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Study on potential sources of heavy metal contamination and their bioaccumulation in fish species in the Gomati River

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ABSTRACT

This study assesses the health risks to humans from six heavy metals (lead, chromium, copper, cadmium, arsenic, and mercury) in two common fish species, Channa punctatus and Heteropneustesfossilis, collected from surface water and sediment at Pakkapul, Hanuman Setu, and Gomti Barrage in Lucknow, India. The highest chromium concentration was in Gomti Barrage silt (1.69 mg/l), while lead levels were highest at Hanuman Setu silt (1.81 mg/l). Although lead concentrations were below acceptable criteria at all locations, chromium, cadmium, arsenic, and mercury levels in the river water exceeded safe limits. Copper levels remained within acceptable ranges. The WHO reported that lead, cadmium, and chromium levels in fish tissues surpassed safe limits, with the highest lead concentrations in the liver of C. punctatus (75.273 µg/g) and the gills of H. fossilis (129.435 µg/g). The accumulation order of metals in tissues was Pb > Cd > Cr > As.

Key words: Heavy metals, *Channa punctatus*, *Heteropnuestesfossilis,* liver, gill

INTRODUCTION

Gomat Taal, formerly known as Fulhaar Jheel, is the birthplace of the Gomti. It is located close to Madho Tanda in Pilibhit, India (Taslima *et al.,* 2022). It runs 900 km through Uttar Pradesh before joining the Ganges River close to Gazipur's Saidpur Kaithi. It covers over 22,735 square kilometres with water. The Gomti goes over 240 km before entering Lucknow, where it continues for 16 km. The most well-known of the 15 towns in the Gomti's catchment region are the city of Lucknow, Lakhimpur Kheri, Sultanpur, and Jaunpur, which are situated on its banks. Because it mostly depends on the presence of rain, the river's flow is extremely forgiving during the monsoon season. As the river passes through Uttar Pradesh's densely populated regions, which are home to almost 18 million people, it gathers a lot of industrial and human pollutants (Chaudhary et al, 2023). The Gomti's environment is negatively impacted by high pollution levels, endangering its aquatic life. Gomti receives garbage from Sitapur's sugar and distillery businesses before arriving in Lucknow. In addition to home wastewater, all industries, including the dairy, distillery, and vegetable oil sectors, release their effluent straight into the Gomti River (Shahjahan *et al.,* 2022). The main threat to river biodiversity is pollution, particularly from partly and unprocessed garbage. Uttar Pradesh contributes the largest amount of wastewater (3289 MLD, 45 drains). Heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, and Zn) and sediments from industrial wastes (Srivastava *et al.,* 2011), sewage effluent (Yadav *et al.,* 2012), agricultural runoff, and household wastes (Pali *et al.,* 2022) have been found in river water before (Namdev and Singh, 2012). Toxic metal pollution of the environment has spread around the planet, impacting soil fertility, biomass, and agricultural yields while also causing bioaccumulation and biomagnifications throughout the chain (Prasad, 2011).The primary pollutants found in foods and beverages are lead, cadmium, arsenic, and mercury, each of which has its own permissible limit (Mishra *et al.,* 2023). From 2006 to 2008, the River Gomti showed high concentrations of all metals, including Cr, Cu, Ni, Pd, and Zn (Mishra and Mishra, 2008). Drinking water that has heavy metal traces in it is harmful to your health. Heavy metal bioaccumulation also affects freshwater fish (Vinodhini and Narayanan, 2008).Heavy metals in fish cause structural damage, alter condition markers, and cause genetic material damage, impacting their biodiversity, despite their high number of

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species (Bharti *et al.,* 2024). Fish is a staple diet for many people around the world. The amount of fish consumed annually per person worldwide has increased to about 20 kg (FAO, 2016). The majority of residents who live close to riverbanks rely on fish as a source of protein. About 50% of the world's fish consumption occurs in India, where the general population consumes 5–6 kg of fish annually and the fish-eating population consumes 8–9 kg (Salim, 2016). 6.57 million tons come from current inland fish output. The Gomati River provides its residents with a significant amount of fish. This river is home to many kinds of fish, including *Heteropnuestesfossilis* and *Channa punctatus*. The main sources of protein for the human diet are all of the fish listed above. Kidney and bone damage, neurological conditions, endocrine disruption, cardiovascular dysfunction, and carcinogenic consequences are the main health hazards associated with metal toxicity (Renieri *et al.,* 2019). Some of these heavy metals must exist within a specific concentration range because they are vital to the biological system. For instance, humans require iron (Fe), cobalt (Co), and manganese (Mn) for several physiological and metabolic processes. Other heavy metals that can cause contact dermatitis, lung fibrosis, cardiovascular and kidney illnesses, and lung and nasal malignancies include mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), and nickel (Ni) (Ali and Khan, 2018; Maurya *et al.,* 2019). Fish and water samples from Lucknow's urban and city core were gathered for this study at various locations, including Khadra Pakka Pul, Hanuman Setu, and Gomti Barrage. Therefore, the present study was undertaken to determine: (1) the concentration of non-essential heavy metals in the water and sediments of the Gomti River in Lucknow, and (2) the metal load of Cu, Zn, Fe, Mn, Ni, Pb, and Cd in the tissue of the chosen fish's muscles, gills, liver, and gonads.

MATERIAL AND METHODS

Study area

A tributary of the Ganga River is the Gomti River. The Gomti meanders for roughly 12 miles as it enters Lucknow, which is around 240 km away. For the investigation, a 9-kilometer section of the Gomti was chosen. Six sampling locations were chosen, including the surface and sediment-water at Pakkapul, Hanuman Setu, and Gomti Barrage, respectively. The concentration of various contaminants, including heavy metals, in the riverine water is rising as a result of the partial or complete pre-treatment of industrial effluents and household sewage/wastes that are dumped into these rivers. There are three distinct seasons in the Gomati River region: summer (March-June), monsoon (June-September), and winter (November-February). These rivers deposit fine and very fine sand-dominated sediments in their active channel and floodplain sections during the post-monsoon decline phase, which often impacts local population life and agricultural practices.

COLLECTION OF SAMPLE

Water samples

A total of 108 water and sediment samples were collected seasonally during 2020–21, with six samples taken from each site in each season. One liter of water was gathered in polyethylene bottles, which were rinsed twice with deionized water. The samples were kept in an icebox and transported to the lab for further examination. .

Fish samples

In 2020–21, local fishermen from each study site-Pakkapul, Hanuman Setu, and Gomti barrage, surface and sediment-water, respectively-collected two sexually mature fish species based on their high consumption by the local community (Table 1). To prevent any skin infections, they will be transported to the lab in plastic containers with wide mouths and treated for two to five minutes with a 0.05% $KMnO_4$ solution. Using 100 L well-aerated glass aquariums (100×40×40 cm3) filled with 40 L of 7-day-aged tap water, fish will be acclimated to laboratory conditions (hardness 72.90 as $CaCO_3$ mg/L, dissolved oxygen (DO) 7.1 mg/L, total dissolved solids (TDS) 197.89 mg/L, pH 6.9, and temperature 27 ± 3 oC) for 10 days, as per standard protocol (APHA *et al.,* 2012). Fresh goat liver and commercial aquarium food pallets made by Perfect

Companion Group Company Limited in Thailand will be served to them twice a day. 24 hours before the start of the experiment, feeding will be discontinued. Three groups of fish—two experimental and one control—each with 15 specimens will be housed in different aquariums for the in vivo tests.

They will be provided with the aforementioned feeding material once a week during the studies. For 45 days, the fish in each experimental group will be kept in triplicate in different aquariums and exposed continually in a semi-static condition. Glass aquariums will then be evacuated every day to ensure that all waste and excretory materials are removed (Palermo *et al.,* 2015). The same relative concentration of the test chemical will be applied to the specimens again in their aquariums. Fish will be subjected to two sub-lethal test doses to estimate cellular distresses: 3.93 mg/L (5% of 96 h-LC50 of chromium trioxide for T1 group) and 7.85 mg/L (10% of 96 h-LC50 of chromium trioxide for T2 group). Samples of tissues will be taken at intervals of 0, 15, 30, and 45 days after exposure. Three fish from each replication of a group will be anaesthetized with 0.1% (v/w) diethyl ether on the day of sampling. The fish will then have their hearts punctured using a heparinized syringe to extract their blood, which will be preserved in vials coated with EDTA (1.8 mg/mL) for the MN test. After that, the fish will be put down so that the liver tissues may be removed.

Table 1: The measurement of ecological characteristics and morphometric (biometrics) of selected fish species

Common Name	Scientific name	Habitat	Feeding Behaviour	Conservation Status	No of Samples	Length (cm)	Weight (gm)
Murrel	*Channa punctatus*	Inhabit large freshwater, bottom water- feeders	Mainly carnivorous, phytoplankton, and Zooplankton	Least Concern	10-25	9-25	25-155
Catfish	*Heteropnuestesfos silis*	Surface and bottom water- feeders	Mainly omnivorous	Least Concern	15-28	9-30	80-170

Instruments and reagents

Cu, Zn, Fe, Mn, Ni, Pb, and Cd were measured in the samples using a Varian AA240 atomic absorption spectrometer (AAS) with Zeeman background correction system and a graphite furnace (GTA 120). Acetylene and standard gases have respective purity levels of 99.99% and 99.999%. Zn (213.8 nm and slit 0.5), Pb (283.3 nm and slit 0.5 nm), Cu (324.75 nm and slit 0.5 nm), Cd (228.8 nm and slit 0.5 nm), and Cr (248.3 nm and slit 0.5 nm) were all detected using hollow cathode lamps. The instrument was used in accordance with the manufacturer's instructions. Zn, Pb, Cu, Cd, and Cr atomic signals were measured in peak area mood. A Bio Technics BTI-22 9 hotplate was used to carry out the digestions. Deionized water was used to prepare each solution (18 MΩ/cm). Before being used, all containers and glassware were cleaned by soaking in 20% nitric acid for 24 hours and then washed twice with deionized water.

Sample digestion

Water: Concentrated HNO_3 (20 ml) was used to digest 100 ml of filtered water samples at 100 0C. After cooling to room temperature, the digested water was diluted and passed through the Whatmann-42 filter paper. The samples were prepared for analysis after the filtrate was produced up to 50 ml using 0.01 N nitric acid.

Fish: On a heated plate, 5 g of dried identifiable tissue was digested for 4–6 hours in analytical grade HNO3:HClO4:HCl (3:2:9). Following digestion, the samples were allowed to cool before being filtered using Whatman No. 42 filter paper. For analysis, the samples were diluted with 50 millilitres of distilled water.

Experimental analysis

A portable meter was used to monitor the temperature and pH on-site. A multimeter water checker (Horiba U-10) and a DO data meter (EutechCyberScan DO 3000) were used to measure turbidity and dissolved oxygen (DO) in nephelometric units (NTUs). The volumetric titration technique was used to measure the total hardness (TH) and total dissolved solids content (APHA, 1995). The following formula was used to determine the amount of heavy metals present in the water sample (APHA, 1998).

Heavy metal concentration (μg/ml) = AAS reading × V/ Volume of the sample (ml)
where, V = volume of dilution solution
The concentration of heavy metals in fish tissue was calculated using the following formula: Heavy metal concentration (μg/ml) = AAS reading ×V/Volume of the sample (ml)
where, V = volume of diluted solution

Bioaccumulation factor

The ratio of the concentration of heavy metals in fish organs to that in water is known as the bioaccumulation factor, or BAF. The Lau *et al.* (1998) formula was used to calculate BAF.
BAF = Concentration of heavy metals in fish concentrations of heavy metals in water

Statistical analysis

The statistical software SPSS (version 16.0) was used to statistically evaluate the data. The metal concentrations in fish species were estimated as mean ± standard deviations. In terms of the correlation coefficient level, a statistically significant difference between the groups was considered to exist if $p < 0.05$.

RESULT AND DISCUSSION

Analysis of physicochemical parameters

Table 2 displays the findings of the physicochemical characteristics of surface and sediment-water samples taken from the Pakkapul, Hanuman Setu, and Gomti barrages, respectively. With an average temperature of 17.40 °C, the river water's temperature was found to range between 16.12 and 18.69 °C. The samples' pH readings had a mean of 8.13 and varied from 7.80 to 8.47. Another research found that the Gomati water between the Gaughat and Gomati barrage ranged from 6.88 to 8.59, with an average of 7.73 (Kumar *et al.,* 2013). This might be because the region drains more sewage water and industrial waste than the other locations. River water samples' rising pH levels were caused by an increase in the pollutant load. Water extracted from the river's other sections often had higher pH values than the water at sewage disposal stations. The pH range was 6.5 to 8.5, which is suitable for drinking water. Drinking beverages that are too acidic or alkaline can upset the delicate equilibrium of the body, leading to infection, sickness, and disease. A nutritional imbalance or the presence of a poisonous ion that corrodes sprinkler pipes might result from irrigation water with a pH outside of the typical range.

Table 2: Physico-chemical parameters of the Gomati River water sample at different sites

Parameters	Khadra pakka pul surface water	Khadra pakka pul sediment	Hanuman setu surface water	Hanuman setu sediment	Gomti barrage surface water	Gomti barrage sediment	BIS, 1993
Tem (°C)	16.22 ± 0.22	16.12 ± 0.18	17.46 ± 0.34	18.37 ± 0.41	18. 69 ± 0.28	17.98 ± 0.19	20-30
pH	8.30 ± 0.23	8.45 ± 0.21	7.80 ± 0.17	7.87 ± 0.19	8.28 ± 0.27	8.47 ± 0.29	6.5-8.5
Total dissolved solids (mg/l)	480 ± 9.24	481 ± 9.56	440 ± 7.65	437 ± 7.95	497 ± 5.14	886 ± 10.50	
Total hardness (mg/l)	249.54±7.65	265.33± 6.78	183.34 ± 5.67	191.43± 7.45	161.23 ± 5.69	178.43± 9.87	600
Turbidity	2.8 ± 0.06	2.98 ± 012	3.16 ± 0.18	3.67 ± 0.24	3.56 ± 0.42	3.83 ± 0.12	5
DO (mg/l)	8.32 ± 0.18	7.83 ± 0.24	7.67 ± 0.29	6.45 ± 0.61	7.14 ± 0.67	6.67 ± 0.45	-
BOD (mg/l)	9.62 ± 0.12	19.85 ± 2.45	16.18 ± 1.94	24.12 ± 2.21	20.06 ± 1.16	26.28 ± 2.21	-

As seen in the current study at six sample locations of the Lucknow stretch, Gomati water has a considerable buffering ability but also ties its water on the upper side of neutral pH. This suggests that the alkaline character of the water sample is not only marginally harmful to fish (Khan *et al.,* 2020), but also detrimental to human health (Yadav *et al.,* 2012). But for fisheries and aquatic life, the European Union set pH protection limits of 6.0 to 9.0 (Chapman, 1996). The Bureau of Indian Standards (BIS) states that water is safe if its turbidity is less than 5 NTU (BIS, 1993). The reported total soluble solids ranged from 437 to 886 mg/l. As the pollution load increases, the total soluble solids in Gomati water continue to rise. According to Gupta *et al.* (2013), a high total soluble solids value suggests that the water body contains strong bases and weak acids in the form of hydroxides, bicarbonates, and carbonates. High concentrations of dissolved calcium, magnesium, and other mineral salts, including iron, are referred to as hard water. Throughout the sampling site, the hardness values ranged from 161.23 to 265.33 mg/l, with an average of 213.28 mg/l. According to BIS, the chosen site had a relatively high total hardness content (600 mg/l).

Water purity is determined by the DO measurement. Water quality studies and the regular operation of water reclamation facilities both employ the quantity of DO, which is a measure of the biological activity of the water masses. The River Gomati's DO level at the chosen location for this investigation was rather low. 6.45–8.32 mg/l, with a mean DO of 7.38 mg/l throughout the investigation. It was found that organic matter, depth, temperature, and turbulence all significantly affect the DO content in Gomati River water. DO falls to its lowest level because bacteria usually utilize it for breakdown. A drop in the DO volume was a sign of the river's organic pollution burden, albeit it might simply be the result of rising temperatures.

Throughout the research, the biological oxygen demand (BOD) values ranged from 9.62 to 26.28 mg/l. Because the sewage line in this area combined at the sampling location, the Gomati barrage sediment sample had the highest BOD value of 26.28 ± 2.21 mg/l during the current investigation. The rise in organic pollution from untreated home sewage, agricultural runoff, and leftover fertilizers might be the cause of the elevated BOD in the water. For plants and microbes to survive, CO2 is essential. The respiration of aquatic creatures produces it. The primary cause of the elevated CO2 levels in water bodies is the respiration of aquatic plants, the addition of a significant quantity of sewage, and the breakdown and decomposition of organic waste.

Table 3: Heavy metals concentration (mg/L) in River Gomati water at selected sites

Heavy metals	Seasons	Khadra pakka pul surface water	Khadra pakka pul sediment	Hanuman setu surface water	Hanuman setu sediment	Gomti barrage surface water	Gomti barrage sediment	WHO, 2011
Cr	Monsoon	0.12 ± 0.03	0.44 ± 0.26	0.17 ± 0.06	0.38 ± 0.11	0.18 ± 0.07	0.92 ± 0.35	0.05
	Winter	0.15 ± 0.04	0.78 ± 0.28	0.16 ± 0.03	0.59 ± 0.14	0.21 ± 0.09	1.05 ± 0.29	
	Summer	0.18 ± 0.04	0.79 ± 0.11	0.21 ± 0.06	0.71 ± 0.21	0.32 ± 0.11	1.69 ± 0.47	
Cu	Monsoon	0.17 ± 0.04	0.26 ± 0.06	0.24 ± 0.07	0.47 ± 0.12	0.21 ± 0.05	0.27 ± 0.07	1.5
	Winter	0.22 ± 0.04	0.43 ± 0.07	0.28 ± 0.09	0.99 ± 0.33	0.26 ± 0.15	0.86 ± 0.36	
	Summer	0.36 ± 0.19	1.13 ± 0.67	0.45 ± 0.12	0.87 ± 0.23	0.39 ± 0.16	0.78 ± 0.45	
Cd	Monsoon	0.02 ± 0.01	0.11 ± 0.02	0.014 ± 0.03	0.12 ± 0.07	0.021 ± 0.09	0.16 ± 0.07	0.005
	Winter	0.05 ± 0.02	0.14 ± 0.05	0.02 ± 0.001	0.16 ± 0.04	0.02 ± 0.001	0.25 ± 0.06	
	Summer	0.09 ± 0.02	0.12 ± 0.03	0.08 ± 0.02	0.15 ± 0.06	0.09 ± 0.03	0.19 ± 0.04	
Pb	Monsoon	0.08 ± 0.02	0.15 ± 0.04	0.04 ± 0.01	0.08 ± 0.02	0.15 ± 0.04	0.88 ± 0.24	0.01
	Winter	0.06 ± 0.02	0.19 ± 0.06	0.08 ± 0.03	0.26 ± 0.09	0.16 ± 0.08	0.34 ± 0.13	
	Summer	0.14 ± 0.05	0.69 ± 0.13	0.57 ± 0.14	1.81 ± 0.48	0.45 ± 0.12	0.94 ± 0.19	
Hg	Monsoon	0.0005 ± 0.00001	0.0 ± 0.00001	0.0 ± 0.00	0.0 ± 0.00	0.00025 ± 0.00001	0.0 ± 0.00	0.001
	Winter	0.0006 ± 0.00001	0.008 ± 0.001	0.0009 ± 0.002	0.007 ± 0.001	0.0002 ± 0.0001	0.01 ± 0.003	
	Summer	0.0009 ± 0.00001	0.01 ± 0.001	0.005 ± 0.001	0.003 ± 0.001	0.0009 ± 0.0001	0.70 ± 0. 25	
As	Monsoon	0.005 ± 0.001	0.0007 ± 0.001	0.0056 ± 0.002	0.0015 ± 0.001	0.0057 ± 0.001	0.0043 ± 0.002	0.001
	Winter	0.004 ± 0.001	0.008 ± 0.001	0.006 ± 0.001	0.01 ± 0.001	0.006 ± 0.002	0.014 ± 0.003	
	Summer	0.007± 0.001	0.004 ± 0.001	0.0086 ± 0.001	0.0198 ± 0.001	0.007 ± 0.001	0.019 ± 0.001	

Table 3 shows the levels of heavy metals in water and sediment samples from six chosen locations during the monsoon, winter, and summer seasons of the Gomati River. The following ranges of heavy metal concentrations were noted: Cu: 0.17–0.47 mg/l during the monsoon; 0.22-0.99 mg/l during the winter and 0.36–1.13 during the summer; Cr: 0.12–0.92 mg/l during the monsoon; 0.15–1.05 92 mg/l during the winter; and 0.08–0.19 92 mg/l during the summer; Pb: 0.04-0.88 mg/l during the monsoon; 0.06-0.34 mg/l during the winter; and 0.14-1.81 mg/l during the summer; Hg: 0.00–0.0005 mg/l during the monsoon; 0.0002-0.01 mg/l during the winter; and 0.0009–0.70 mg/l during the summer; and As: 0.0015–0.005 mg/l during the monsoon; 0.004-0.01 mg/l during the winter; 0.004-0.019 mg/l during the summer.

The average levels of heavy metals in the water of the Gomati River at various locations were as follows: Gomati barrage surface water: Pb > Cu > Cr > Cd > As > Hg; Gomati barrage sediment: Cr > Pb > Cu > Hg > Cd > As; Hanuman Setu surface water and sediment: Pb > Cu > Cr > Cd > As > Hg; and Khadra pakkapul surface water: Cu > Cr > Pb > Cd > As > Hg.

All of the chosen heavy metals in this investigation, except Cu, were found to be beyond the World Health Organization's (WHO) allowable limits. The Gomati barrage sediment site exhibited the greatest concentration of Cr (1.69 mg/l) in the water of the Gomati River, followed by the Khadra Pakka Pul sediment (0.79 mg/l) and the Hanuman Setu sediment sites (0.71 mg/l) (Table 3). The Hanuman Setu sediment sites had the greatest Pb content (1.81 mg/l), followed by the Gomati Barrage sediment site (0.94 mg/l). The Khadra Pakka Pul sediment site had the lowest Pb value (0.69 mg/l). The Gomati barrage sediment site and the Hanuman Setu surface water monitoring sites had the greatest and lowest levels of Cd contents, respectively, at 0.25 and 0.014 mg/l. The Gomati barrage sediment location has the greatest and lowest Hg values (0.70 & 0.00 mg/l). The Hanuman Setu sediment site had the highest quantities, at 0.007 mg/l, while the Khadra Pakka surface water and sediment location had the lowest values, at 0.004 mg/l. At the Gomati barrage sediment site, Hanuman Setu sediment site, and Khadra Pakka sediment site, the Cu concentrations were 1.13, 0.99, and 0.86 mg/l, respectively. At many locations, the Cu levels were measured below the allowable limits.

The metal's interactions with water, sediments, and aquatic life forms, as well as their interactions with other metals and environmental factors, greatly influence the movement of heavy metals in the environment (Atobatelea and Olutona, *et al.,* 2015; Hosseini *et al.,* 2019). The other heavy metal loadings were found to be significantly regulated by the solid particles and their transportation through particulate matter in the aquatic ecosystem. Borovec (2000) examined the effect of grain size distribution in the transport of lead, zinc, copper, and chromium. According to the current study's findings, human waste—particularly industrial effluent discharge and agricultural runoff—is dumped into the Ganga River, causing the water to become seasonally contaminated with heavy metals. The buildup of these persistent pollutants poses a serious threat to fish health.

Analysis of heavy metal concentrations in fish tissue

The two fish species had heavy metal concentrations in the following order: liver > gill > muscle > gonads. Around the world, people mostly eat the muscles of fish. The fish species *C. punctatus* and *H. fossilis* are widely consumed in Lucknow and are important sources of protein. Therefore, a few species were chosen for this investigation and were examined for various metals. The two fish species under study had the greatest Pb loads. In practically every fish species, the trend for heavy metal concentrations was Pb > Cr > Cd > As. The current study's findings also supported those found in Javed and Usmani (2013) and Begum *et al.* (2013). However, trophic transfer has a species-specific function in the amount of bioaccumulation (Spry and Wiener, 1991).

Significant differences in the amounts of heavy metals among the several species were found in the current study. The greatest quantities of nearly all four metals were found in *H. fossilis* compared to *C. punctatus* (Table 4). This resulted from these species' bigger size (higher biomass); larger fish tend to collect more heavy metals (Maurya and Malik, 2016). Furthermore, this is most likely caused by variations in the age of the chosen fish species as well as variations in the heavy metal content in the surrounding water medium. Furthermore, temperature, pH, and metal speciation in the aquatic system must all be taken into account when analyzing metal accumulation (Dhanakumar *et al.,* 2015).

Table 4: Concentrations of heavy metals (µg/g wet weight) in some organs of fish species collected from the Ganga River (Mean (± SD)

Fish species	Fish Tissues	Heavy Metal/Seasons											
		Cr			Cd			Pb			As		
		Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer
C. punctatus	Liver	8.933 ± 1.22	44.186 ± 3.87	6.419 ± 0.44	4.415± 0.98	50.215 ± 6.78	1.301 ± 0.98	33.585 ± 2.21	75.273 ± 5.02	13.457 ± 1.06	0.021 ± 0.003	0.191 ± 0.004	0.013 ± 0.001
	Muscles	2.395 ± 0.67	2.472 ± 0.87	4.976 ± 0.98	2.473 ± 0.78	1.291 ± 0.34	1.868 ± 0.56	7.496 ± 1.09	7.505 ± 1.02	9.358 ± 1.25	0.016 ± 0.001	0.008 ± 0.001	0.006 ± 0.001
	Gills	7.556 ± 1.34	3.167 ± 1.23	3.533 ± 0.87	9.946 ± 1.16	1.838 ± 0.99	2.586 ± 0.54	35.485 ± 4.32	10.781 ± 1.12	8.513 ± 1.04	0.032 ± 0.001	0.231 ± 0.001	0.021 ± 0.001
	Gonads	10.94 ± 2.12	7.291 ±	2.694 ± 0.98	8.666 ± 1.54	6.373 ± 1.67	1.658 ± 0.18	21.113 ± 2.45	19.523 ± 1.02	11.518 ± 1.44	0.045 ± 0.003	0.011 ± 0.002	0.003 ± 0.001
H. fossilis	Liver	3.468 ± 1.15	10. 275 ± 1.87	19.488 ± 1.98	1.996 ± 0.65	3.006 ± 1.09	4.496 ± 1.13	2.921 ± 0.68	3.246 ± 1.02	36.518 ± 3.28	0.012 ± 0.001	0.026 ± 0.001	0.055 ± 0.002
	Muscles	3.443 ± 1.06	9.831 ± 1.89	4.375 ± 0.87	2.378 ± 0.67	1.846 ± 0.45	5.248 ± 1.33	9.548 ± 1.34	3.128 ± 1.02	6.258 ± 2.13	0.068 ± 0.001	0.015 ± 0.001	0.032 ± 0.001
	Gills	26.186 ± 4.67	26.426 ± 8.67	12.591 ± 1.38	83.318 ± 6.79	8.618 ± 1.32	3.356 ± 1.26	16.308 ± 1.78	129.435 ± 7.87	27.915 ± 1.28	0.146 ± 0.001	0.073 ± 0.002	0.014 ± 0.002
	Gonads	27.973 ± 7.75	21.416 ± 9.87	94.393 ± 8.97	10.113 ± 2.22	12.528 ± 3.14	16.525 ± 2.67	23.251 ± 1.22	8.513 ± 1.02	20.823 ± 2.22	0.089 ± 0.002	0.062 ± 0.001	0.011 ± 0.001

Lead

The fish chosen from the research region had lead (Pb) concentrations ranging from 2.921 ± 0.68 to 129.435 ± 7.87 µg/g. The greatest Pb concentrations were found in the gills of *H. fossilis* (129.435 ± 7.87 µg/g) and the liver of *C. punctatus* (75.273 ± 5.02 µg/g). Both fish species differed in weight and length from one another. The FEPA established a limit of 2.0 µg/g for Pb in food, but the FAO and WHO suggested a limit of 0.5 µg/g. Due to their wide column feeding habits, bigger fish (*H. fossilis* and *C. punctatus*) tend to collect more heavy metals (FAO, 1993; Farkas *et al.,* 2003). Because of surface action and feeding amount, their metal buildup has increased.

Cadmium

The fish chosen from the research region had lead (Pb) concentrations ranging from 2.921 ± 0.68 to 129.435 ± 7.87 µg/g. The greatest Pb concentrations were found in the gills of *H. fossilis* (129.435 ± 7.87 µg/g) and the liver of *C. punctatus* (75.273 ± 5.02 µg/g). Both fish species differed in weight and length from one another. The FEPA established a 2.0 µg/g limit for Pb in food, but the FAO and WHO suggested a limit of 0.5 µg/g. Due to their wide-column feeding habits, bigger fish (*H. fossilis* and *C. punctatus*) tend to collect more heavy metals (FAO, 1993; Farkas *et al.,* 2003). Because of surface action and feeding amount, their metal buildup has increased. The authors of Singh (2014) found that the muscles of the carnivorous fish *C. striatus* had the largest amount of Cd, measuring 1.42 ± 0.23 µg/g. In comparison to the current study, Vannoort and Thomson found that vacuum-packaged smoked fish species (*Mackerel, S. salar,* and *O. mykiss*) had a lower Cd content, ranging from 0.003-0.036 mg/kg with a mean of 0.01367 mg/kg (Vannoort and Thomson, 2006). Another investigation on the seasonal concentration of Cd in fish and oysters in Bangladesh's Shitalakhya River found that the levels ranged from 1.09 to 1.21 mg/kg (Ahmed *et al.,* 2010).

Chromium

The concentration of chromium (Cr) in the chosen fish tissue varied between 2.395 ± 0.67 and 94.393 ± 8.97. The muscle of *C. punctatus* had the lowest chromium content, measuring 2.395 ± 0.67 µg/g, whereas the gonads of *H. fossilis* had the greatest concentration, measuring 94.393 ± 8.97 µg/g. While the FEPA and WHO recommended 0.15 µg/g and 0.15 µg/g, respectively, the European Union Commission recommended a daily acceptable chromium value of 1 µg/g. According to earlier research, the Cr values from India's southeast coast ranged between 0.41 and 1.56 µg/g and 0.65 and 0.92 µg/g (Lakshmanan *et al.,* 2009). Paints used in boats, leaching from rocks in the research region, and agricultural runoff might all be sources of Cr (Maurya and Malik, 2016). Fish in the Ganga River are at serious risk due to the high levels of Cr and Pb that have been previously discovered in river water and fish tissues (Malik *et al.,* 2015). The concentrations of Mn, Pb, and Zn in the muscles of Gangetic fishes are greater than those of Cd, Cu, Cr, and Ni (Srivastava and Srivastava, 2008).

Arsenic

In both surface and groundwater, geothermal water may include inorganic arsenic (Welch *et al.,* 2000). The BIS Standard (IS 10500:2012) states that 0.01 mg/l of arsenic is the most amount that can be present in water. The concentration of chromium (As) in the chosen fish tissue varied between 0.003 ± 0.001 and 0.146 ± 0.001. The muscle of *C. punctatus* had the lowest chromium content, measuring 0.003 ± 0.001 µg/g, whereas the gonads of *H. fossilis* had the greatest concentration, measuring 0.146 ± 0.001 µg/g.

Determination of bio-concentration factor

The ratio of the heavy metals in the tissue to the surrounding water is known as the bio-concentration factors (BCFs) of heavy metals in fish tissues (Hatem *et al.,* 2015). There was a significant possibility of the various heavy metals bioaccumulating in the fish body organ tissues, according to the BCF of the heavy metals in the species-specific fish tissues, such as the gills, liver, gonad, and muscle, in the current study. For every fish species, the BCF value was lower in the muscle and gonad and greater in the liver and gills. It was shown that the water carried the heavy metal content to the tissues of every fish that was chosen. The current study's BCF demonstrated that the metal concentrations in the tissues were arranged as follows: liver > gill > muscle > gonads. According to Table 5, BCF's magnitude ranking was Pb, Cd, Cr, and As. Compared to other tissues including skin and muscles, metabolically active tissues—such as the gills, liver, kidneys, and gonads—exhibited greater accumulations of heavy metals (Ali *et al.,* 2019).

Table 5: Bio-concentration factor (BCF) index of the selected fish in different heavy metals

Fish species	Fish Tissues	Heavy Metal/Seasons											
		Cr			Cd			Pb			As		
		Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Summer
C. punctatus	Liver	15.401	94.012	6.055	33.961	278.97	8.673	90.770	289.511	11.804	10.00	18.018	0.915
	Muscles	4.129	5.259	4.694	19.023	7.172	12.453	20.259	28.865	8.208	7.619	0.754	0.422
	Gills	13.027	6.738	3.333	76.507	10.211	17.24	95.905	41.465	7.467	15.238	21.792	1.478
	Gonads	18.862	15.512	2.541	66.661	35.405	11.053	57.062	75.088	10.103	21.428	1.037	0.211
H. fossilis	Liver	5.979	21.861	18.384	15.353	16.70	29.973	7.894	12.484	32.033	5.714	2.452	3.873
	Muscles	5.936	20.917	4.127	18.292	10.255	34.986	25.805	12.03	5.489	32.380	1.415	2.253
	Gills	45.148	56.225	11.878	640.90	47.877	22.373	44.075	497.826	24.486	69.523	6.886	0.985
	Gonads	48.229	45.565	89.05	77.792	69.60	110.166	62.840	32.742	18.265	42.380	5.849	0.774

CONCLUSION

In comparison to national and international drinking water standards (BIS and WHO), the results of this study indicated that the water from the Gomati River is unfit for human consumption at the selected locations unless it is properly treated. The following ranges of heavy metal concentrations were observed:

Copper (Cu): 0.17–0.47 mg/l during the monsoon; 0.22–0.99 mg/l during the winter; and 0.36–1.13 mg/l during the summer. Chromium (Cr): 0.12–0.92 mg/l during the monsoon; 0.15–1.05 mg/l during the winter;

and 0.08–0.19 mg/l during the summer. Lead (Pb): 0.04–0.88 mg/l during the monsoon; 0.06–0.34 mg/l during the winter; and 0.0009–0.70 mg/l during the summer. Arsenic (As): 0.0015–0.005 mg/l during the monsoon; 0.004–0.01 mg/l during the winter; and 0.004–0.019 mg/l during the summer. At each sampling location, the levels of Pb, Cr, Cd, As, and Hg were found to exceed the recommended safe limits. However, Cu was consistently measured below the allowable limit of 1.5 mg/l at all sample locations. The muscle, gills, liver, and gonads of the fish collected from the river showed the presence of hazardous metals, with the liver and gills exhibiting the highest concentrations. It was noted that the carcinogenic risk for consumers associated with Cd, Cr, and Pb was beyond acceptable levels. Nevertheless, the heavy metal content estimated through the Estimation of Daily Intake (EDI) remained below the recommended daily intake. The concentration of heavy metals in the fish from the Gomati River significantly exceeded the acceptable limits set by the FAO and WHO. The bioaccumulation factors (BAFs) indicated that Pb, Cd, and Cr were the most readily absorbed heavy metals in the fish. This bioaccumulation poses a potential warning regarding the harmful effects of consuming these fish on human health. This study highlights the urgent need for appropriate preventive measures to avoid future contamination of the Gomati River's water. Immediate and remedial actions from all stakeholders are necessary not only to stop and mitigate the existing problem but also to greatly safeguard the health of the local community.

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