr =90, Cu = 45, Fe = 47200, Pb = 20, Zn = 95, Ni = 68, Hg = 0.4, Mn = 850). With this, the pollution load index (PLI) and Concentration Factor (CF) were calculated for five river sediments. Four classes with respect to CF values were discovered to track the release of one metal, and they are listed below- (Turekian *et al.* 1961; Loska *et al.* 1997).

· Low degree ($CF < 1$)
· Moderate degree($1 \le CF < 3$)
· Considerable degree ($3 \le CF < 6$)
· Very high degree($CF \ge 6$)

CF values are applied to assess the enrichment of metals to sediments over time. A PLI value is equal to zero signifies the ideal state. In contrast, value one (1) indicates the existence of just a baseline amount of impurities, and a value above one (1) forecasts an increasingly threatening condition (Tomlinson *et al.* 1980). The PLI evaluates the sample's overall toxicity status.

Risk evaluation for health

Estimated metal consumption per day

Adequate quantities of fish organisms were used to estimate the daily consumption of metallic vestiges. Estimated daily intake (EDI) of metal was determined based on (Islam *et al.* 2014).

$$\mathrm{EDI} = \mathrm{FIR} \times \mathrm{C} \tag{3}$$

Here, FIR = food intake rate (g/person/day), and C = metal contamination in fish (mg/kg, wet weight). Fish consumption rates for adult inhabitants in Bangladesh were estimated to be 0.07184 kg, 0.08716 kg, and 0.1274 kg on a fresh mass basis for low, medium, and high fish consumers. The current tentative permissible daily consumption did not match the EDI in a web-based database of the Joint FAO/WHO specialist panel on dietary supplements (WHO 2005; Heikens *et al.* 2006).

Evaluation of non-carcinogenic threat

It is assumed that the consumed amount is equal to the quantity of contaminants that have been absorbed. It was also said that cooking heat did not affect the contaminant (USEPA1989). According to target hazard quotients (THQs), the non-carcinogenic dangers to health associated with the local buyers (low, moderate, and large consumers of fish) of the affected fish species were assessed in these studies. For an integrated USEPA risk evaluation, computations were performed using conventional assumptions.

$$THQ = \frac{EFr \times ED \times FIR \times C}{RfD \times BW \times AT} \tag{4}$$

Where, Exposure Frequency, EFr = 365 days; Exposure Duration, ED = 70 years (equivalent to the average lifetime; Oral reference dose = RfD (Cr = 1.5, Zn = 0.3, Cd = 0.0005, Mn = 0.14, Hg = 0.0001, Fe = 0.7, Pb = 0.0035, Cu = 0.04, Ni = 0.02 (Islam *et al.* 2015); Average Bodyweight, BW = Adult, 60 kg; Averaging Time for non-carcinogens, AT = 365 × number of exposure years, assuming 70 years.

RESULTS AND DISCUSSION

Heavy metal content in surface water

Table 2 shows the contamination level of nine heavy metals (Cd, Cr, Cu, Fe, Mn, Pb, Zn, Ni, and Hg) in the water of five rivers over three seasons (winter, summer, and rainy), and Table 3 highlights the international standard as well as some reported value of other published work. It was seen that in the winter season, the sequence of heavy metals contamination in the Buriganga river water was found in order Cr > Ni > Fe > Zn > Mn > Cu > Cd > Pb > Hg; in summer season, it is almost same as winter except Cu and Cd was equal and Pb were nil in the last order; where in the rainy season, the order of first three elements same as winter season except Zn and Mn alter their position where Cu and Cd were zero.

For the Shitalakhya river, the sequence of heavy metals during winter season was found as order Fe > Ni > Cu > Zn > Pd > Mn > Cr > Hg > Cd; in summer season, the sequence remains the same except Pb and Mn and Cd were reported nil; however in the rainy season, the arrangement were found to be same as previous two season except Hg and Pb was found nil where value of Mn becomes greater than Ni.

For Karnaphuli River, the sequence of metal during winter was found to be as Cu > Fe > Zn > Ni > Mg > Cr > Pd > Cd > Hg (nil); in the summer season, the sequence remains the same, except contamination of Hg that was not nil; and in the rainy season, the hierarchy followed as same as winter.

For the Meghna River, during the winter season, the sequence of metal showed an order as Fe > Cu > Ni > Zn > Pd > Cd > Mn > Cr > Hg; in the summer season, the order remains nearly the same except Mn and Cr was found equal in the last portion; but in the rainy season there is a change in the order where Ni and Pd were found equal and Cu, and Hg was found nil.

For Padma River, the order of heavy metals was found to be Fe > Zn > Mn > Cu > Ni > Hg > Pd > Cr > Cd. In the summer season, Pb becomes higher than Cu, and the values of Ni and Hg become the same in order; in the rainy season, the contamination of Pb became higher than

Table 2. Heavy metal contamination (mg/l) obtained in the water of five investigated river

River	Season	Metal(mg/l) Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg
Buriganga	Winter	0.010± 0.006	5.531± 0.410	0.029± 0.070	1.814± 0.410	0.811± 0.589	0.011± 0.019	1.036± 0.569	2.074± 0.534	0.013± 0.000
	Summer	0.021± 0.008	5.123± 0.611	0.020± 0.065	1.434± 0.299	0.764± 0.800	BDL	0.954± 0.156	2.888± 0.612	0.010± 0.000
	Rainy	BDL	4.710± 0.210	BDL	0.860± 0.398	0.725± 0.000	0.025± 0.007	0.564± 0.000	1.885± 0.459	0.014± 0.000
	Mean±SD	0.015± 0.007	5.121± 0.410	0.025± 0.071	1.359± 0.471	0.757± 0.459	0.015± 0.007	0.844± 0.258	2.284± 0.532	0.014± 0.000
Shitalakhya	Winter	0.010± 0.000	0.090± 0.049	0.820± 0.000	3.013± 0.745	0.164± 0.089	0.235± 0.009	0.711± 0.000	1.086± 0.089	0.023± 0.000
	Summer	BDL	0.072± 0.061	0.540± 0.091	2.490± 0.909	0.222± 0.833	0.223± 0.009	0.643± 0.187	1.770± 0.529	[a]BDL
	Rainy	0.015± 0.000	0.024± 0.000	0.741± 0.061	4.417± 0.890	1.424± 0.090	BDL	0.881± 0.071	0.980± .0.324	BDL
	Mean±SD	0.013± 0.000	0.061± 0.031	0.690± 0.133	3.300± 0.990	0.600± 0.713	0.222± 0.007	0.741± 0.127	1.270± 0.433	0.021± 0.000
Karnaphuli	Winter	0.033± 0.001	0.544± 0.071	2.015± 0.000	1.575± 0.393	0.713± 0.099	0.535± 0.090	1.214± 0.100	0.784± 0.054	BDL
	Summer	0.031± 0.000	0.460± 0.060	2.445± 0.034	2.031± 0.458	0.756± 0.049	0.424± 0.128	1.223± 0.066	0.881± 0.0398	0.014± 0.000
	Rainy	0.024± 0.009	0.391± 0.081	2.179± 0.021	2.110± 0.000	0.545± 0.078	0.093± 0.180	1.451± 0.081	0.914± 0.0765	BDL
	Mean±SD	0.024± 0.050	0.461± 0.071	2.210± 0.222	1.891± 0.280	0.674± 0.100	0.344± 0.221	1.290± 0.134	0.854± 0.068	0.012± 0.000
Meghna	Winter	0.081± 0.005	0.040± 0.000	1.144± 0.000	22.924 ±2.467	0.055± 0.000	0.271± 0.088	0.433± 0.089	0.667± 0.399	0.023± 0.000
	Summer	0.050± 0.003	0.040± 0.000	1.460± 0.650	20.127 ±2.009	0.043± 0.000	0.213± 0.058	0.352± 0.289	0.554± 0.244	BDL
	Rainy	0.073± 0.008	0.040± 0.000	BDL	18.490 ±2.123	0.112± 0.090	0.192± 0.039	0.091± 0.000	0.190± 0.034	BDL
	Mean±SD	0.061± 0.015	0.040± 0.000	1.333± 0.222	20.517 ±2.229	0.063± 0.033	0.224± 0.046	0.294± 0.177	0.473± 0.244	0.024± 0.000
Padma	Winter	BDL	0.015± 0.005	0.052± 0.000	2.700± 0.299	0.352± 0.944	0.023± 0.198	0.754± 0.0888	0.041± 0.001	0.032± 0.007
	Summer	BDL	0.021± 0.001	0.041± 0.06	2.459± 0.513	0.337± 0.691	0.051± 0.690	0.551± 0.076	0.013± 0.018	0.011± 0.009
	Rainy	0.011± 0.000	0.025± 0.009	0.013±0.000	1.887± 0.390	0.225± 0.048	0.933± 0.398	0.611± 0.099	0.012± 0.009	BDL
	Mean±SD	0.011± 0.000	0.016± 0.005	0.034±0.021	2.340± 0.422	0.303± 0.071	0.322± 0.492	0.635± 0.102	0.022± 0.017	0.021± 0.014

[a]BDL – Below Detection Limit

in the summer, and the values of Hg went down where Ni, Cd, and Cu were found to be same in the last order.

From Table 2, for Buriganga, the highest Cr level was found in the winter, which was 5.531 mg/l; the amount gradually fell in the summer and rainy seasons, which was 5.123 mg/l and 4.710 mg/l, respectively. The lowest contamination of heavy metal was found for Hg (0.010 mg/l). The Mean Cr (5.121 mg/l) contamination is almost 1023 times, and the mean Hg (0.014 mg/l) contamination is nine-fold greater than the WHO's acceptable limit for edible water (Cr = 0.005 mg/l, Hg = 0.001 mg/l). Again, Ni was found in a prominent amount after Cr. But, there was no Cd and Cu in the rainy season. Islam *et al.* (2014) also reported 0.078 mg/l Cr at Korotoa River, Bangladesh. Cr abundance is quite reasonable because the riverside tanneries of the Buriganga River dispose of wastewater in the river incessantly. The wastewater contains chromium derivatives, which are used for leather tanning, and from the CETP (Central Effluent

Table 3. Comparison of metals content in water with several international standards and global research

River, location	Metal(mg/l)									Reference
	Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg	
Buriganga (Bangladesh)	0.015	5.121	0.025	1.359	0.757	0.015	0.844	2.284	0.014	Present study
Shitalakhya(Bangladesh)	0.013	0.061	0.690	3.300	0.600	0.222	0.741	1.270	0.021	Present study
Karnaphuli (Bangladesh)	0.024	0.461	2.210	1.891	0.674	0.344	1.290	0.854	0.012	Present study
Meghna (Bangladesh)	0.061	0.040	1.333	20.517	0.063	0.224	0.294	0.473	0.024	Present study
Padma (Bangladesh)	0.011	0.016	0.034	2.340	0.303	0.322	0.635	0.022	0.021	Present study
Korotoa (Bangladesh)	0.0095	0.078	0.067	-	-	0.031	-	0.0355	-	Islam *et al.* 2015
River Ganges (India)	0.009	0.012	0.017	-	-	0.043	0.072	-	-	Gupta *et al.* 2009
Okumeshi River (Nigeria)	0.03	0.09	-	-	0.13	0.01	-	0.27	-	Ekeanyanwu *et al.* 2010
DWSB[a]	0.005	0.05	1.0	0.3-1.00	0.1	0.05	5	0.1	0.001	BDWS 1997
TRV[b]	0.002	0.011	0.009	-	-	0.003	0.081	0.052	-	USEPA 1989
WHO (2004)	0.003	0.005	2.0	0.3	-	0.01	-	0.07	-	WHO 2005

[a]DWSB- Drinking water standard for Bangladeshi people (BDWS 1997)
[b]TRV- Toxicity Reference Value for edible water (USEPA 1989)

Treatment Plant), a hexavalent chromium (Cr^{+6}) complex emerges in this river water (Hossain *et al.* 2021).

Whereas, for Shitalakhya, the foremost heavy metal contamination found for Fe in the rainy season was 4.417 mg/l; the value of this metal went down in the winter and summer seasons, which was 3.013 mg/l and 2.490 mg/l, respectively. The minimum heavy metal level found for Cd in the winter and rainy seasons was 0.01 mg/l. Here, the mean Fe contamination of 3.30 mg/l was almost ten times, and Cd's mean contamination of 0.013 mg/l was 2.33 times higher than the WHO's standard (Fe = 0.300 mg/l, Cd = 0.003 mg/l) (WHO 2005). The presence of a large amount of Fe in this river is mainly due to the bleaching wastage of textile and dyeing industries (Uddin *et al.* 2021).

The largest contamination for Cu was found in Karnaphuli River water (2.445 mg/l) in the summer; in the winter and rainy seasons, the contamination was found at 2.015 mg/l and 2.179 mg/l, respectively. The most insignificant level of heavy metal was found to be Hg, which was 0.014 mg/l in the summer season. The mean Cu level of 2.210 mg/l was almost 0.120 times, and the mean Hg level of 0.010 mg/l was nine times higher than the WHO's standard (Cu = 2.000 mg/l, Hg = 0.001 mg/l) (WHO 2005).

In the case of the Meghna River, the highest heavy metal was found for Fe (22.924 mg/l) in the winter season. The level of this metal decreased in the summer and rainy seasons to 20.127 mg/l and 18.490 mg/l, successively. The minimum contamination was found for Hg in the winter season, which was 0.023 mg/l. The mean Fe (20.517 mg/l) contamination was 67.33 times, and the mean Hg (0.020 mg/l) contamination was 19 times higher than the WHO's standard (Fe = 0.300 mg/l, Hg = 0.001 mg/l) (WHO 2005). The excess presence of Fe metal is predominantly for battery industry wastage (Hossain *et al.* 2021; Khatun *et al.* 2021; Uddin *et al.* 2023). Like Shitalakhya and Meghna, the most prominent heavy metal contamination in Padma River was measured for Fe in the winter season, which was 2.700 mg/l. The contamination of this metal was systematically reduced in the summer and rainy seasons to 2.459 mg/l and 1.887 mg/l. The slightest heavy metal level alluded to Cd in the rainy season, which was 0.011mg/l. The mean Fe level of 2.340 mg/l was 6.8 times, and the mean Cd level of 0.011mg/l was 2.33 fold higher than the WHO's standard (0.300 mg/l) (WHO 2005). The enrichment of this metal in

Table 4. Heavy metal contamination (mg/kg) of sediment for five studied rivers

River	Season	Metal (mg/kg)								
		Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg
Buriganga	Winter	0.49	277.6	21.43	14971.33	299.89	40.54	210.35	27.4	0.54
	Summer	0.41	284.1	28.46	14020.33	275.8	42.15	201.3	23.4	0.45
	Rainy	0.52	245.3	22.4	13980	246.65	34.41	185.1	24.1	0.4
	Mean ± SD	0.47 ± 0.05	269 ± 20.78	24.09 ± 3.80	14323.89 ± 561.06	274.11 ± 26.66	39.03 ± 4.08	198.91 ± 12.79	24.96 ± 2.13	0.46 ± 0.07
Shitalakhya	Winter	1.47	16.5	0.45	4820.36	125.4	8.45	20.38	28.7	0.37
	Summer	1.21	18.2	0.61	4515	122.1	8.98	17.54	20.4	0.31
	Rainy	1.41	22.4	0.12	4560.36	130.4	6.25	18.4	15.3	0.27
	Mean ± SD	1.36 ± 0.13	19.03 ± 3.03	0.39 ± 0.24	4631.9 ± 164.77	125.96 ± 4.17	7.89 ± 1.44	18.77 ± 1.45	21.46 ± 6.76	0.31 ± 0.05
Karnaphuli	Winter	0.21	57.4	20.42	2160.43	480.8	25.11	68.82	20.8	0.21
	Summer	0.1	68.4	16.42	2005.27	460.1	22.45	66.84	19.4	0.17
	Rainy	0.22	55.4	22.4	1860	415.2	26.41	55.71	18.1	0.21
	Mean ± SD	0.17 ± 0.066	60.4 ± 7.0	19.74 ± 3.04	2008.56 ± 150.24	452.03 ± 33.53	24.65 ± 2.01	63.79 ± 7.06	19.43 ± 1.35	0.19 ± 0.02
Meghna	Winter	0.87	102	9.81	10083.04	172.42	17.51	35.42	30.4	0.74
	Summer	0.57	77.4	4.25	10482.21	185.4	15.42	30.45	30.4	0.81
	Rainy	0.88	75.1	4.49	9847.33	210.51	16.4	27.89	25.3	0.62
	Mean ± SD	0.77 ± 0.17	84.83 ± 14.91	6.18 ± 3.14	10137.53 ± 320.92	189.44 ± 19.36	16.44 ± 1.04	31.25 ± 3.82	28.7 ± 2.94	0.72 ± 0.09
Padma	Winter	0.41	6.82	0.7	6050.04	178.1	1.04	2.83	18.2	10.44
	Summer	0.62	4.21	0.5	6120.28	158.4	0.84	2.72	16.4	10.2
	Rainy	0.22	4.51	0.6	5780.17	184.3	1.51	2.14	15.3	10.01
	Mean ± SD	0.41 ± 0.20	5.18 ± 1.42	0.6 ± 0.1	5983.49 ± 179.55	173.6 ± 13.52	1.13 ± 0.34	2.56 ± 0.37	16.63 ± 1.46	10.21 ± 0.21

the following river is mainly for releasing industrial effluents. Seasonal value change in the contamination of heavy metal levels can occur due to temperature, sedimentation, ebb, flow, forming re-suspension, etc. (Hossain *et al.* 2021; Khatun *et al.* 2021; Islam *et al.* 2015).

Table 3 also suggests that some heavy metal values crossed DWSB lines and exceeded the TRV safety lines (USEPA 1989; BDWS 1997). Most heavy metals are found to be the highest in the winter compared to the other two seasons. Bangladesh is a farming-based country. In the winter, various types of paddy fields like Aman, Boro, Wheat, Mustard, and other vegetables take under irrigation, which might increase the heavy metal level washing away from the farmlands. Besides these, brickfields and industries can also play some role in increasing heavy metal content (Islam *et al.* 2015; Ekeanyanwu *et al.* 2010).

Heavy metal content in sediment

Table 4 represents the contamination of heavy metals obtained from the sediment of the five studied Rivers, and Table 5 highlights the international guidelines and some other published literature regarding sediment.

For the Buriganga River, during winter, the series of heavy metals in sediment was found to be in order as Fe > Mn > Cr > Zn > Pb > Ni > Cu > Hg > Cd; in the summer season, the order of the metal series remained quite similar except the changes of position between Cu and Ni; in the rainy season, the series remains the same as previous two seasons except contamination of Hg went down to least. The order of heavy metals for Shitalakhya River in the winter season was determined as Fe > Mn > Ni > Zn > Cr > Pb > Cd > Cu > Hg; in the summer season, the order was found same as the winter season except Cr becomes greater than Zn; however, in the rainy season, the contamination of Cr and Hg becomes greater than Zn and Cu in the order. In the case of the Karnaphuli River, the series of metals were recorded in the order Fe > Mn > Zn > Cr > Pb > Ni > Cu > Hg = Cd in the winter season. However, the contamination of Cr and

Table 5. Comparison of metals in sediment (mg/kg) with different international guidelines and other studies

River, location	Metal (mg/kg)									Reference
	Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg	
Buriganga (Bangladesh)	0.47	269	24.09	14323.89	274.11	39.03	198.91	24.96	0.46	Present study
Shitalakhya (Bangladesh)	1.36	19.03	0.39	4631.9	125.96	7.89	18.77	21.46	0.31	Present study
Karnaphuli (Bangladesh)	0.17	60.4	19.74	2008.56	452.03	24.65	63.79	19.43	0.19	Present study
Meghna (Bangladesh)	0.77	84.83	6.18	10137.53	189.44	16.44	31.25	28.7	0.72	Present study
Padma (Bangladesh)	0.41	5.18	0.6	5983.49	173.6	1.13	2.56	16.63	10.21	Present study
Korotoa (Bangladesh)	1.2	109	76	-	-	58	-	95	-	Islam *et al.* 2015
Bangshiriver (Bangladesh)	0.61	98	31	-	-	60	117.15	28	-	Rahman *et al.* 2014
Jamuna River (Bangladesh)	-	110	28	4.20%	-	19	83	33	-	Facetti *et al.* 1998
Okumeshi River (Nigeria)	1.32	0.87	-	-	-	0.45	-	1.21	-	Ekeanyanwu *et al.* 2010
Haraz River (Iran)			33			24	37	34		Nasrabadi *et al.* 2018
ASV	0.3	90	45	47200	850	20	95	68	0.4	Turekian *et al.* 1961
TRV	0.6	26	-	110	-	31	16	16	-	USEPA2001
LEL	0.6	26	16	2%	460	31	120	16	-	Persaud *et al.* 1993
SEL	10	110	110	4%	1100	250	820	75	-	Ahamad *et al.* 2020

TRV= Toxicity Reference Value, ASL = Average Shale Value, LEL= Low Effect Level, - NA= Not available, SEL= Severe Effect Level.

Hg was found to be greater than Cd and Zn in the series reported in the summer season, but the value of Cd and Cu became greater than Hg and Ni in the arrangement series for the rainy season. For the Meghna River, in the winter season, the series was recorded as Fe > Mn > Cr > Zn > Ni > Pb > Cu > Cd > Hg, whereas in the summer, the order remains the same except the value of Hg becomes more than Cd; surprisingly in the rainy season, the metal contamination order follows the same sequence as winter. In the Padma River, the sequence of metal in the winter season was found in order Fe > Mn > Ni > Hg > Cr > Zn > Pb > Cu > Cd; however, in the rainy season, the order remains the same, and only the contamination of Cd increases more than Cu in the summer season.

Based on the above result, we can explain that the highest Fe content was obtained for sediment samples for the five selected rivers. In the case of the Buriganga River (Table 4), the most significant content of heavy metals found in sediment for Fe in the winter season was 14971.33 mg/kg. The value of this metal ranged from 14971.33 to 13980 mg/kg in three seasons. In the rainy season, the lowest heavy metal contamination of Hg was 0.4 mg/kg. The mean level of Fe 14323.89 mg/kg was almost 13020.72 % higher than the TRV or Toxicity Reference Value (Fe = 110 mg/kg) (USEPA 2001). In the summer, a greater amount of Cr (284.1 mg/kg) was also found in the same river. Though the average Cr's value was much greater than the average Fe in Buriganga's water, Fe found the transcendental place of contamination in the case of sediment. It might be that the higher atomic mass of Fe (55.847 g/mol) than Cr (51.996g/mol) made the metal well precipitate (Zolitschka *et al.* 2015). Like Buriganga, the highest heavy metal level for Shitalakhya was carved for Fe in the winter season, which was 4820.36 mg/kg. This metal scaled from 4820.36-4560.36 mg/kg in three different seasons. The lowest level was illustrated for Cu (0.12 mg/kg) in the rainy season. The mean Fe (4631.9 mg/kg) contamination was nearly 4209.82 % greater than TRV (Fe = 110 mg/kg) (USEPA 2001).

In the Karnaphuli, the excess amount of heavy metal is portrayed for Fe (2160.43 mg/kg) in the winter season. It comes with a limit of 1860 mg/kg in the rainy season. The most stooping level for Cd found in summer was 0.1 mg/kg. The mean level of Fe (2008.56 mg/kg) was around

Table 6. Concentration factor (CF) and Pollution Load Index (PLI) of heavy metals in sediment of five studied Rivers

River	Season	Metal (CF)									PLI
		Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg	
Buriganga	Winter	1.63	3.08	0.48	0.32	0.35	2.03	2.21	0.40	1.35	0.95
	Summer	1.37	3.16	0.63	0.30	0.32	2.11	2.12	0.34	1.13	0.92
	Rainy	1.73	2.73	0.50	0.30	0.29	1.72	1.95	0.35	1.00	0.85
Shitalakhya	Winter	4.90	0.18	0.01	0.10	0.15	0.42	0.21	0.42	0.93	0.26
	Summer	4.03	0.20	0.01	0.10	0.14	0.45	0.18	0.30	0.78	0.24
	Rainy	4.70	0.25	0.003	0.10	0.15	0.31	0.19	0.23	0.68	0.20
Karnaphuli	Winter	0.70	0.64	0.45	0.05	0.57	1.26	0.72	0.31	0.53	0.45
	Summer	0.33	0.76	0.36	0.04	0.54	1.12	0.70	0.29	0.43	0.39
	Rainy	0.73	0.62	0.50	0.04	0.49	1.32	0.59	0.27	0.53	0.43
Meghna	Winter	2.90	1.13	0.22	0.21	0.20	0.88	0.37	0.45	1.85	0.59
	Summer	1.90	0.86	0.09	0.22	0.22	0.77	0.32	0.45	2.03	0.49
	Rainy	2.93	0.83	0.10	0.21	0.25	0.82	0.29	0.37	1.55	0.49
Padma	Winter	1.37	0.08	0.02	0.13	0.21	0.05	0.03	0.27	26.10	0.20
	Summer	2.07	0.05	0.01	0.13	0.19	0.04	0.03	0.24	25.50	0.18
	Rainy	0.73	0.05	0.01	0.12	0.22	0.08	0.02	0.23	25.03	0.17

1824.96 % higher than TRV (Fe = 110 mg/kg) (USEPA 2001). At the same time, Meghna River witnessed 10482.21 mg/kg of Fe in the summer season. The metal contamination during the rainy season was 9847.33 mg/kg. A minor level of Cd (0.57 mg/kg) was found in the summer season. The mean level of Fe 10137.53 mg/kg which was around 9215% stronger than TRV (Fe = 110 mg/kg) (USEPA 2001).

Like the above four rivers, pinnacle contamination was also detected for Fe in the summer season, measured as 6120.28 mg/kg reported for Padma River. This metal contamination went down to 5780.17 mg/kg in the rainy season. The lowest level found for Cd in the rainy season was 0.22 mg/kg.

From Table 5 it is conspicuous that the mean Fe contaminations 14323.89 mg/kg and 5983.49 mg/kg for Buriganga and Padma were just about 13021.72% and 5438.54% superior, respectively, to TRV (Fe = 110 mg/kg) (USEPA 2001). Almost all the cases showed that the Fe level took the peak position in sediment. Some previous reports also showed higher Fe concentrations in the sediment of the Buriganga River. Our findings are well supported by Bhuiyan *et al*. (2015) and Mohiuddin *et al.* (2016). Bhuiyan *et al*. (2015) reported Fe concentration ranged from 9480–15435 mg/kg in sediment for Buriganga; though they declared comparatively low Fe concentration (90-2200 µg/l) for water. Again, Mohiuddin *et al.* (2016) also reported higher Fe concentrations ranging from 11943–14129 mg/kg for the sediment of the Buriganga River. Uddin M.J and Jeong Y.K. (2021) ascribed heavy metals settled down with organic materials; thus, the concentration rapidly increases in sediment. The mean values of Cd, Ni, and Hg achieved prominent status for river Meghna, which was 0.77 mg/kg, 28.7 mg/kg, and 0.72 mg/kg in sediment, respectively. The reason behind this might be the possible situation of Battery industries near the river (Hossain *et al.* 2021).

Concentration Factor (CF) and Pollution Load Index (PLI)

Figure 2 and Figure 3 illustrate the PLI and CF graph, which denotes the level of pollution and extent of risk for every metal. The analyses of the sediment of river Buriganga, Cu, Fe, Mn,

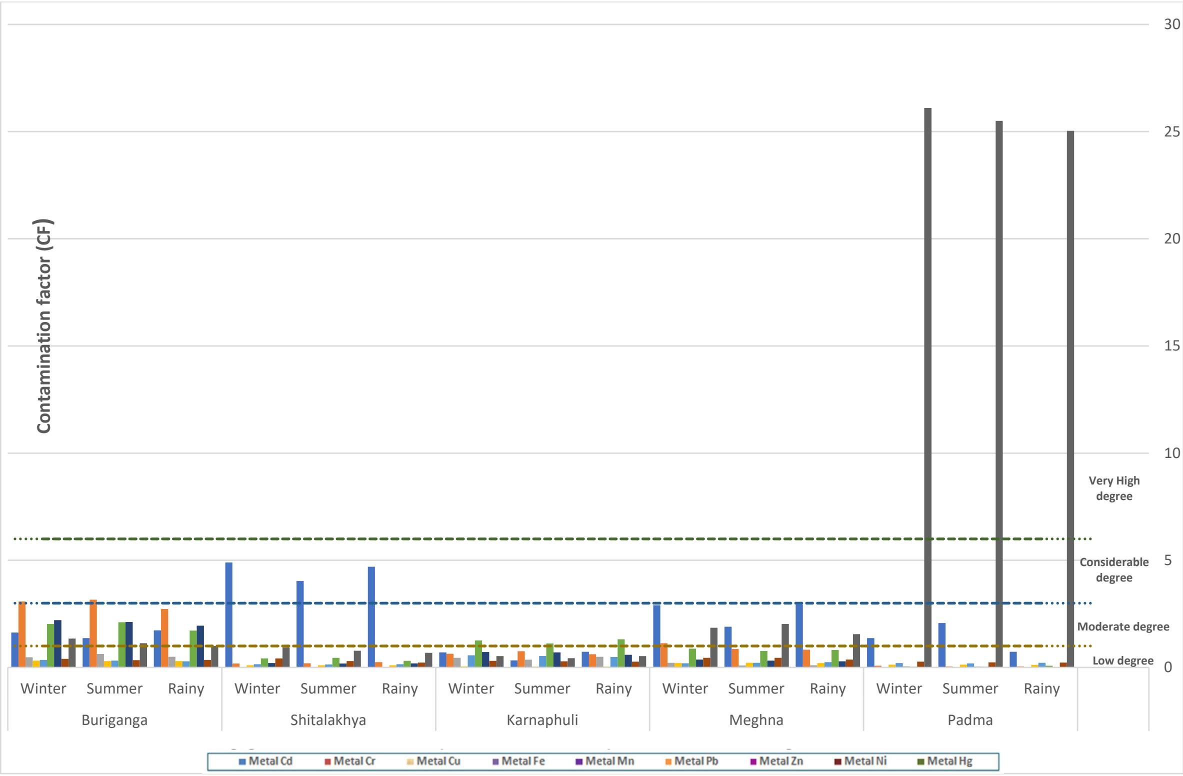


Fig. 2. Sediment's concentration Factor (CF) of heavy metals

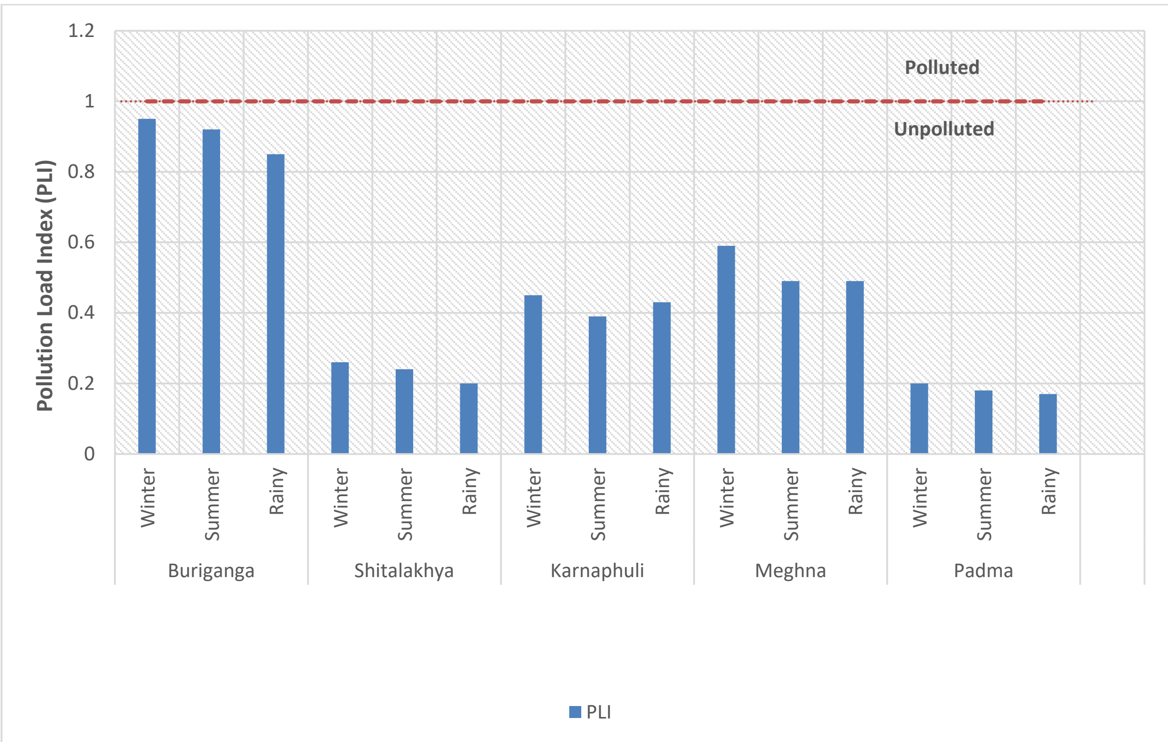


Fig. 3. Sediment's pollution load index (PLI) for heavy metals

and Ni showed a low contamination level (CF < 1), and Cd, Pb, Zn, and Hg showed a moderate contamination level (1 ≤ CF < 3) for all the seasons; Cr showed the average contamination level (1 ≤ CF < 3) in the rainy season and considerable contamination level (3 ≤ CF < 6) in two other seasons. The order of CF for winter and summer seasons followed as Cr > Zn > Pb > Cd > Hg > Cu > Ni > Mn > Fe, and for the rainy season it was Cr > Zn > Cd > Pb > Hg > Cu > Ni > Fe > Mn. The highest PLI was found in the winter season, which was 0.95.

For river Shitalakhya, studied heavy metals indicated a low contamination level (CF < 1) for all the seasons. Cd indicated a considerable level of contamination (3 ≤ CF < 6) for the three seasons. The order of CF for the winter season formed as Cd > Hg > Pb > Ni > Zn > Cr > Mn > Fe > Cu; for the summer season, the order remains the same except Zn and Cr alter their position where in the rainy season only the value of Cr increased than Ni and Zn along the order. The top value of PLI was noticed in the winter season, which was 0.26.

For the river Karnaphuli, selected heavy metals reported a low concentration level (CF < 1), except Pb, which showed a moderate contamination level (1 ≤ CF < 3) for each of the seasons. In the winter season, the order was found as Pb > Zn > Cd > Cr > Mn > Hg > Cu > Ni > Fe; however, in the summer season, the order was found to be Pb > Cr > Zn > Mn > Hg > Cu > Cd > Ni> Fe and in the rainy season the order was Pb > Cd > Cr > Zn > Hg > Cu > Mn > Ni > Fe. The crest value of PLI was observed in the winter season, which was 0.45.

For the river Meghna, Cu, Fe, Mn, Pb, Zn, and Ni responded with a low concentration factor (CF < 1) for all the seasons; Cd was found with a moderate contamination level (1 ≤ CF < 3) for each season; the value of CF for Cr fall within the medium contamination level (1 ≤ CF < 3) in the winter season and low contamination level (CF < 1) in summer and rainy seasons; Hg also exhibited with the moderate contamination level (1 ≤ CF < 3) in every season. In the winter season, the order of CF followed as Cd > Hg > Cr > Pb > Ni > Zn > Cu > Fe > Mn; however, in the summer season, the order of CF remains the same as in winter except Hg and Cd altering their position where in rainy season Mn and Cu alter their position along the order. The uppermost value of PLI (0.59) was remarked in the winter season for this river.

The CF value of Cr, Cu, Fe, Mn, Pb, Zn, and Ni in the Padma River signified the low contamination level (CF < 1) for each season; Cd indicates the moderate contamination level (1 ≤ CF < 3) in winter and summer seasons and low contamination level (CF < 1) in the rainy season. However, Hg demonstrated a very high degree of contamination level (CF ≥ 6) for every season. In the winter and summer seasons, the same order of CF was found as Hg > Cd > Ni > Mn > Fe > Cr > Pb > Zn > Cu, whereas in the rainy season, only a change of position occurs between Pb and Cr along the order. The highest value of PLI was observed in the winter season, which was 0.20.

Figure 2 shows that the Cr level of Buriganga and the Cd level of Shitalakhya have reached a considerable contamination level (3 ≤ CF < 6). Occupational breathing problems, perforated eardrums, respiratory irritation, harm to the kidneys, injury to the liver, congestion and edema, upper abdominal pain, nostril annoyance and damage, breathing cancer, skin irritation, and tooth erosion and color change are all side effects occur due to Cr (VI) contact (Khatun *et al.* 2021; Ahamad *et al.* 2020; Rao and Padmaja 2000).

From Figure 3, the PLI values for all the rivers are below one during all seasons. Buriganga has the highest PLI values among the five rivers, which signifies it receives a higher pollution load than the other four rivers. Some previous reports also support this result (Hassain *et al.* 2021; Haque *et al.* 2023). PLI is a crucial parameter in judging environmental quality and helping innovative policies for ecological scientists.

Metal contamination in fish samples of the selected rivers

The accumulated heavy metal content in three common fish species collected from the five studied rivers is displayed in Table 7. The Buriganga River witnessed the highest amount of Cr

Table 7. Heavy metal contaminations of three regularly eaten fish species from the five rivers

River	Name of the fish	Season	Metal (mg/kg)								
			Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg
Buriganga	*Heteropneustes fossilis*	Winter	BDL	80	0.11	34.5	0.2	0.21	5.5	2.01	0.01
		Summer	0.05	75	0.18	35.4	BDL	BDL	4.12	2.66	BDL
		Rainy	0.04	72	0.24	31.1	BDL	0.14	1.85	4.56	0.02
	Channa punctatus	Winter	0.11	65.4	0.01	28.53	0.44	0.4	2.77	1.07	0.24
		Summer	0.59	78.5	BDL	24.87	0.41	BDL	1.86	1.55	0.09
		Rainy	0.78	55.4	BDL	22.49	0.25	BDL	1.94	0.98	BDL
	Channa striata	Winter	BDL	71.45	0.21	40.45	0.36	0.19	3.21	2.27	0.04
		Summer	0.05	49.54	0.45	37.86	0.45	0.26	2.46	1.56	0.02
		Rainy	0.02	86.45	0.42	55.45	BDL	0.32	1.89	3.45	0.01
Shitalakhya	*Heteropneustes fossilis*	Winter	0.01	0.09	0.06	16.99	0.15	0.5	1.02	0.87	0.03
		Summer	0.02	0.05	0.07	19.54	BDL	0.21	1.48	0.59	BDL
		Rainy	0.01	0.11	0.14	27.5	0.08	0.91	0.08	1.99	BDL
	Channa punctatus	Winter	BDL	0.5	2.5	17.58	0.81	BDL	2.01	0.62	BDL
		Summer	0.01	BDL	1.45	11.76	0.55	BDL	3.45	BDL	0.09
		Rainy	BDL	0.12	BDL	9.87	0.91	0.01	BDL	2.45	BDL
	Channa striata	Winter	0.04	0.7	0.2	21.66	BDL	0.24	1.52	1.17	0.04
		Summer	0.02	1.05	0.7	23.59	BDL	0.31	1.2	0.86	0.03
		Rainy	BDL	2.41	BDL	16.86	BDL	0.61	0.98	0.84	BDL
Karnaphuli	*Heteropneustes fossilis*	Winter	0.01	0.58	0.11	34.4	0.18	0.51	2.05	0.37	0.04
		Summer	0.01	0.45	0.11	15.7	0.09	BDL	4.45	0.15	BDL
		Rainy	0.01	0.4	0.08	20.8	0.45	BDL	4.11	0.12	BDL
	Channa punctatus	Winter	0.01	0.2	0.56	40.75	0.41	0.06	4.51	0.8	BDL
		Summer	0.02	BDL	BDL	85.49	0.43	BDL	5.59	0.54	BDL
		Rainy	0.02	BDL	1.45	96.45	BDL	0.01	9.56	0.56	BDL
	Channa striata	Winter	BDL	0.12	1.28	13.45	0.13	0.13	1.04	1.05	0.01
		Summer	BDL	BDL	1.12	33.46	0.3	0.99	0.86	0.77	BDL
		Rainy	BDL	0.45	0.85	31.99	BDL	0.6	0.69	0.59	BDL
Meghna	*Heteropneustes fossilis*	Winter	0.08	18.04	2.1	88	0.55	0.31	2.44	0.08	0.01
		Summer	0.09	21.45	2.22	97	0.88	0.47	1.41	0.05	BDl
		Rainy	0.05	20.47	1.55	102	0.94	BDL	1.77	0.01	0.02
	Channa punctatus	Winter	0.02	30.1	0.17	68.54	0.33	0.16	1.95	0.43	0.45
		Summer	0.09	22.45	0.09	45.45	0.28	0.11	2.48	BDL	BDL
		Rainy	BDL	25.05	BDL	65.99	BDL	0.11	2.22	BDL	0.12
	Channa striata	Winter	0.12	18.7	0.84	98.71	0.51	0.12	1.06	0.47	0.12
		Summer	0.08	16.05	0.19	88.49	0.43	BDL	0.59	0.34	0.21
		Rainy	BDL	12.45	0.08	85.46	0.36	BDL	0.87	0.33	0.16
Padma	*Heteropneustes fossilis*	Winter	0.14	BDL	0.11	8.45	0.2	BDL	3.04	0.02	BDL
		Summer	0.05	BDL	0.25	10.9	BDL	0.14	5.42	0.01	BDL
		Rainy	0.08	BDL	0.11	10.2	0.11	0.3	2.99	0.01	BDL
	Channa punctatus	Winter	BDL	0.3	1.67	20.57	BDL	0.72	1.21	0.02	0.07
		Summer	BDL	0.09	1.45	18.91	0.47	0.12	1.45	BDL	0.05
		Rainy	BDL	0.45	0.31	15.87	BDL	BDL	BDL	BDL	0.02
	Channa striata	Winter	0.05	0.12	0.12	8.73	0.16	0.21	1.35	BDL	BDL
		Summer	BDL	0.08	0.29	4.69	0.22	0.09	1.64	BDL	BDL
		Rainy	BDL	0.04	BDL	5.64	0.34	0.51	1.56	0.08	BDL

(86.45 mg/kg) in *Channa striata* fish samples during the rainy season. The heavy metals found in the *Heteropneustes fossilis* body during the winter season as order Cr > Fe > Zn > Ni > Pb > Mn > Cu > Hg > Cd (nil); however, in the summer season, no presence of Mn, Pb, and Hg were found, but in the winter season the value of Mn decreased, and Cd increased in the fish body. In the winter season, the order of series was found as Cr > Fe > Zn > Ni > Mn > Pb > Hg > Cd > Cu in the *Channa punctatus* body, but in the summer season, no presence of Pb and Cu was found. Again, in *Channa striata,* the series arranged as Cr > Fe > Zn > Ni > Mn > Cu > Pb > Hg > Cd (nil) in the winter season; in summer, the value of Cd increased than Hg and in the rainy season, no presence of Mn were found.

In the Shitalakhya River, the highest amount of Fe (27.5 mg/kg) was found in the tissue of *Heteropneustes fossilis* during the rainy season. During the winter season, the presence of heavy metals was found in *Heteropneustes fossilis* body as order Fe > Zn > Ni > Pb > Mn > Cr > Cu > Hg > Cd; but in summer and rainy seasons, no presence of Hg and Mn was detected though other metals follow the same order like winter season. In the body of *Channa punctatus*, the order was found as Fe > Cu > Zn > Mn > Ni > Cr > Cd/ Pb / Hg (nil) in winter; however, no existence of Pb, Ni, and Cr during summer and Cd, Cu, Zn, and Hg during the rainy season were found. During winter in the *Channa striata's* body, the presence of metals was found as order Fe > Zn > Ni > Cr > Pb > Cu > Cd > Hg > Mn (nil), whereas, in the summer season, the level of Hg got higher than Cd in the last order and in rainy season absence of Cd, Cu, Mn, and Hg metal were detected.

In the Karnaphuli River, the value of metal contamination was found in order Fe > Zn > Cr > Pb > Ni > Mn > Cu > Hg > Cd in the *Heteropneustes fossilis* body during the winter season, where the highest presence of Fe was 96.45 mg/kg detected. However, an exception was found during the summer and rainy seasons, where no presence of Pb and Hg was found. In the *Channa punctatus* body, the heavy metal series was found in order as Fe > Zn > Ni > Cu > Mn > Cr > Pb > Cd > Hg (nil) in winter. However, the absence of metals like Cr, Cu, Pb, Hg, and Mn was observed during the summer and rainy seasons. For *Channa striata's* body, the order series was found in the winter season as Fe > Cu > Ni > Zn > Mn > Pb > Cr > Hg > Cd (nil), along with the absence of Cd, Cr, Hg, and Mn during summer and rainy season. According to the analyses of fish samples from Meghna River, the highest amount of Fe was detected in the body of *Heteropneustes fossilis*, which was 102 mg/kg during the rainy season and followed the order as Fe > Cr > Zn > Cu > Mn > Pb > Cd > Ni > Hg. However, the contamination of Hg was found to be higher than Pb and Ni in the rainy season, accompanied by the absence of Hg in the summer season. In the *Channa punctatus* body, the metal series went as Fe > Cr > Zn > Hg > Ni > Mn > Cu > Pb > Cd in winter, denoting the absence of Ni and Hg in the summer season. However, the unavailability of Cd, Cu, Mn, and Ni metals was detected during the rainy season. The order of metal series in the winter season found in the body of *Channa striata* as Fe > Cr > Zn > Cu > Mn > Ni > Cd > Pb > Hg. However, the contamination of Hg went higher than Pb and Cd during the summer season, whereas no presence of Cd and Pb was detected in the rainy season along the order.

In the Padma River, the highest amount of Fe was recorded in the body of *Channa punctatus* during the winter season, which was 20.57 mg/kg, and the sequence of metals went down as Fe > Cu > Zn > Pb > Cr > Hg > Ni > Cd/ Mn (nil). During summer, no presence of Ni was detected, and the absence of Cd, Mn, Pb, Zn, and Ni was also observed in the fish tissue. In the sample of *Heteropneustes fossilis*, the metal series was found to be as Fe > Zn > Mn > Cd > Cu > Ni > Cr/ Pb/ Hg (nil) during winter. The absence of Mn was recorded in the summer season, where the values Cr and Hg still remained the same in the rainy season as in winter. Within the tissue of the *Channa striata* body, during the winter season, the order of metal followed as Fe > Zn > Pb > Mn > Cr > Cu > Cd > Ni/ Hg (nil), whereas Ni, Hg, and Cd remain absent in the summer season in the following sequence. However, the contamination of Ni was found to be more in the rainy season, having no presence of Cd, Cu, and Hg metal in the tissue.

Heavy metals accumulate in different body parts of fish (prostate, gill, liver, renal system, digestive tract, intestines, musculature, etc.) through contiguity with contaminated water. The level of bioaccumulation differs from the power of affinity of these metals and gives dissent value for diverse fish according to the association (Rao *et al.* 2000).

The heavy metal level of the investigated three species' can be arranged in the following order: *Heteropneustes fossilis* is superior to *Channa punctatus* and *Channa striata*. Their eating habits are probably liable for this hierarchy. *Channa striata* and *Channa punctatus* are carnivorous among the examined species. In contrast, due to their wide feeding range, omnivore *Heteropneustes fossilis* have a greater capacity for metal accumulation (Baki *et al.* 2020). According to many studies (Khatun *et al.* 2021; JRC 1828), heavy metal accumulation varies for different fish organs (such as the liver, kidneys, gills, muscles, etc.); the edible portion of the fish has less heavy metal than the inedible region (Jalali *et al.* 2007). However,

Table 8. Bioaccumulation factor (BAF) of three fish species of five studied rivers

River	Name of the fish	Season	Cd	Cr	Cu	Fe	Mn	Pb	Zn	Ni	Hg
Buriganga	*Heteropneustes fossilis*	Winter	-	14.46	3.66	19.06	0.24	21	5.33	0.97	1
		Summer	2.5	14.64	9	24.75	-	-	4.33	0.92	-
		Rainy	-	15.28	-	36.16	-	7	3.30	2.41	2
	Channa punctatus	Winter	11	11.82	0.33	15.76	0.54	40	2.68	0.51	24
		Summer	29.5	15.33	-	17.39	0.53	-	1.95	0.53	9
		Rainy	-	11.76	-	26.15	0.34	-	3.46	0.518	-
	Channa striata	Winter	-	12.92	7	22.34	0.44	19	3.11	1.09	4
		Summer	2.5	9.67	22.5	26.47	0.59	-	2.58	0.53	2
		Rainy	-	18.35	-	64.47	-	16	3.37	1.82	1
Shitalakhya	*Heteropneustes fossilis*	Winter	1	1	0.075	5.64	0.9375	2.17	1.43	0.80	1.5
		Summer	-	0.714	0.129	7.84	-	0.95	2.31	0.33	-
		Rainy	1	5.5	0.189	6.23	0.05	-	0.09	2.03	-
	Channa punctatus	Winter	-	5.55	3.125	5.84	5.06	-	2.83	0.57	-
		Summer	-	-	2.68	4.72	2.5	-	5.39	-	-
		Rainy	-	6	-	2.23	0.64	-	-	2.5	-
	Channa striata	Winter	4	7.77	0.25	7.19	-	1.04	2.14	1.08	2
		Summer	-	15	1.29	9.47	-	1.40	1.87	0.48	-
		Rainy	-	120.5	-	3.82	-	-	1.11	0.857	-
Karnaphuli	*Heteropneustes fossilis*	Winter	0.33	1.07	0.054	21.91	0.25	0.96	1.69	0.474	-
		Summer	0.33	0.978	0.044	7.81	0.12	-	3.64	0.170	-
		Rainy	0.5	1.025	0.036	9.85	0.81	-	2.83	0.131	-
	Channa punctatus	Winter	0.33	0.37	0.278	25.95	0.57	0.11	3.72	1.02	-
		Summer	0.66	-	-	42.53	0.573	-	4.58	0.61	-
		Rainy	1	-	0.66	45.71	-	0.11	6.59	0.615	-
	Channa striata	Winter	-	0.22	0.636	8.56	0.18	0.24	0.859	1.34	-
		Summer	-	-	0.457	16.64	0.4	2.35	0.70	0.875	-
		Rainy	-	1.15	0.389	15.16	-	6.66	0.47	0.64	-
Meghna	*Heteropneustes fossilis*	Winter	1	451	1.84	3.83	11	1.14	5.67	0.119	0.5
		Summer	1.8	536.25	1.52	4.81	22	2.23	4.02	0.090	-
		Rainy	0.71	511.75	-	5.51	8.54	-	19.66	0.052	-
	Channa punctatus	Winter	0.25	752.5	0.149	2.99	6.6	0.59	4.53	0.64	22.5
		Summer	1.8	561.25	0.061	2.25	7	0.52	7.08	-	-
		Rainy	-	626.25	-	3.56	-	0.57	24.66	-	-
	Channa striata	Winter	1.5	467.5	0.73	4.30	10.2	0.44	2.46	0.70	6
		Summer	1.6	401.25	0.130	4.39	10.75	-	1.68	0.618	-
		Rainy	-	311.25	-	4.62	3.27	-	9.66	1.73	-
Padma	*Heteropneustes fossilis*	Winter	-	-	2.2	3.12	0.57	-	4.05	0.5	-
		Summer	-	-	6.25	4.43	-	2.8	9.85	1	-
		Rainy	8	-	11	5.42	0.5	0.33	4.90	1	-
	Channa punctatus	Winter	-	30	33.4	7.61	-	36	1.61	0.5	2.33
		Summer	-	4.5	36.25	7.68	1.38	2.4	2.63	-	5
		Rainy	-	22.5	31	8.44	-	-	-	-	-
	Channa striata	Winter	-	12	2.4	3.23	0.45	10.5	1.8	-	-
		Summer	-	4	7.25	1.90	0.64	1.8	2.98	-	-
		Rainy	-	2	-	3	1.54	0.56	2.55	8	-

in Bangladesh, people often only eat the fish's muscles. Therefore, in this study, only the edible fish parts are considered.

From the exploration (Table 8), Cr and Fe have a lead contamination value among the heavy metals. The level of Cr in the Buriganga and Meghna rivers has exceeded the USFDA (1993) guidelines (USFDA 1993; USEPA 1989), which was 12-13 mg/kg. Moreover, the Zn, Fe, Pb, Cu, and Ni contamination was below the acceptable food limit according to FAO (FAO 1983) and WHO (WHO 2005).

Bioaccumulation Factor (BAF)

Table 8 lists the BAF values for the five Rivers' examined fish species. From the analyses, *Channa striata* from the Shitalakhya River has BAF values of 120.5 for Cr in the rainy season. Besides, from the Meghna River, *Heteropneustes fossilis* has BAF values in winter (451), summer (536.25) and rainy season (511.75); as well as *Channa punctatus* in winter (752.5), summer (561.25) and rainy season (626.25); along with *Channa striata* in winter (467.5), summer (401.25) and rainy season (311.25) for Cr has surpassed the value of 100.

The ability of aquatic organisms to accumulate chemicals from water was assessed using the bioaccumulation factor (BAF). A BAF value greater than 1 indicates the potentiality for the fish to accumulate metals from the water. But when the BAF value turns to more than 100, quick action must be taken. Based on the obtained results, we can say that the Meghna River deposits more metals in the fish body than in other rivers. Table 8 shows different BAF values for the selected species and metals in various rivers and seasons. These values differ from fish to fish, season to season, and river to river because of different accumulation capacities, migration, aquatic environment, etc., of fish species (Khatun *et al.* 2021).

HEALTH RISK ANALYSIS

Estimation of estimated daily intake (EDI) and Target Health Quotient (THQ)

In Dhaka, there are almost 20 million residents, and many eat various kinds of fish (Hossain *et al.,* 2021). Since the examined fishes are mostly eaten, the potential health risks from consuming fishes gathered from the five studied rivers should have come up. The health risk can be determined by calculating the target hazard quotients (THQ) and estimated daily intakes (EDI) of metal. Table 9 displays the EDI and THQ results from the examined fish species.

Analyzing the fish samples of river Buriganga, the order of THQ for low and medium fish consumers followed as Hg > Cd > Ni > Fe > Cr > Pb > Zn > Cu > Mn, where high fish consumers almost represent the same as low and medium consumers except for the change in the position between Pb and Cr. For river Shitalakhya, the THQ for low, medium, and high fish consumers was found to be in order Hg > Pb > Ni > Fe > Cd > Cu > Zn > Mn > Cr. For river Karnaphuli, the THQ in the low, medium, and high fish consumer categories is represented as Pb > Fe > Hg > Ni > Cd > Cu > Zn > Mn > Cr. For the river Meghna, the order of THQ for low, medium, and high fish consumers followed as Hg > Fe > Cd > Pb > Cu > Cr > Ni > Zn > Mn. In the case of river Padma, the THQ order for low fish consumers was arranged as Cr > Hg > Pd > Cd > Fe > Cu > Zn > Mn > Ni, whereas for medium and high fish consumers, it went down as Hg > Pb > Cd > Fe > Cu > Zn > Mn > Ni > Cr.

The EDI values for Cr in Buriganga, Meghna, and Fe for Shitalakhya, Karnaphuli, Meghna, and Padma are comparatively high. Cr has passed the MTDI value with low, medium, and high fish consumer EDI for river Buriganga. Without this metal, all the EDI values are under the MTDI. We know that a THQ value greater than 1 imposes a potential health risk to the fish consumer (Hossain *et al.* 2021; Khatun *et al.* 2021). However, Table 9 shows that all THQ values are less than one except Hg in Meghna River and Cr in Padma River, indicating that fish consumers from those rivers are at greater health risk. Therefore, citizens must immediately avoid the potential health dangers of consuming foods contaminated with heavy metals. Therefore, it is recommended that ongoing efforts to reduce industrial emissions, particularly in the leather and textile industries, should be given priority. Routinely examining all dangerous chemicals in all food products is crucial to identifying substantial health hazards (Khatun *et al.* 2021; Lu *et al.* 2015).

Table 9. Estimated daily intake (EDI), non-carcinogenic risk of metals from fish consumption.

River	Metal	Metal (conc.)	Estimated Daily Intake of trace metal			MTDI (mg/day)	Target Health Quotient (THQ)		
			Low Fish Consumer	Medium Fish Consumer	High Fish Consumer		Low Fish Consumer	Medium Fish Consumer	High Fish Consumer
Buriganga	Cd	0.182	0.013	0.015	0.023	0.062	0.43	0.528	0.77
	Cr	70.41	5.05	6.13	8.97	2[b]	0.056	0.068	0.09
	Cu	0.18	0.012	0.015	0.022	30[d]	0.005	0.006	0.009
	Fe	34.51	2.47	3.007	4.39	-	0.059	0.071	0.104
	Mn	0.234	0.016	0.020	0.029	2.3	0.002	0.0024	0.003
	Pb	0.168	0.012	0.0146	0.02	0.21[c]	0.05	0.06	0.10
	Zn	2.84	0.204	0.247	0.36	-	0.011	0.01	0.020
	Ni	2.23	0.16	0.194	0.28	0.3[e]	0.133	0.16	0.236
	Hg	0.04	0.002	0.003	0.005	-	0.478	0.58	0.849
Shitalakhya	Cd	0.012	0.0008	0.001	0.0015	0.062	0.02	0.034	0.05
	Cr	0.55	0.039	0.047	0.07	2	0.0004	0.0005	0.0007
	Cu	0.56	0.040	0.048	0.071	30	0.016	0.0203	0.02
	Fe	18.37	1.31	1.60	2.34	-	0.031	0.038	0.055
	Mn	0.27	0.019	0.023	0.034	2.3	0.0023	0.002	0.004
	Pb	0.31	0.02	0.027	0.039	0.21	0.106	0.128	0.188
	Zn	1.3	0.09	0.113	0.16	-	0.005	0.006	0.0092
	Ni	1.04	0.074	0.090	0.13	0.3	0.062	0.075	0.110
	Hg	0.021	0.0015	0.0018	0.0026	-	0.251	0.30	0.44
Karnaphuli	Cd	0.008	0.0005	0.0006	0.001	0.062	0.019	0.023	0.033
	Cr	0.24	0.017	0.02	0.03	2	0.00019	0.0002	0.0003
	Cu	0.61	0.043	0.053	0.07	30	0.018	0.022	0.032
	Fe	41.38	2.97	3.60	5.27	-	0.070	0.085	0.125
	Mn	0.22	0.015	0.019	0.028	2.3	0.0018	0.002	0.003
	Pb	0.25	0.017	0.02	0.03	0.21	0.085	0.103	0.151
	Zn	3.65	0.262	0.318	0.465	-	0.0145	0.017	0.0258
	Ni	0.55	0.039	0.047	0.07	0.3	0.0329	0.039	0.058
	Hg	0.005	0.00035	0.0004	0.0006	-	0.059	0.0726	0.10
Meghna	Cd	0.05	0.0035	0.004	0.006	0.062	0.119	0.145	0.212
	Cr	20.52	1.47	1.78	2.61	2	0.016	0.019	0.02
	Cu	0.8	0.057	0.069	0.10	30	0.023	0.0290	0.042
	Fe	82.18	5.90	7.16	10.46	-	0.140	0.170	0.249
	Mn	0.47	0.033	0.04	0.05	2.3	0.0040	0.004	0.007
	Pb	0.14	0.010	0.012	0.017	0.21	0.047	0.058	0.084
	Zn	1.64	0.117	0.142	0.20	-	0.0065	0.0079	0.01
	Ni	0.19	0.013	0.016	0.02	0.3	0.011	0.0138	0.020
	Hg	0.12	0.008	0.010	0.01	-	1.4368	1.74	2.54
Padma	Cd	0.03	0.002	0.002	0.003	0.062	0.07	0.087	0.1274
	Cr	0.12	0.008	0.01	0.015	2	9.57	0.0001	0.0001
	Cu	0.47	0.033	0.04	0.05	30	0.014	0.017	0.024
	Fe	11.55	0.82	1.006	1.47	-	0.019	0.02	0.035
	Mn	0.16	0.011	0.013	0.02	2.3	0.001	0.0016	0.0024
	Pb	0.23	0.016	0.02	0.029	0.21	0.078	0.095	0.139
	Zn	2.07	0.148	0.18	0.26	-	0.008	0.01	0.01
	Ni	0.01	0.0007	0.0008	0.001	0.3	0.0005	0.0007	0.0010
	Hg	0.01	0.0007	0.0008	0.001	-	0.119	0.145	0.21

[a]MTDI: maximum tolerable daily dietary intake
[b]ESADDI: estimated safe and adequate daily dietary intake (Tao *et al.* 2012)
[c]PTDI: provisional tolerable daily intake (60 kg body weight) (WHO 2005; Heikens *et al.* 2006)
[d]PMTDI: provisional maximum tolerable daily intake (Adolf *et al.* 1960)
[a]Average daily intake of food (Duruibe *et al.* 2007)

CONCLUSION

According to the findings, the sediment, water, and fishes of the analyzed rivers had varying amounts of Cr, Zn, Fe, Cu, Pb, Mn, Cd, Hg, and Ni. The levels of heavy metals in the water and sediment were higher than several widely accepted thresholds. In the majority of cases, it was obtained that the heavy metals content in water and sediment during the winter exhibited substantial values, as did the contamination of metals in fish during the rainy season. According to the concentration factor (CF), the sediments of Shitalakhya and Buriganga were moderately contaminated with Cd and Cr, respectively. The *Heteropneustes fossilis* act as a bioindicator to examine heavy metal contamination. BAF values indicate the presence of Cr in the fishes of Meghna River is significantly higher than the others. The results of this study show that the rivers Buriganga, Shitalakhya, Meghna, Karnaphuli, and Padma are highly polluted. The use of water and sediment and consumption of these rivers' fish species seriously endanger human health. Hence, to make the right decisions, constant monitoring and periodic assessment are needed. It is also strongly advised to treat the rivers under consideration for longer to reduce the contamination of heavy metals. Monitoring other fish, fauna, flora, aquatic biota, etc. is critical to guarantee that food is free of heavy metal pollution and safeguard consumers from any health risks related to their regular diet.

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REFERENCES

Adolf, L.(1960). "Recommended Dietary Allowances." *Nutrition Reviews,* 18(7); 203–5. doi: 10.1111/j.1753-4887.1960.tb01770.x.

Ahamad, M.I., Song, J., Sun, H., Wang, X., Mehmood, M.S., Sajid, M., Su, P., & Khan, A.J. (2020). Contamination level, ecological risk, and source identification of heavy metals in the hyporheic zone of the Weihe River, China. *International journal of environmental research and public health*, Feb17(3);1070.

Alhashemi, A.H., Sekhavatjou, M.S., Kiabi, B.H., & Karbassi, A.R.(2012). Bioaccumulation of trace elements in water, sediment, and six fish species from a freshwater wetland, Iran. *Microchemical Journal*, *104*; 1-6.

Alhashemi, H., Karbassi, A., Kiabi, H.,Monavari, S.M., & Sekhavatjou, M.S.(2012). Bioaccumulation of trace elements in different tissues of three commonly available fish species regarding their gender, gonadosomatic index, and condition factor in a wetland ecosystem. *Environmental Monitoring and Assessment*, *184*; 1865-1878.

Alhashemi, H., Karbassi, A.S., Hassanzadeh, A.R., Kiabi, B., Monavari, S.M., Nabavi, S.M.B., & Sekhavatjou, M.S.(2011). Bioaccumulation of trace elements in trophic levels of wetland plants and waterfowl birds. *Biological trace element research*, *142*; 500-516.

Baki, M.A., Shojib, M.F., Sehrin, S., Chakraborty, S., Choudhury, T.R., Bristy, M.S., Ahmed, M.K., Yusoff, S.B., & Khan, M.F. (2020) Health risk assessment of heavy metal accumulation in the Buriganga and Turag River systems for *Puntius ticto*, *Heteropneustes fossilis,* and *Channa punctatus. Environmental geochemistry and health*, Feb42; 531-43.

BDWS, (Bangladesh Dringking Water Standards). (1997). "The Environment Conservation Rules, 1997." *Bangladesh Department of Environment, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh;* 179–227.

Bhuiyan, M.A.H. Dampare, S.B. Islam, M.A. Suzuki, S. (2015). Source apportionment and pollution evaluation of heavy metals in water and sediments of Buriganga River, Bangladesh, using multivariate analysis and pollution evaluation indices, *Environmental Monitoring Assessment,* 187(2015); 222-236

Bhuyan, M.S., Bakar, M.A., Akhtar, A., Hossain, M.B., & Islam, M.S.(2017). Analysis of water quality of the Meghna River using multivariate analyses and RPI. *Journal of the Asiatic Society of Bangladesh, Science.* Jun 20; 43(1); 23-35.

Braulik, G., Atkore, V., Khan, M.S., & Malla, S. (2021). Review of Scientific Knowledge of the Ganges river dolphin. WWF, commissioned by the World Bank.

Cenci, R.M., & Martin, J.M. (2004). Contamination and fate of heavy metals in Mekong River Delta. *Science of the total Environment*. Oct 1; 332 (1-3); 167-82.

Duncan, A.E., de Vries, N., & Nyarko, K.B. (2018). Assessment of heavy metal pollution in the sediments of the River Pra and its tributaries. *Water, Air, & Soil Pollution.* Aug; 229;1-0.

Duruibe, O.J., Ogwuegbu, M.O.C., & Egwurugwu, J.N. (2007). "Heavy Metal Pollution and Human Biotoxic Effects." *International Journal of Physical Sciences,* 2(5);112–18. Ekeanyanwu, C.R., Ogbuiny,i C.A., & Etienajirhevwe, O.F. (2010).Heavy metals distribution in fish tissues, bottom sediments and water from Okumeshi River in Delta State, Nigeria. *Ethiopian Journal of Environmental Studies and Management.* 2010; 3(3).

Facetti, J., Dekov, V.M., & Van,Grieken. R. (1998). Heavy metals in sediments from the Paraguay River: a preliminary study. *Science of the total environment.* 1998 Jan 8; 209 (1); 79-86.

FAO (1983). "Compilation of Legal Limits for Hazardous Substances in Fish and Fishery Product." *Library* 746;104.

Gupta, A., Rai, D.K., Pandey, R.S., & Sharma, B. (2009). Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environmental monitoring and assessment.* 2009 Oct;157; 449-58.

Haque, M.R., Ali, M.M., Ahmed, W., Siddique, M.A., Akbor, M.A., Islam, M.S., & Rahman, M.M. (2023). Assessment of microplastics pollution in aquatic species (fish, crab, and snail), water, and sediment from the Buriganga River, Bangladesh: *An ecological risk appraisals. Science of the Total Environment.* 2023 Jan 20; 857; 159344.

Heikens, A. (2006). Arsenic contamination of irrigation water, soil and crops in Bangladesh: Risk implications for sustainable agriculture and food safety in Asia. *Rap Publication (FAO).* 2006.

Hossain, M.N., Rahaman, A., Hasan, M.J., Uddin, M.M., Khatun, N., & Shamsuddin, S.M. (2021). Comparative seasonal assessment of pollution and health risk associated with heavy-metals in water, sediment and fish of Buriganga and Turag River in Dhaka city. Bangladesh *SN Applied Science,* 3(3); 509

Islam, M.S., Ahmed, M.K., & Habibullah, A.M.M. (2015). Determination of heavy metals in fish and vegetables in Bangladesh and health implications. *Human and Ecological Risk Assessment: An International Journal.* 2015 May 19; 21(4); 986-1006.

Islam, M.S., Ahmed, M.K., Raknuzzaman, M., Habibullah, A.M.M., & Islam, M.K. (2015). Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. *Ecological indicators.* 2015 Jan 1; 48; 282-91.

Islam, M.S., Chowdhury, M.A., Billah, M.M., Tusher, T.R., & Sultana, N. (2012). Investigation of effluent quality discharged from the textile industry of Purbani group, Gazipur, Bangladesh and its management. *Bangladesh Journal of Environmental Science.* 2012; 23; 123-30.

Islam, M.S., Han, S., Ahmed, M.K., & Masunaga, S. (2014). Assessment of heavy metal contamination in water and sediment of some rivers in Bangladesh. *Journal of water and environment technology.* 2014; 12 (2); 109-21.

Islam, M.S., Kabir, M.H., Sifat, S.A., Meghla, N.T., & Tusher, T.R. (2014). Status of water quality from the Padma river at Bheramara point of Kushtia in Bangladesh. *Bangladesh Journal of Environmental Science.* 2014; 27; 110-5.

Jalali, J.B., & Agazade, M. (2007)."Fish Intoxication Heavy Metals and Its Significance on Public Health." *Maane Ketab Pub*. 2007.

JRC, Van-Duijn. (1828). "Diseases of Fishes." *The Lancet* 9(231); 651. doi: 10.1016/S0140-6736(02)97064-9.

Kamal, M.M., Malmgren-Hansen, A., & Badruzzaman, A.B. (1999). Assessment of pollution of the River Buriganga, Bangladesh, using a water quality model. *Water science and technology.* 1999 Jan 1; 40 (2); 129-36.

Karbassi, S., Nasrabadi, T., & Shahriari, T.(2016). Metallic pollution of soil in the vicinity of National Iranian Lead and Zinc (NILZ) Company. *Environmental Earth Sciences*, 75; 1-11.

Khalid, A.R. (2004). The interlinking of rivers project in India and International water law: an overview. *Chinese J. Int'l L.* 2004; 3; 553.

Khatun, N., Hossain, M.N., Islam, M.D., & Rahaman, A. (2023). Hazard Estimations Result from Arsenic Contamination in Common Foodstuffs, Soil, Sediment, and Water of Joypurhat District, Bangladesh. *Pollution.* 2023 Feb 1; 9(2); 531-44.

Khatun, N., Nayeem, J., Deb, N., Hossain, S., & Kibria, M.M. (2021). Heavy metals contamination: possible health risk assessment in highly consumed fish species and water of Karnafuli River Estuary, Bangladesh. *Toxicology and Environmental Health Sciences.* 2021 Dec;13(4); 375-88.

Li, H., Shi, A., Li, M., & Zhang, X. (2013). Effect of pH, temperature, dissolved oxygen, and flow rate of overlying water on heavy metals release from storm sewer sediments. *Journal of Chemistry.* 2013 Aug; 2013.

Loska, K., Cebula, J., Pelczar, J., Wiechuła, D., & Kwapuliński, J. (1997). Use of enrichment, and contamination factors together with geoaccumulation indexes to evaluate the content of Cd, Cu, and Ni in the Rybnik water reservoir in Poland. *Water, Air, and Soil Pollution.* 1997 Jan; 93; 347-65.

Lu, Y., Song, S., Wang, R., Liu, Z., Meng, J., Sweetman, A.J., Jenkins, A., Ferrier, R.C., Li, H., Luo, W., & Wang, T. (2015). Impacts of soil and water pollution on food safety and health risks in China. *Environment international.* 2015 Apr 1;77; 5-15.

Mendil D, Ünal O.F., Tüzen, M., & Soylak, M. (2010). Determination of trace metals in different fish species and sediments from the River Yes_ilirmak in Tokat, Turkey. *Food and Chemical Toxicology*, 48 (2010); 1383–1392

Mohiuddin, K., Alam, M., Ahmed, I., & Chowdhury, A. (2016). Heavy metal pollution load in sediment samples of the Buriganga river in Bangladesh. *Journal of Bangladesh Agricultural University,* 13 (2016); 229–238.

Mohiuddin, K.M., Otomo, K., Ogawa, Y., & Shikazono N. (2012). Seasonal and spatial distribution of heavy elements in the water and sediments of the Tsurumi River in Japan. *Environmental monitoring and assessment.* 2012 Jan;184; 265-79.

Nasrabadi, T., & Bidabadi, N.S.(2013). Evaluating the spatial distribution of quantitative risk and hazard level of arsenic exposure in groundwater, case study of Qorveh County, Kurdistan Iran. *Iranian Journal of Environmental Health Science and Engineering*, *10*; 1-8.

Nasrabadi, T., Abbasi Maedeh, P., Sirdari, Z.Z., ShiraniBidabadi, N., Solgi, S., & Tajik, M.(2015). Analyzing the quantitative risk and hazard of different waterborne arsenic exposures: case study of Haraz River, Iran. *Environmental earth sciences*, *74*; 521-532.

Nasrabadi, T., Ruegner, H., Schwientek, M., Bennett, J., Fazel Valipour, S., & Grathwohl, P. (2018). Bulk metal contaminations versus total suspended solids in rivers: Time-invariant & catchment-specific relationships. *PloS one*, *13*(1); p.e0191314.

Persaud, D., Jaagumagi, R., & Hayton, A. (1993). "Guidelines for the Protection and Management Of." *Aquatic Sediment Quality in Ontário, Water Resources Branch, Ontario Ministry of the Environmental Toronto,*.Jan; 73; 347-65.

Rahman, K., Barua, S., Ahammad, F., & Alam, M.A. (2020). Assessment of pollution and sources of heavy metals in the sediments of the Shitalakhya river, Bangladesh. *International Journal of Advance Geoscience,* 2020; 8 (1); 89-94.

Rahman, M.B., Islam, M.M., Ruma, M., & Rahman, M.M. (2020). Effects of environmental condition on spatial-temporal changes of fish diversity and morphology of Shitalakshya River. *Ecologia.* 2020; 10(1); 38-49.

Rahman, M.S., Saha, N., & Molla, A.H. (2014). Potential ecological risk assessment of heavy metal contamination in sediment and water body around Dhaka export processing zone, Bangladesh. *Environmental earth sciences.* 2014 Mar;71; 2293-308.

Rajendran, S., Priya, T.A., Khoo, K.S., Hoang, T.K., Ng, H.S., Munawaroh, H.S., Karaman, C., Orooji, Y., & Show, P.L. (2022). A critical review on various remediation approaches for heavy metal contaminants removal from contaminated soils. *Chemosphere.* 2022 Jan 1; 287; 132369.

Rao, L.M., & Padmaja, G. (2000). Bioaccumulation of heavy metals in M. cyprinoids from the harbor waters of Visakhapatnam. *Bull Pure Appl Sci.* 2000; 19(2); 77-85.

Report, TBS. (2019). "Savar Tannery ETP Stuck by a String | The Business Standard." *The Business Standard*.

Suresh, G., Sutharsan, P., Ramasamy, V., & Venkatachalapathy, R. (2012). Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam lake sediments, India. *Ecotoxicology and environmental safety.* 2012 Oct 1; 84; 117-24.

Tao, Y., Yuan, Z., Xiaona, H., & Wei, M. (2012). Distribution and bioaccumulation of heavy metals in aquatic organisms of different trophic levels and potential health risk assessment from Taihu lake, China. *Ecotoxicology and Environmental Safety.* 2012 Jul 1; 81; 55-64.

Tomlinson, D.L., Wilson, J.G., Harris, C.R., & Jeffrey, D.W. (1980). Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländermeeresuntersuchungen. 1*980 Mar; 33; 566 -75.

Turekian, K.K., & Wedepohl, K.H. (1961). Distribution of the elements in some major units of the earth's crust. *Geological society of America bulletin.* 1961 Feb 1; 72 (2):175-92.

Uddin M.J and Jeong Y.K. (2021). Urban river pollution in Bangladesh during last 40 years: potential public health and ecological risk, present policy, and future prospects toward smart water management. *Heliyon*7 (2); (2021); e06107

Uddin, M., Kormoker, T., Siddique, M.A., Billah, M.M., Rokonuzzaman, M., Al Ragib, A., Proshad, R., Hossain, M.Y., Haque, M.K., Ibrahim, K.A., & Idris, A.M. (2023). An overview on water quality, pollution sources, and associated ecological and human health concerns of the lake water of megacity: a case study on Dhaka city lakes in Bangladesh. *Urban Water Journal.* 2023 Mar 16; 20(3); 261-77.

UN. (2017). "Goal 6: Clean Water and Sanitation in The Sustainable Development Goals Report." *United Nations* 60.

USEPA, December (1989) "Risk Assessment Guidance for Superfund." *Human Health Evaluation Manual Part A* I(202).

USEPA. (2001). "Methods for Collection, Storage and Maripulation of Sediment for Chemical and Toxicological Analyses: Technical Manual." (October).

USFDA (1993). United States Food and Drug Administration, Guidance Document for Chromium in Shell Fish. DHHS/PHS/FDA/CFSAN/Office of Seafood, Washington DC.

WHO. World Health Organization. (2005). "Evaluation of Certain Food Additives : Sixty-Third Report of the Joint FAO/WHO Expert Committee on Food Additives." 157.

Yahaya, M.I., Mohammad, S., & Abdullahi, B.K. (2009). Seasonal variations of heavy metals contamination in abattoir dumping site soil in Nigeria. *Journal of Applied Sciences and Environmental Management.* 2009; 13(4).

Yasasve, M., Manjusha, M., Manojj, D., Hariharan, N.M., Preethi, P.S., Asaithambi, P., Karmegam, N., & Saravanan, M. (2022). Unravelling the emerging carcinogenic contaminants from industrial waste water for prospective remediation by electrocoagulation–a review. *Chemosphere.* 2022 Aug 14:136017.

Zolitschka, B., Francus, P., & Ojala, A.E. (2015). Schimmelmann A. Varves in lake sediments–a review. *Quaternary Science Reviews.* 2015 Jun 1;117:1-41.