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Heavy Metals in Fishes, Water and Macrophyte of the Ganga River and Risk Related to their Consumption

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Abstract

The study was conducted along the Ganga River and aimed to assess the contamination levels of six heavy metals (Pb, Cd, Hg, Cu, Cr, and Zn) in fishes, water, and macrophyte (*Eichornia crassipes*) of Haridwar (Bhadrabad - A1), Bijnor (Near Ravidas temple-A2) and Muzaffarnagar (Bairaj Ganga bridge-A3) using a flame atomic absorption spectrophotometer (Avanta Σ). The findings revealed a concerning level of heavy metal contamination in various components of the Ganga River ecosystem. In fishes, the order of heavy metal occurrence was Cr>Zn>Pb>Cu>Cd>Hg, with Pb levels exceeding the recommended WHO/FAO limits in some samples. Water samples showed heavy metals in the order Pb>Cu>Zn>Cr>Cd>Hg, with elevated levels of Pb and Cr at site Haridwar (Bhadrabad - A1) exceeding WHO's maximum permissible limits. Macrophyte analysis indicated heavy metals in the order Zn>Cr>Pb>Cu>Hg>Cd, with Pb and Cr levels surpassing WHO recommendations. The heavy metal bioaccumulation was higher during the post-monsoon and pre-monsoon seasons while lower in the monsoon season. Significant differences in heavy metal concentrations among different organs of fishes highlight the variability in metal accumulation and distribution. The study underscores the importance of regular biomonitoring to assess the risks posed by heavy metals, especially considering the significant reliance of the local population on the Ganga River for various purposes. Continued monitoring and implementation of mitigation measures are essential to safeguard human health and the integrity of the ecosystem in the face of heavy metal contamination.

Keywords: *Eichornia crassipes,* Fishes, Ganga, Heavy Metals, River

1. Introduction

Efforts to address the pollution of the Ganga have been ongoing for years, with various initiatives launched by the Indian government and non-governmental organisations. The Ganga River, one of India's most revered water bodies, holds immense cultural, religious, and ecological significance. However, rampant pollution, primarily attributed to industrial effluents, agricultural runoff, and urban sewage, has severely compromised its water

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quality. Among the various pollutants, heavy metals pose a significant threat to the health of the river ecosystem and human populations relying on its resources. The concentration of pollutants and the discharge into the river are the dependent factors that cause increasing pollution in rivers[1]. Each concentration and outflow are verified by hydrologic, geomorphic, topographic, and cultural parameters. Municipal sewage, industrial effluents, and agricultural run-off are all potential sources of pollution. The discharge of untreated sewage accounts for approximately seventy-five per cent of Ganga contamination. The stream also serves as a location for non-secular bathing (Kanvarmela, Kumbhmela, etc.), animal laundry and watering, as well as the disposal of human and animal bodies. In addition to these activities, a very major issue commercial company is supporting a bigger pollution load to the Ganga. However, the environmental health of the Ganga has been severely compromised due to widespread pollution stemming from industrial effluents, agricultural runoff, and untreated sewage discharge[2]. Among the numerous pollutants, heavy metals have garnered significant attention due to their persistence, bioaccumulative nature, and adverse effects on ecosystems and human health.

Heavy metals have recently become a major source of concern because they are extremely persistent in the environment due to their non-biodegradable and non-thermodegradable properties, and they can quickly accumulate to hepatotoxic levels when an organism is exposed[3]. They are also considered unhealthful since they have a propensity to bioaccumulate in numerous organisms and plants and bio-magnify inside the organic phenomena, which then attack certain organs or tissues. Heavy metals, including lead (Pb), cadmium (Cd), mercury (Hg), copper (Cu), chromium (Cr), and zinc (Zn), are commonly found in aquatic environments due to anthropogenic activities such as mining, industrial processes, and urbanization[4]. These metals can enter the aquatic ecosystem through various pathways, including direct discharge, atmospheric deposition, and runoff from contaminated soils. Once in the water, heavy metals can accumulate in sediments, aquatic plants (macrophytes), and biota, including fish, posing serious ecological and human health risks. A few of these metals will pose serious human health risks since they are likely to be harmful and induce malignant neoplastic illness in low quantities if they reach the organic phenomena. Significant metals from many sources react with the natural environment, contaminating water, air, and soil[1]. Heavy metals are therefore considered a universal contaminant. The presence of heavy metals in the Ganga ecosystem raises serious concerns regarding human health risks associated with the consumption of contaminated fish, water, and macrophytes. Fish, being a vital protein source for millions of people residing along the river, can accumulate high concentrations of heavy metals through bioaccumulation and biomagnification processes[5]. Similarly, macrophytes, which provide habitat and food for aquatic animals, can operate as heavy metal sinks, affecting their distribution and cycling throughout the environment. Furthermore, heavy metals dissolved in water can have a direct impact on human health through contaminated drinking water and indirect exposure through food chains. Human activity is the primary driver of heavy metal pollution in water, soil, and air; urbanization, industry, agriculture, and mining all contribute to higher levels of these pollutants[6]. Numerous times, plants, forest fires, or rocks containing minerals may cause contamination of the aquatic environment. This is known as earth science contamination[7]. Fish and other aquatic organisms may accumulate heavy metals through direct ingestion of water or other substances, uptake through epithelia, such as the gills, skin, and digestive tube, or through sedimentation, which combines the most specific metals with other pollutants that are hazardous to aquatic life[8,9]. Many fish consume benthic populations that are directly exposed to polluted material, while others are exposed to harmful metals in sediment. Fish are considerably sensitive and heavily exposed to major metal pollution as a result of their eating and surroundings inside the aquatic system since they can't shake off the detrimental effects of pollutants[10,11]. Understanding the distribution, sources, and potential impacts of heavy metals in fish, water, and macrophytes of the Ganga River is crucial for effective environmental management and risk mitigation strategies. Previous studies have highlighted the widespread occurrence of heavy metal contamination in the Ganga River basin, emphasizing the need for continued monitoring and remediation efforts[12]. However, comprehensive assessments integrating multiple environmental compartments are essential to evaluate the overall contamination status and associated risks to human and ecosystem health. This study aims to investigate the levels of heavy metals in fishes, water, and macrophytes of the Ganga River, assess spatial and temporal variations, and evaluate potential exposure risks

to human populations relying on Ganga's resources. This research contributes to informed decision-making and sustainable management practices aimed at preserving the ecological integrity and ensuring the safety of water resources in the region.

2. Material and Methods

2.1 Sampling Location

In the Ganga river, three sites from each district *viz*: Haridwar (Bhadrabad- A1), Bijnor (Near Ravidas temple-A2) and Muzaffarnagar (Bairaj Ganga bridge-A3) were selected. Monthly samples of fish, water and macrophytes (*Eichornia crassipes*) were collected from March 2019 to February 2020 for the present study. The flexibility of the river stretch, taking into account changes in pollution, biodiversity, and hydrological regimes, served as the foundation for the selection of sample sites. The selection of these heavy metals (Pb, Cd, Hg, Cu, Cr and Zn) is typically based on their prevalence in environmental pollution and their known adverse effects on human health and ecosystems.

Geographical locations of the sampling sites

2.2 Sample Collection

Local fishermen assisted in the collection of fish from each test site. Fish samples were transported to the laboratory in ice boxes. River water samples were collected and acidified in plastic bottles that had been previously cleaned (1.5 millilitres of strong nitric acid per litre of sample). To prevent volume changes due to evaporation, the bottles were stored in a refrigerator set at 4°C. The macrophyte was cleansed of large dirt particles using river water. These were then transported to the lab in polypropylene bags, and each sample was thoroughly cleaned with distilled water.

2.3 Digestion of Samples and Heavy Metal Analysis

After dissection, fish samples from the liver, gills, kidney, and muscle were homogenized in a blender, and one gram of the mixture was microwave-dried. The samples were then combined in polypropylene vials with 5 ml HNO_3 (65%) and 5 ml H_2SO_4. Following a 10-minute mixing period, 1 millilitre of H_2O_2 was added, and the samples were microwaved for 1 hour at 105°C. The residue was diluted to 50 millilitres using HNO_3 (0.3%).

For macrophyte (*Eichornia crassipes*), samples were air-dried and placed in an oven at 70°C for 48 hours. Once completely dried, the samples were crushed into a powdered form using a mortar and pestle. 0.5 g of the dried powdered bulk samples were moistened with 1-2 ml of deionized water, and then 10 ml of concentrated HNO_3 was added slowly and left overnight. The mixture was heated on a hot plate until complete leaching/digestion of the sample. After cooling to ambient temperature, it was filtered through No. 40 filter paper. The filtrate was made up of 50 ml of deionized water for analysis in the Atomic Absorption Spectrophotometer (AAS).

All the digested filtrates (fishes and water) were analyzed to quantify the amount of Pb, Cd, Hg, Cu, Cr and Zn using flame atomic adsorption spectrophotometer (Avanta Σ)[13]. Different concentrations of standards were prepared for the calibration of the atomic absorption spectrophotometer.

Ganga river	**A1**	**A2**	**A3**
Map Location	29°55'15.1"N 78°04'42.2"E	29°38'07.0"N 78°06'21.7"E	29°22'26.1"N 78°02'03.5"E

2.4 Statistical Analysis

The average values of three measurements were used to report the results. To inspect the equipment and reduce errors, blank and control standards were evaluated after each of the ten samples was examined. The significant differences between sample stations for various metal levels were analyzed using One-way ANOVA. Data analysis was conducted using Microsoft Excel 2019 and IBM SPSS Statistics 26.

3. Results and Discussions

3.1 Heavy Metals in Fish

In the liver of *Cyprinus carpio* at site A1, the maximum mean concentration of heavy metals in mg/kg: Pb (1.241), Cd (0.028), Hg (0.048), Cr (0.346), and Zn (0.589) was found during the post-monsoon period, whereas Cu (0.482) was found during the pre-monsoon period. In the liver of *Bagarius bagarius* at site A2, the maximum mean concentration of Pb (0.797), Cd (0.036), Hg (0.075), Cu (0.622), and Cr (0.844) was found during the post-monsoon period, whereas Zn (0.956) was found during the pre-monsoon period. In the liver of *Wallago attu* at

site A3, the maximum mean concentration of Pb (1.238), Cd (0.038), Hg (0.090), Cu (0.886), Cr (0.726), and Zn (0.820) was found during the post-monsoon period, which are presented in Table 1.

In the gills of *Cyprinus carpio* at site A1, the maximum mean concentration of heavy metals in mg/kg: Pb (0.844), Cd (0.019), Hg (0.045), Cu (0.405), and Zn (0.416) was found during the post-monsoon period, whereas Cr (0.120) was found during the pre-monsoon period. In the gills of *Bagarius bagarius* at site A2, the maximum mean concentration of Pb (0.902), Cd (0.034), Hg (0.047), Cu (0.426), and Cr (0.416) was found during the post-monsoon period, whereas Zn (0.813) was found during the pre-monsoon period. In the gills of *Wallago attu* at site A3, the maximum mean concentration of Pb (0.921), Cd (0.025), Hg (0.061), Cu (0.668), and Zn (0.713) was found during the post-monsoon period, whereas Cr (0.518) was found during the pre-monsoon period, which are presented in Table 2.

In the kidney of *Cyprinus carpio* at site A1, the maximum mean concentration of heavy metals in mg/kg: Hg (0.062), Cu (0.716), Cr (0.508), and Zn (0.816) was found during the post-monsoon period, whereas Pb (0.147) and Cd (0.031) were found during the pre-monsoon period. In the kidney of *Bagarius bagarius* at site A2, the maximum mean concentration of Pb (0.976), Cd (0.056), Hg (0.074), Cu (0.610), Cr (0.523), and Zn (0.976) was found during the post-monsoon period. In the kidney of *Wallago attu* at site A3, the maximum mean concentration of Pb (1.335), Cd (0.042), Hg (0.084), Cu (0.834), and Zn (1.040) was found during the post-monsoon period, whereas Cr (0.605) was found during the pre-monsoon period, which are presented in Table 3.

In the muscle of *Cyprinus carpio* at site A1, the maximum mean concentration of heavy metals in mg/kg: Pb (1.319), Cd (0.043), Hg (0.071), Cu (0.826), Cr (0.604), and Zn (0.813) was found during the post-monsoon period. In the muscle of *Bagarius bagarius* at site A2, the maximum mean concentration of Pb (1.133), Cd (0.059), Hg (0.081), Cu (0.655), Cr (0.618), and Zn (1.018) was found during the post-monsoon period. In the muscle of *Wallago attu* at site A3, the maximum mean concentration of Pb (1.333), Cd (0.059), Hg (0.081), Cu (0.655), Cr (0.618), and Zn (1.018) was found during the post-monsoon period, which are presented in Table 4.

The occurrence of heavy metals in fishes of the Ganga River was in order Pb> Zn > Cu > Cr > Hg > Cd. In the present study, the heavy metal bioaccumulation was higher in the post-monsoon and pre-monsoon seasons while lower in the monsoon season as reported by Sani *et al.,* and Tiwari *et al.*,[14,15] in their study. During the monsoon season, rivers are heavily flooded with rainwater, drastically affecting the system and resulting in the mixing of impure and pure waters. This leads to a decrease in serious metal concentrations, whereas an increase in metal concentrations during the summer and winter seasons could be due to drought and a reduction in water levels[16]. This phenomenon has been observed in various aquatic ecosystems worldwide and underscores the importance of understanding the hydrological dynamics in mediating heavy metal transport and accumulation[17]. The observed variations in heavy metal concentrations across different fish species, organs, and sampling periods are consistent with previous studies[18,19]. In the present study, a higher concentration of Pb and Zn was observed in all the organs of fishes which matches with many field studies by Zhao *et al.,* and Dural *et al*[20,21]. Pb was found above the maximum permissible limit in the liver, gill, kidney and muscle of all the fishes set by FAO/WHO[22] which is presented in Table 5. The tendency for the liver and kidney to accumulate higher concentrations of heavy metals compared to gills and muscle is well-documented due to their roles in detoxification and metabolism[23]. Pb sources of environmental contamination are from mining, smelting and reprocessing operations and as a combustion product of lead additives in gasoline[24]. Lead-acid batteries are extensively used in various applications, including automotive, industrial, and stationary power supply in the Haridwar region. Mining activities in the catchment area of the Ganga River can release lead and other heavy metals into the water through erosion, runoff, and leaching from mine tailings and waste dumps. The lowest concentration of Cd in organs of different fishes was similar to the finding for *Astacusastacus*[25]. Variations in heavy metal accumulation patterns among different fish species are consistent with their ecological niches, dietary preferences, and metabolic rates[26]. The higher concentrations of Pb, Cd, and Cr observed in *Bagarius bagarius* compared to other species could be linked to its habitat preferences and feeding behavior[27]. When organisms are exposed to high levels of metal in an aquatic environment, they can absorb the available metals directly from the aquatic environment via the gills or contaminated water media and through their food intake. This leads to accumulation in their tissues, entering the food chain and posing numerous health

issues to mankind[28]. The high levels of Pb, Cu and Zn in fishes of the Ganga River can be attributed to industrial and agricultural discharge[29]. The elevated concentrations of heavy metals in fish tissues pose significant risks to both aquatic organisms and human consumers[30]. Chronic exposure to Pb, Cd, and Hg through contaminated fish consumption can lead to adverse health effects, including neurological disorders and carcinogenicity[31]. The one-way ANOVA between groups for different heavy metals in the liver of fishes in the Ganga River was found significant ($p < 0.05$) for Pb, Hg, Cu, Cr, and Zn but non-significant for Cd. In gills, it was found significant for all the heavy metals, i.e., Pb, Cd, Hg, Cu, Cr, and Zn. In the kidney, it was significant for Pb, Hg, Cu, Cr, and Zn but non-significant for Cd. In muscle, it was significant for Pb, Hg, Cu, Cr, and Zn but non-significant for Cd. The significant differences observed in heavy metal concentrations among different organs of fishes highlight the variability in metal accumulation and distribution within the fish body. The liver, being a vital organ for detoxification and metabolism, tends to accumulate a wide range of heavy metals, reflecting its role in the detoxification process[19]. Gills, being in direct contact with the aquatic environment, serve as primary sites for metal uptake, thus showing significant accumulation of all heavy metals tested[26]. The kidney, responsible for the excretion and regulation of ions, also accumulates significant levels of heavy metals, indicating potential renal toxicity and metabolic disturbances[27]. Muscle tissue, often consumed by humans, also reflects variations in heavy metal accumulation among different fish groups, emphasizing the importance of monitoring and regulating heavy metal contamination for food safety[17].

3.2 Heavy Metals in Water

In water samples from site A1, the maximum mean concentration of Pb (0.950 mg/l), Cd (0.033 mg/l), Hg (0.011 mg/l), and Zn (0.437 mg/l) was observed during the post-monsoon season, while Cu (0.430 mg/l) and Cr (0.320 mg/l) were observed during the pre-monsoon season. The minimum mean concentrations of heavy metals Pb, Cd, Hg, Cu, Cr, and Zn were 0.632 mg/l, 0.006 mg/l, 0.003 mg/l, 0.250 mg/l, 0.210 mg/l, and 0.261 mg/l, respectively, during the monsoon season. At site A2, the maximum mean concentration of Cd (0.004 mg/l), Hg (0.004 mg/l), Cr (0.118 mg/l), and Zn (0.140 mg/l) was observed during the post-monsoon season, while Pb (0.329 mg/l) and Cu (0.291 mg/l) were observed during the pre-monsoon season. The minimum mean concentrations of heavy metals Pb, Cd, Cu, Cr, and Zn were 0.231 mg/l, 0.002 mg/l, 0.176 mg/l, 0.078 mg/l, and 0.092 mg/l, respectively, during the monsoon season, except for Hg, which was not determined. At site A3, the maximum mean concentration of Cd (0.027 mg/l), Hg (0.002 mg/l), Cr (0.064 mg/l), and Zn (0.249 mg/l) was observed during the post-monsoon season, while Pb (0.234 mg/l) and Cu (0.253 mg/l) were observed during the pre-monsoon season. The minimum mean concentrations of heavy metals Pb, Cd, Cu, Cr, and Zn were 0.186 mg/l, 0.003 mg/l, 0.143 mg/l, 0.023 mg/l, and 0.109 mg/l, respectively, during the monsoon season, except for Hg, which was not determined. These values are presented in Table 6.

The highest concentrations of Pb, Cd, Hg, Cu, Cr, and Zn were found at site A1, and the minimum at site A2, which may be related to the intensity of human activities, such as the volume of domestic sewage and industrial wastewater discharge[32] as Haridwar is the highly and densely populated district of Uttarakhand, lack of treatment in wastewater capacity[33], and increased level of heavy traffic activity because of holy and pilgrimage place of Uttarakhand. This variation could be attributed to differences in industrial activities, urbanization, agricultural runoff, and natural geological factors in the respective catchment areas of each site[34]. The high levels of Cu and Pb in Ganga water can be associated with industrial and agricultural discharge[29] and also matched the findings[35,36]. Higher levels of Pb often occur in aquatic pathways which are situated near highways and big cities due to elevated gasoline combustion which conforms with the findings[37]. The higher concentrations of heavy metals at site A1 could be associated with nearby industrial activities, including metal processing, manufacturing, and urban runoff from densely populated areas[38]. Site A2 might be influenced by agricultural practices, as evidenced by relatively lower concentrations of heavy metals compared to site A1 but higher than site A3. Pesticide and fertilizer runoff can contribute to heavy metal contamination in water bodies. Site A3, with the lowest concentrations of heavy metals, could be less impacted by anthropogenic activities and may have better water quality due to fewer sources of pollution. The lower concentration of heavy metals during monsoon months might be due to the dilution effect of water[39-41]. In general, a high concentration of metals in water samples was observed in the pre-monsoon and post-monsoon periods, and

Table 1. Mean concentration with a standard deviation of heavy metals in the liver of fishes (mg/kg) from sites A1, A2 and A3

Sites	Site A1			Site A2			Site A3		
Fish species	*Cyprinus carpio*			*Bagarius bagarius*			*Wallago attu*		
Element	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
Pb	1.198±0.034	1.115±0.033	1.241±0.109	0.776±0.039	0.738±0.038	0.797±0.028	1.237±0.016	1.111±0.101	1.238±0.038
Cd	0.024±0.004	0.018±0.004	0.028±0.005	0.032±0.004	0.026±0.005	0.036±0.003	0.033±0.006	0.025±0.009	0.038±0.009
Hg	0.048±0.005	0.035±0.008	0.048±0.009	0.068±0.005	0.064±0.006	0.075±0.003	0.077±0.008	0.076±0.009	0.090±0.011
Cu	0.482±0.048	0.344±0.076	0.464±0.092	0.606±0.031	0.566±0.033	0.622±0.017	0.867±0.042	0.823±0.069	0.886±0.054
Cr	0.302±0.036	0.282±0.044	0.346±0.036	0.842±0.030	0.786±0.048	0.844±0.038	0.696±0.038	0.678±0.043	0.726±0.018
Zn	0.556±0.023	0.528±0.012	0.589±0.036	0.956±0.030	0.870±0.045	0.946±0.053	0.788±0.036	0.748±0.065	0.820±0.038

Table 2. Mean concentration with standard deviation of heavy metals in Gill of fishes (mg/kg) from sites A1, A2 and A3

Sites	Site A1			Site A2			Site A3		
Fish species	*Cyprinus carpio*			*Bagarius bagarius*			*Wallago attu*		
Element	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
Pb	1.474±0.033	1.257±0.161	1.440±0.099	0.954±0.046	0.894±0.058	0.976±0.038	1.245±0.144	1.157±0.134	1.335±0.069
Cd	0.031±0.006	0.020±0.008	0.030±0.007	0.051±0.011	0.040±0.011	0.056±0.009	0.041±0.008	0.032±0.010	0.042±0.005
Hg	0.060±0.007	0.050±0.007	0.062±0.004	0.071±0.010	0.060±0.013	0.074±0.011	0.081±0.010	0.072±0.010	0.084±0.006
Cu	0.712±0.022	0.668±0.035	0.716±0.018	0.588±0.047	0.531±0.053	0.610±0.014	0.809±0.032	0.765±0.044	0.834±0.026
Cr	0.505±0.024	0.455±0.037	0.508±0.028	0.509±0.035	0.461±0.038	0.523±0.020	0.605±0.060	0.519±0.061	0.594±0.052
Zn	0.812±0.023	0.767±0.034	0.816±0.028	0.967±0.038	0.891±0.060	0.976±0.043	1.000±0.086	0.909±0.067	1.040±0.075

Table 3. Mean concentration with a standard deviation of heavy metals in the Kidney of fishes (mg/kg) from sites A1, A2 and A3

Sites	Site A1			Site A2			Site A3		
Fish species	*Cyprinus carpio*			*Bagarius bagarius*			*Wallago attu*		
Element	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
Pb	0.836±0.027	0.75±0.063	0.844±0.042	0.892±0.021	0.858±0.025	0.902±0.022	0.896±0.029	0.866±0.046	0.921±0.015
Cd	0.017±0.004	0.012±0.004	0.019±0.003	0.032±0.003	0.025±0.005	0.034±0.004	0.022±0.004	0.016±0.004	0.025±0.003
Hg	0.040±0.007	0.034±0.005	0.045±0.007	0.044±0.003	0.035±0.005	0.047±0.005	0.059±0.007	0.049±0.007	0.061±0.007
Cu	0.403±0.032	0.356±0.020	0.405±0.026	0.421±0.019	0.371±0.032	0.426±0.020	0.655±0.050	0.619±0.024	0.668±0.034
Cr	0.120±0.012	0.099±0.014	0.119±0.013	0.419±0.013	0.371±0.031	0.416±0.022	0.518±0.014	0.449±0.028	0.514±0.018
Zn	0.403±0.031	0.353±0.039	0.416±0.026	0.813±0.022	0.759±0.038	0.800±0.032	0.705±0.015	0.663±0.008	0.713±0.010

Table 4. Mean concentration with standard deviation of heavy metals in Muscle of fishes (mg/kg) from sites A1, A2 and A3

Sites	Site A1			Site A2			Site A3		
Fish species	*Cyprinus carpio*			*Bagarius bagarius*			*Wallago attu*		
Element	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
Pb	1.260±0.100	1.159±0.125	1.319±0.038	1.082±0.099	1.002±0.078	1.133±0.081	1.082±0.155	1.002±0.122	1.133±0.097
Cd	0.039±0.006	0.033±0.009	0.043±0.005	0.056±0.011	0.041±0.010	0.059±0.006	0.056±0.008	0.041±0.011	0.059±0.011
Hg	0.069±0.008	0.061±0.010	0.071±0.006	0.074±0.012	0.066±0.009	0.081±0.008	0.074±0.012	0.066±0.011	0.081±0.008
Cu	0.805±0.029	0.739±0.051	0.826±0.019	0.638±0.059	0.591±0.052	0.655±0.045	0.638±0.034	0.591±0.044	0.655±0.020
Cr	0.601±0.029	0.557±0.044	0.604±0.028	0.609±0.018	0.570±0.049	0.618±0.014	0.609±0.046	0.570±0.048	0.618±0.019
Zn	0.796±0.030	0.76±0.038	0.813±0.012	0.993±0.051	0.952±0.032	1.018±0.027	0.993±0.042	0.952±0.092	1.018±0.028

Table 5. Maximum Permissible Limit (MPL) of heavy metals in fishes (mg/kg)

Heavy Metal / Source	Pb	Cd	Hg	Cu	Cr	Zn
FAO/WHO (2004)	0.5	0.5	0.5	10	2	40

similar results were matched with earlier studies on heavy metal concentration in Pulicat Lake water[42]. Elevated concentrations of heavy metals in water samples pose potential risks to aquatic ecosystems, including adverse effects on aquatic organisms' health and biodiversity[43]. Additionally, heavy metals can bioaccumulate in aquatic organisms and enter the food chain, posing risks to human health through the consumption of contaminated water and aquatic products[44]. The heavy metals in Ganga River water were found in the order: Pb> Cu> Zn> Cr> Cd> Hg which matches with findings[45]. The level of Pb& Cr at site A1 in Ganga River water was found above the maximum permissible limit recommended by WHO[46] which is presented in Table 7. Prolonged exposure to lead and chromium through drinking water can result in chronic health issues such as kidney damage, liver dysfunction, respiratory illnesses, and increased cancer risk[47].

3.3 Heavy Metals in Macophyte (*Eichornia crassipes*)

The prospering presence of aquatic macrophytes in contaminated waters is typically because of their behaviour to bio-accumulate metal concentrations larger than the adjacent water[48]. In macrophyte (*E. crassipes)* the maximum mean concentration of heavy metals Pb (2.323 mg/kg), Cd (0.137 mg/kg), Hg (0.268 mg/kg), Cu (1.161 mg/kg), Cr (2.635 mg/kg) and Zn (5.980 mg/kg) was observed from site A1 while lowest at site A2 which are presented in Table 8. The various phylogenesis activities in combination with land-use patterns (activities related to vehicles, use of fertiliser and pesticides for agricultural practices, urban farming and domestic waste disposals) around site A1 may be associated with the elevated pollution in the river. The highest concentration of Pb, Cr and Zn was recorded at site A1 similar has been reported earlier in *C. demersum*[49,50]. This spatial variability could be attributed to differences in upstream sources of pollution, industrial activities, and urbanization in the respective catchment areas of each site[27]. Cr was found in higher concentrations and it affects several processes in plants, namely seed germination,

Table 6. Mean concentration with standard deviation of heavy metals in water (mg/l) from sites A1, A2 and A3

Sites	Site A1			Site A2			Site A3		
Element	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
Pb	0.873±0.088	0.632±0.096	0.950±0.108	0.329±0.099	0.231±0.078	0.306±0.081	0.234±0.015	0.186±0.009	0.231±0.022
Cd	0.009±0.003	0.006±0.001	0.033±0.038	0.001±0.001	0.002±0.001	0.004±0.002	0.002±0.001	0.003±0.001	0.027±0.035
Hg	0.004±0.001	0.003±0.001	0.011±0.013	0.001±0.001	ND	0.004±0.004	ND	ND	0.002±0.001
Cu	0.430±0.041	0.250±0.053	0.421±0.049	0.291±0.059	0.176±0.015	0.258±0.030	0.253±0.056	0.143±0.063	0.249±0.020
Cr	0.320±0.041	0.210±0.016	0.293±0.031	0.109±0.007	0.078±0.017	0.118±0.006	0.046±0.005	0.023±0.022	0.064±0.019
Zn	0.373±0.025	0.261±0.048	0.437±0.051	0.124±0.009	0.092±0.016	0.140±0.048	0.132±0.011	0.109±0.017	0.249±0.070

Note: ND= Not Detected

growth, yield and also physiological processes such as photosynthesis impairment and nutrient and oxidative imbalances[51]. Furthermore, macrophytes play essential roles in nutrient cycling, habitat provision, and water quality improvement. Heavy metal contamination in macrophytes can impair these ecosystem services and disrupt ecological processes[52]. Pb, Zn and Cr contamination may also stem from industrial effluents, particularly from metal plating, tanning, and leather industries located in the vicinity of site A1. The order of occurrence of heavy metal in the macrophyte of Ganga River was found in order: Zn > Cr > Pb > Cu > Hg > Cd. This reflects the relative abundance of these metals in the environment and their uptake and accumulation by the macrophyte. This order aligns with previous studies that have shown certain heavy metals, such as zinc and chromium, to be more readily accumulated by aquatic plants compared to others[53]. Similar metal accumulation patterns were observed in *Myriophyllum spicatum* growing in contaminated water sources in Egypt[54], in *E. crassipus, Ceratophyllum demersum, and Typhadomengensis* growing naturally in the waters of river Nile[55], and *E. crassipus*, *Pistia stratiotes, M. quadrifolia* in an anthropogenic lake in India[56]. The concentrations of the metals found are low compared to values reported in other studies[57],[58]. Zn is an essential element for plants and is normally present at concentrations of 10-200mg/kg[59]. One-way ANOVA for heavy metal in the macrophyte of the Ganga River shows a significant difference ($p>0.05$) between different locations for all the heavy metals. Pb and Cr were found above the recommended level set by WHO[60] in *Eichornia crassipes* of the Ganga river, as given in Table 9. The elevated concentrations of lead (Pb) and chromium (Cr) in macrophyte samples exceeding the recommended levels indicate significant contamination of these heavy metals in the Ganga River ecosystem. Macrophytes play a crucial role in the aquatic environment by providing habitat, stabilizing sediments, and removing pollutants through bioaccumulation and phytoremediation processes. However, their contamination with heavy metals compromises their ecological functions[61].

Table 7. Maximum Permissible Limit (MPL) of heavy metals in water (mg/L)

Heavy Metal / Source	Pb	Cd	Hg	Cu	Cr	Zn
WHO (2006)	**0.01**	**0.003**	**0.006**	**2**	**0.05**	**3**

Table 8. Mean concentration with standard deviation of heavy metals in macrophyte (mg/kg) from sites A1, A2 and A3

Sites	Site A1			Site A2			Site A3		
Element	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**
Pb	2.323±0.068	2.183±0.243	2.318±0.125	1.928±0.070	1.843±0.300	1.943±0.157	2.133±0.107	2.160±0.186	2.228±0.069
Cd	0.132±0.007	0.129±0.020	0.137±0.011	0.109±0.009	0.114±0.020	0.115±0.011	0.117±0.005	0.116±0.013	0.127±0.006
Hg	0.266±0.010	0.224±0.012	0.268±0.026	0.191±0.005	0.179±0.025	0.199±0.019	0.224±0.011	0.223±0.028	0.235±0.006
Cu	1.154±0.009	1.155±0.021	1.161±0.013	1.033±0.012	1.032±0.035	1.032±0.018	1.118±0.003	1.104±0.022	1.126±0.006
Cr	2.635±0.095	2.343±0.422	2.528±0.318	2.205±0.010	2.003±0.276	2.215±0.169	2.353±0.068	2.090±0.318	2.303±0.227
Zn	5.940±0.072	5.668±0.388	5.980±0.162	4.995±0.153	4.915±0.354	5.110±0.188	5.328±0.099	5.175±0.408	5.295±0.099

Table 9. Maximum permissible limit (MPL) of heavy metals in macrophytes (mg/kg)

Heavy Metal / Source	Pb	Cd	Hg	Cu	Cr	Zn
WHO (1996)	2	0.5	-	40	1.30	60

4. Conclusion

In conclusion, significant differences were identified among the liver, gill, kidney, and muscle tissues of the fish from all sites of the rivers. The level of Pb in fishes of the Ganga River was found to be above the recommended level of FAO/WHO[22], indicating they are not safe for consumption regularly. The capability of bioaccumulation of heavy metals by fishes and macrophytes (*E. crassipes*) indicates that they can be used as bioindicators of pollution. The Ganga River should be continuously monitored in potentially polluted areas since collected fish showed a tendency to accumulate Pb. In animals, lead exhibits toxicity in several organs, damaging the nervous, renal, reproductive, organic processes, and vascular systems when ingested, inhaled, or absorbed through the skin. Fish uptake leads from both water and sediment; bioaccumulation within the food chain poses a hazard to fish, birds, marine mammals, and individuals. There is a need for rigorous government policy and monitoring for effluent discharge from industries, and adopting techniques like reutilization, recycling, renovation, and recharge of commercial effluent."

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6. Data Availability

The data that support the findings of this study are available on request from the corresponding author Sumit Kumar. The data are not publicly available due to containing information that could compromise research participant privacy/consent.

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