Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

A Comparative Assessment of Heavy Metal Contamination in Freshwater and Marine Aquatic Biota of the Chittagong Region, Bangladesh: Seasonal Dynamics, Bioaccumulation Mechanisms, and Implications for Public Health and Environmental Sustainability

Md. Main Uddin[1*], Rahul Barua[2], Safat Jawad Siddiqui[3], Jacia Akter Jui[4] & Md. Abadat Hossain[5]

[1]Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Raozan, Chattogram, Bangladesh. [2]Department of Physics, National University, Board Bazar, Gazipur, Bangladesh. [3]Department of Materials and Metallurgical Engineering, Chittagong University of Engineering and Technology, Raozan, Chattogram, Bangladesh. [4]Independent Researcher, Chattogram, Bangladesh. [5]Department of Natural Science, Port City International University, South Khulshi, Chattogram, Bangladesh. Corresponding Author Email: main23489@gmail.com[*]

DOI: https://doi.org/10.38177/ajbsr.2026.8109

Article Received: 14 January 2026 Article Accepted: 19 March 2026 Article Published: 25 March 2026

ABSTRACT

Aquatic resources provide over 60% of the animal protein consumed in Bangladesh. Rapid industrialization has resulted in significant heavy metal pollution throughout the country, which threatens both the environment and public health. A comparison of the concentration levels of four different metals (arsenic, cadmium, lead, chromium) in fresh and salt water fish samples from the Chittagong region, which includes fish from the Karnaphuli River and the Bay of Bengal, indicates that fish residing in the river are significantly more polluted than those found in the Bay, with *Mystus vittatus* being particularly contaminated. River samples collected during winter months had 15% to 25% more metals than those collected during other seasons, while most of the fish sampled from the Bay of Bengal were less contaminated. However, dried fish and crustacean products from the fishery in the Bay frequently exceeded acceptable levels of heavy metal contamination. Results indicate a chasm of potential health problems, including carcinogenic effects, neurodegenerative diseases, and organ damage, associated with the consumption of contaminated fish, as well as significant ecological impacts, including a loss of biodiversity and a disruption in food webs in aquatic systems.

Keywords: Heavy Metal; Fish; Crustacean; Dry Fish; Karnaphuli River; Bay of Bengal; Bioaccumulation; Bangladesh; Public Health Risk.

1. Introduction

The persistence, toxicity, and bioaccumulation of heavy metals (HMs) in the aquatic environment make them an important global environmental issue [1, 2]. Heavy metals are found in the environment from both natural sources (i.e., volcanic eruptions, geological weathering) as well as man-made sources (i.e., industrial discharges, mining operations, agricultural run-off, and urban waste disposal). Increased inputs of toxic metals to aquatic systems have resulted from the rapid growth of urbanization, heavy industrial development, and poor waste management practices [4, 5]. Mercury, cadmium, lead, arsenic, and chromium are heavy metals that can cause irreversible damage to the neurological, liver, kidney, and reproductive systems at very low concentrations in the environment by accumulating in all living organisms through the food chain [3]. In the aquatic environment, heavy metals persist for long periods and create a constant ecotoxicological stress on aquatic organisms and contaminate food chains, thus endangering the health of humans who eat contaminated seafood products [3].

Bangladesh is vulnerable to freshwater pollution due to its situation as a deltaic nation with vast river systems; moreover, Bangladesh's population of over 170 million people utilizes the rivers for fisheries, irrigation for agriculture, transportation, and as water sources [6]. Fish play an essential role in the food security of the country, as aquaculture production reached 2.638 million metric tonnes in 2004 and provided more than 60% of the total amount of animal protein consumed in the country. The contamination of the freshwater systems where these fish are sourced has serious implications for food security and public health [7, 23]. With the increase of anthropogenic activities (e.g., industrial manufacturing, agriculture, and ship-breaking on the coast of Chattogram), the concentrations of arsenic, lead, cadmium, chromium, copper, manganese, nickel, and vanadium in the water bodies of Bangladesh have also increased due to increased industrial production [6]. Studies conducted throughout the interconnected river systems in southwestern Bangladesh (i.e., Rupsha, Bhairab, Atai) demonstrated that the levels of metals in these water bodies were spatially variable and correlated to the proximity of industrial activity and with seasonal fluctuations; the levels of metals were found to be the highest during the winter months. The study showed that there was a higher concentration of metals (i.e., biomagnification) in benthic and carnivorous fish, meaning that there could be potential health problems, including neurotoxic, organ toxicity, and cancerous effects from the consumption of these fish [6].

Bangladesh's Bay of Bengal is an important economic asset, providing major contributions to fisheries, ecological diversity, shipping, and other industries based on a "blue economy" [8,9,10]. However, the marine ecosystem suffers from contaminating materials flowing into it through a variety of means; for example, pressures associated with coastal industrial discharges, port activities, shipbreaking, and via river runoff from rivers such as Karnaphuli [11,12,13]. Salinity affects the availability of heavy metals, while the buildup of heavy metals through sedimentation may also have long-term ecological consequences for benthic organisms [14, 15]. Higher levels of bioaccumulation of the commercially important species of fish and shellfish found in the marine environment raise concerns about food safety [16, 17].

The Karnaphuli River starts in the Lushai Hills of Mizoram, flows to the Bay of Bengal, and is the ecological and economic lifeline of the city of Chattogram (also known as Chittagong) [4,18,19]. Chattogram, as the largest seaport and second largest city in Bangladesh, produces large amounts of industrial effluents containing heavy metals due to textile, steel, dyeing, oil, and food processing plants.

In addition to these industrial discharges, Chattogram discharges untreated urban sewage, thus the Karnaphuli is one of the most polluted ecosystems in Bangladesh. Heavy metal monitoring data indicate that the concentrations of heavy metals in the waters, sediments, and in the biota occasionally exceed acceptable limits, thus posing a risk to the ecosystem as well as human health [16, 22]. The Halda River, a tributary of this system and therefore a primary spawning area for the carp species of Bangladesh, is also showing significant increases in the level of contamination [8, 9].

Fish is an essential part of the worldwide food supply because it provides people with lean protein sources, omega-3 oils (good for heart health), vitamins, and minerals that help reduce the risk of heart disease, improve brain function, and reduce the risk of developing chronic diseases [24, 30]. In Bangladesh, both freshwater and ocean fish are part of the daily diet for people living in the Chittagong area [31]. Heavy metal contamination is a potential hazard to both aquatic life and the safety of food prepared from these fish. Contamination occurs because of industrial discharges into local waterways, agricultural runoff (fertilizers, pesticides, etc.), and improper disposal of solid waste by industries. As the metals accumulate in organisms through food chains and webs, they tend to reach some of their highest levels in predatory and bottom-dwelling species of fish [32, 33]. The different types of pathology caused by heavy metals can result in oxidative injury; changes to the structure of tissues (histopathology); reduced reproductive capability; and high mortality rates among fish and invertebrates living in water bodies contaminated with heavy metals caused by industrial activities [32, 33]. For humans who consume heavy metal-contaminated fish, chronic exposure may lead to serious adverse health effects, such as cancer, developmental disabilities, kidney (renal) failure, and degeneration of the nervous system [34, 36].

1.1. Heavy Metal Contamination in Aquatic Systems

Heavy metals remain an enormous problem as they cannot degrade, are pollutants that bioaccumulate in fish tissues, and biomagnify through the food web to eventually be consumed by humans [32]. These contaminants, which include arsenic, cadmium, copper, chromium, lead, mercury, nickel, selenium, and zinc, have a high degree of stability in both their organic and inorganic forms, and bioaccumulate in sediment and in critical organs (i.e., gills, liver, muscle tissue) of fish [32]. The bioaccumulation of these heavy metals can disrupt essential physiological processes such as reproduction, growth, and neurological behaviour of fish. Aquaculture provides significant amounts of necessary protein; therefore, as one of the fastest-growing food sectors in the world, aquaculture faces some of the most significant problems related to heavy metal pollution in aquatic habitats [32]. Through waterborne exposure and dietary consumption of these metals, fish will bioaccumulate the metals and experience oxidative stress and histopathological changes [32, 33]. The bioaccumulation of heavy metals in fish can vary significantly based on the metal species, fish biology, and environmental parameters; however, bioaccumulation varies dramatically between freshwater and saltwater species, which can result from different feeding ecologies and habitat characteristics [7].

Severe ecological and public health consequences arise from heavy metal contamination. Fish, by nature of being a highly predatory species that eats a lot of highly-fried smaller fishes throughout their lives, will accumulate very large amounts of metals in their bodies via bioaccumulation and biomagnification, giving them toxicological risks for individuals, including neurotoxicity, renal damage, hypertension, and carcinogenicity [32]. When excessive oxidative stress can occur when the levels of reactive oxygen species (ROS) in an organism's body exceed the normal physiological capabilities of the organism's anti-oxidant systems (including catalase, superoxide dismutase, glutathione S-transferase and glutathione peroxidase), chemical reactions between the two will produce an increase in lipid peroxidation, causing significant damage to an organism's DNA, proteins and lipids at the cellular level via chronic inflammation [32]. Important histo-pathological changes will occur in the gills, liver, and kidneys of affected organisms, making it impossible for these organisms to perform their essential biological functions, including respiration, detoxifying the blood, and regulating NaCl and H_2O (osmoregulation). In addition to inducing histo-pathological changes, heavy metals can affect reproductive processes in fish by decreasing gonadosomatic index (an indicator of a healthy female reproductive system), fecundity, and embryonic development, leading to the potential extinction of fish populations due to low reproductive success [33]. Heavy metals such as mercury, lead, cadmium, and arsenic have also caused damage to reproductive systems in fish through endocrine disrupters, oxidative stress, and genetic damage, which have resulted in reproductive success being decreased, sex ratio distortion, and reduced offspring survivorship, thus rendering fish populations unstable [33]. Identifying the levels of heavy metals in commercially contaminated fisheries (like Chittagong) is an important step in ensuring the ecological integrity of our fisheries and ecological system, as well as evaluating any potential human health threats (including neurotoxicity, carcinogenicity, and organ damage) from eating contaminated fish [34].

Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

1.2. Research Context and Knowledge Gaps

Bangladesh has recently reported high levels of contamination from freshwater fish harvested from various locations around the country. Research conducted on 5 species (*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Hypophthalmichthys molitrix*, and *Cyprinus carpio*) in 42 farms located throughout the Natore area revealed the presence of heavy metals (zinc, cadmium, chromium, arsenic, lead, and nickel) in the muscles of fish; Mrigal exceeded safe levels allowed for consumption of chromium [35]. In addition, the Bangshi River was tested for heavy metals in October 2023; cadmium, chromium, and lead were detected in water and soil during both wet and dry seasons, with all fish sampled (8 species) from the wet season having measurable amounts of cadmium and lead exceeding the maximum permissible limit for those substances [34]. An assessment of 20 freshwater river fish species (20+) and brackish water-coastal fish represented a significant quantity of fish that exceeded the maximum allowable heavy metal concentration in accordance with Bangladeshi and international food safety standards. Pollution load indices for individual species indicated the potential for moderate to severe contamination, with target hazard quotients for lead and arsenic exceeding acceptable levels for human consumption [7]. In addition, a study conducted in other countries (Egypt in 2023) did find levels of mercury, cadmium, and lead in wild and farmed freshwater fish above the European Commission's allowable limits of those contaminants. Interestingly, marine fish had much higher levels of arsenic than either freshwater or farmed freshwater fish [36]. Thus, all of these data collectively demonstrate the potential for seasonal, water chemistry, and species-specific differences in the bioaccumulation of certain contaminants.

There has been a considerable amount of research conducted on heavy metal contamination in Bangladeshi aquatic ecosystems. However, most available literature comparing the interlinked freshwater (riverine) and saltwater (marine) ecosystems of Chattogram is quite limited. Although the ecosystems are naturally connected, they probably have different pathways for contaminating the ecosystems, as well as different mechanisms for retention and different levels of ecological risk from contaminants. Moreover, there has been a limited comparative study of the bioaccumulation of metals by freshwater fishes in the Karnaphuli River and marine fishes in the Bay of Bengal. A systematic evaluation of habitat- and fish-specific factors (i.e., salinity, behaviour of fish that feed on metals, and interspecific differences in fish) that may contribute to differences in bioaccumulation of metals and effects on human health is needed. In addition, oxidative stress and histopathology (i.e., injury to the tissues of fish) should be investigated to a greater extent, and a comprehensive monitoring programme should be established to allow for integrated monitoring of both ecosystems.

1.3. Study Objectives

1) To identify and critically analyze literature related to the contamination of heavy metals (arsenic, cadmium, lead, chromium) found in and around the Karnaphuli River and Bay of Bengal near Chittagong, Bangladesh.

2) To determine the differences in levels of contamination and how this impacts the local freshwater, marine, or coastal aquatic ecosystems in the Chittagong area of Bangladesh.

3) To assess how eating fish (including crustaceans), and dried fish products that may be contaminated with heavy metals will adversely impact food safety and the health of humans.

Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

4) To determine how much variability occurs among the levels of contamination in hazardous metals (arsenic, cadmium, lead, chromium) at different times of year (seasonal) for various species of fish located within each aquatic ecosystem.

5) To identify research gaps that have yet to be filled regarding the current monitoring and evaluation protocols used to address aquatic pollution in Bangladesh from heavy metals.

6) To suggest strategies that could be utilized to create integrated monitoring plans and create evidence-based policy changes that could reduce the impact of heavy metals on the aquatic ecosystems of both freshwater and marine environments.

2. Methodology

This manuscript is a review that compares the level of contamination caused by heavy metals within aquatic animals from the Chittagong region. The manuscript's main focus is to compare the heavy metal concentrations of fish, crustaceans, and dried fish products collected from two different ecosystems (Karnaphuli River (freshwater) vs. Bay of Bengal (Marine); Figure 1) as well as how they vary by season, including whether there is any risk to human health due to consumption of these aquatic species. The study lays out findings previously published by other peer-reviewed articles that included quantitative data about heavy metals present in both freshwater and saltwater environments. All of the data presented in this review comes from the following areas of the Chittagong region: Karnaphuli River and surrounding areas, estuary regions, and the sea coast (Cox's Bazar, St. Martin's Island, and Kutubdia Channel). The studies used for this comparative analysis include but are not limited to a review of both fresh and dried fish collected from the areas described above along with details regarding sample location, species name, seasonal sampling (summer and winter), total concentrations of heavy metals and health risks associated with fish consumption (Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Target Risk (TR).

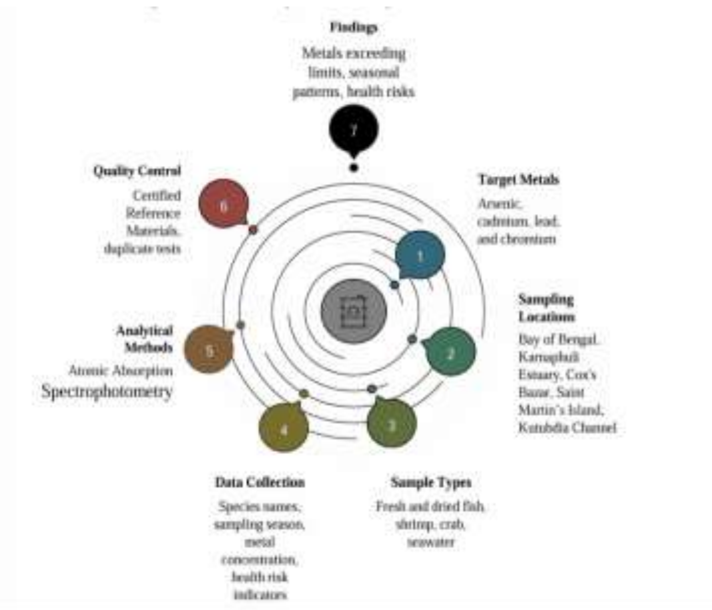

Figure 1. Comparative Distribution and Seasonal Dynamics of Heavy Metal Contamination in Freshwater and Marine Aquatic Organisms of the Chittagong Region, Bangladesh.

Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

Aquatic samples and tissue analysis were done using standardized international methodologies. Sample preparation for heavy metal analyses comprised four separate steps: cleaning, drying, grinding, and acid digestion. The quantification of the heavy metals of cadmium, lead, and chromium was performed using Atomic Absorption Spectrophotometry (AAS) (Figure 2), which is an accepted method for analysis. The analysis of the seasonal metal profile variation in ten species of fish from the Karnaphuli River [21, 44], such as Tenualosa ilisha, Mystus vittatus, Harpadon nehereus, Lates calcarifer, and Sillaginopsis panijus, was completed using AAS for all freshwater samples. Marine species were analysed from the Bay of Bengal and the adjoining coasts, such as Harpadon nigrescens, Saurida rubrum, Sardinella longiceps, Trichiurus lepturus, and Leiognathus equulus [45].

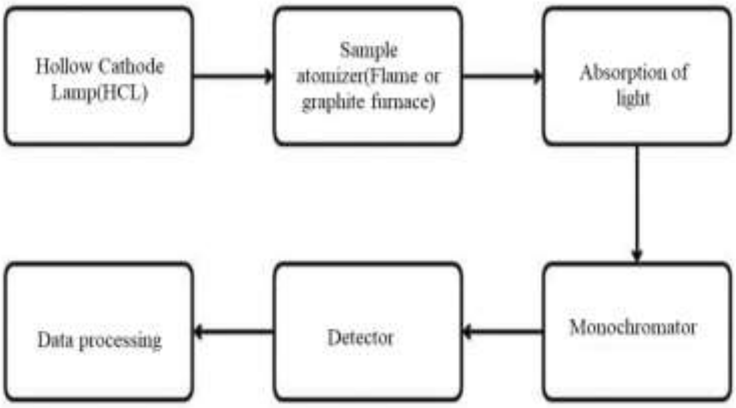

Figure 2. Schematic Representation of Atomic Absorption Spectroscopy (AAS) for Heavy Metal Analysis.

The primary sources of contamination in both the Karnaphuli River and the Bay of Bengal are from the discharges of manufacturing industries, untreated effluent, and agricultural run-off, with the source of most contamination being from factories situated along the riverbank in Chittagong. These sources are also accountable for posing a direct health risk through exposure to arsenic and lead due to their presence in the food chain and also for causing the accumulation of chromium and cadmium in marine organisms and/or the marine food chain (Figure 3). The systematic evaluation of the current state of the environment by reviewing relevant data from the literature, AAS quantification, and seasonal evaluations of the data, provides an assessment of the contamination profiles and the risk assessment of freshwater and marine ecosystems in Chittagong.

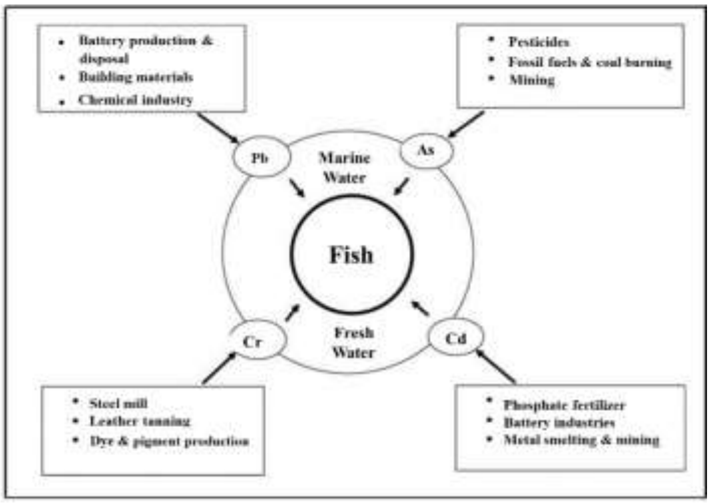

Figure 3. Major Sources and Pathways of Heavy Metal Contamination in Freshwater and Marine Fish.

Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

3. Result and Discussion

3.1 Marine Fish Species Contamination Patterns

Heavy metals were found to have different levels of contamination in marine fish from the Bay of Bengal, Bangladesh (Table 1, Figure 4). Arsenic levels from high to low were as follows: F1 > F2 > F3 > F9 > F8 > F4(BDL) > F5(BDL) > F6(BDL) > F7(BDL) > F10(BDL) > F11(BDL). BDL represents concentrations below the detection limit. Cadmium level order was: F2 > F3 > F7 > F1 > F5 > F4 > F6 > F9 > F8(ND) > F10(BDL) > F11(BDL), where ND means no detectable.

Lead levels were as follows: F5 > F3 > F2 > F1 > F6 > F4 > F9 > F10 > F7 > F11 > F8(0). Chromium levels ranged from high to low: F7 > F11 > F9 > F5 > F4 > F2 > F3 > F1 > F10 > F6(0) > F8(0).

Of the marine fish evaluated, species F2, F3, and F5 were found to have metal concentrations above the maximum allowable limits established by the World Health Organization (WHO). As such, they should not be consumed by humans [51].

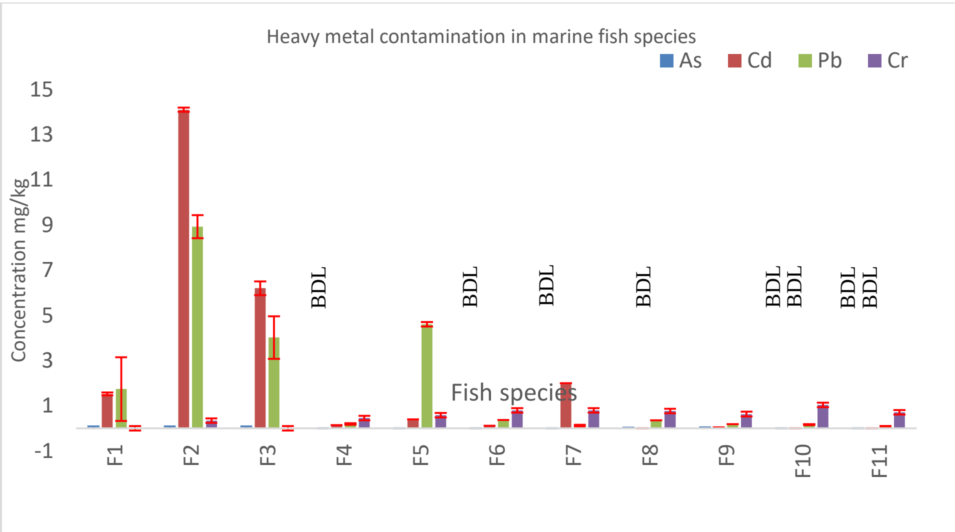

Figure 4. Comparative Concentration of Heavy Metals in Marine Fish Species from the Chittagong Coastal Region (mg/kg).

3.2. Marine Crustacean Species Contamination

Various marine crustaceans displayed different accumulations of metals (see Fig. 5 and Table 1):

1) As (strongest to weakest) = C7>C6>C4>C5>C9>C1(BDL) = C2(BDL) = C3(BDL) = C8(BDL);

2) Cd = (accumulation order) C6 > C5 > C1 > C7 > C4 > C2 > C9 > C3 > C8;

3) Pb = (strongest to weakest) C8 > C2 > C1 > C3 > C4 > C5 > C9 > C6 > C7; and

4) Cr = (strongest to weakest) C3 >C4 > C6 > C8 > C7 > C2 > C9 > C1 > C5. Crustaceans C1, C2, C3, C6, and C7 showed metals at levels above the WHO safety threshold; as a group, crustaceans showed the highest level of contamination compared to other marine groups, indicating either significant environmental contamination or typical post-harvest processing contamination for other processing methods.

Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

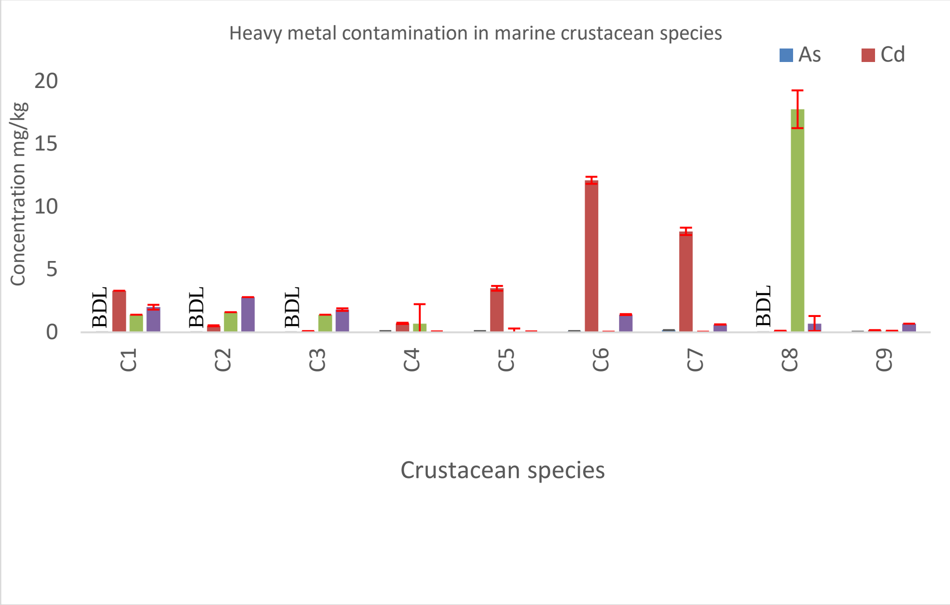

Figure 5. Heavy Metal Concentration Profiles in Marine Crustacean Species from the Chittagong Coastal Region (mg/kg).

3.3. Marine Dried Fish Products

Contamination levels in dried fish species were found to be a concern (see Figure 6, Table 1). Arsenic was in the following order of contamination: D2 > D1 > D3 > D4 > D5(BDL), cadmium in the sequence of D4 > D5 > D1 > D2 > D3, lead in the order of D4 > D5 > D2 > D3 > D1 and chromium in the distribution of D4 > D5 > D2 > D1(BDL) > D3(BDL). Samples D3, D4, and D5 exceeded safe levels for three or more heavy metals, indicating there was likely a high amount of material buried in the production process or storage of dry products. The levels of heavy metal found in the dried products compared to fresh fish were likely there due to the concentration effect of dehydrating fish and possibly due to impurities on the drying surfaces or from the environment prior to being dried [50].

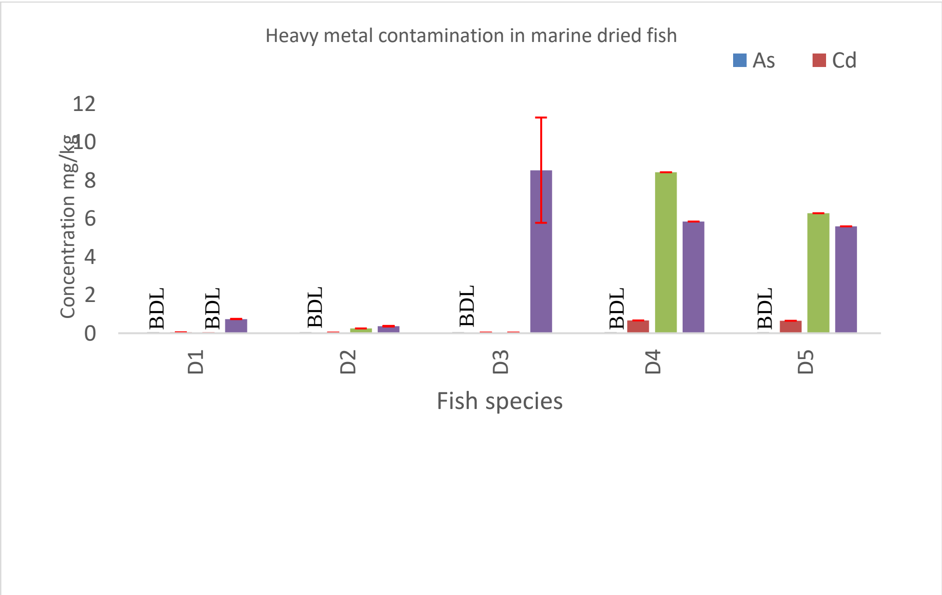

Figure 6. Heavy metal contamination in marine dry fish species concentration (mg/kg).

Asian Journal of Basic Science & Research
Volume 8, Issue 1, Pages 92-107, January-March 2026

Table 1. Comparative Concentration of Heavy Metals in Marine Fish, Crustacean, and Dry Fish Samples from the Chittagong Coastal Region, Bangladesh (mg/kg).

	Fish species	Sample Id	As	Cd	Pb	Cr	Ref.
Sea fish	*R.kanagurta*	F1	<0.08	1.52±0.06	1.74±1.41	<0.05	[41]
	H.nigresceus	F2	<0.08	14.10±0.09	8.92±0.51	0.34±0.01	
	S.rubrum	F3	<0.08	6.20±0.3	4.02±0.94	<0.05	
	Tenualosa ilisha	F4	BDL	0.14 ±0.00	0.19 ±0.04	0.45± 0.00	[45]
	Sardinella longiceps	F5	BDL	0.39 ±0.00	4.6± 0.1	0.58± 0.00	
	Trichiurus lepturus	F6	BDL	0.11± 0.00	0.37± 0.00	0.79± 0.00	
	Konosirus punctatus	F7	BDL	2.0 ±0.0	0.12± 0.03	0.79± 0.00	
	Leiognathus equulus	F8	0.03	ND	0.35	0.76	[48]
	Burmese loach	F9	0.04	0.04	0.19	0.63	
	Apocryptes bato	F10	BDL	BDL	0.165± 0.02	1.036± 0.005	[37]
	Polynemus paradiseus	F11	BDL	BDL	0.086± 0.008	0.709± 0.014	
Crustacean	*Portunus sanguino lentus*	C1	BDL	3.3± 0.0	1.4 ±0.0	2.0 ±0.2	
	Scylla serrata	C2	BDL	0.52± 0.04	1.6 ±0.0	2.8 ±0.0	[45]
	Hemigrapsus takano	C3	BDL	0.10 ±0.00	1.4± 0.0	1.8 ±0.1	
	P.sculptilis	C4	<0.1	0.713±0.06	0.690±1.56	<0.08	
	P.versicolor	C5	<0.1	3.505±0.19	<0.3	<0.08	
	T.crenata	C6	0.109±0.00	12.1±0.29	<0.06	1.412±0.04	
	M.victor	C7	0.18±0.00	8.03±0.29	<0.06	0.623±0.008	[41]
	P.monodon	C8	BDL	0.09± 0.03	17.75 ±1.5	0.69± 0.6	[37]
	Metapenaeusmo noceros	C9	0.04	0.19	0.13	0.70	[46]
Dry fish	*Devario devario*	D1	BDL	0.0456 ± 0.01	BDL	0.7415 ±0.01	[39]
	Nemipterus vigatus	D2	BDL	0.0209 ± 0.001	0.2571 ± 0.001	0.3702 ±0.01	
	Stromateus chinensis	D3	BDL	0.0191 ± 0.008	0.0277 ± 0.003	8.5352±2.75	
	S. cinereus	D4	BDL	0.68	8.43	5.85	[49]
	L. calcarifer	D5	BDL	0.65	6.28	5.60	
Safe limit by WHO (mg/k)			1.0	1.0	2.0	1.0	[35]

3.4. Karnaphuli River Freshwater Fish: Seasonal Variation

Most of the fish samples taken from the Karnaphuli River showed levels of heavy metals that exceeded the acceptable limits set by the World Health Organization (WHO) during the summer months. These metals were found in various concentrations: arsenic (1.0 mg/kg), cadmium (1.0 mg/kg), lead (2.0 mg/kg), and chromium (1.0 mg/kg) (see Table 2). Fish from the K1-K9 sample category exceeded the arsenic level, making them unsafe for consumption. The fish sample K6 indicated a significant level of contamination from three different metals: arsenic (4.50 mg/kg), lead (5.91 mg/kg), and chromium (1.05 mg/kg). Each of these metals was at a level well above what is considered acceptable according to WHO standards. Additionally, K7 was contaminated with both arsenic and chromium at levels that were greater than acceptable. The K10 sample did not have an elevated level of heavy metals during the summer months. The following is a description of heavy metal concentrations collected during summer months, in order of contamination level:

Arsenic: K6>K7>K4>K5>K9>K3>K2>K1>K8>K10(Figure:7a);

Cadmium: K6>K7>K4>K10>K8>K3>K5>K9>K2>K1 (Figure:7b);

Lead: K6>K7>K3>K5>K4>K8>K10>K9>K2>K1 (Figure:7c);

Chromium: K6>K7>K5>K3>K4/K9>K10>K2>K8>K1 (Figure:7d).

Winter sampling consistently revealed high levels of contamination, with all ten samples (K1-K10) exceeding the WHO arsenic limit and showing significant pollution. Each sample exceeded the arsenic threshold of 1.0 mg/kg; however, there were additional occurrences of exceeding both allowable limits of the four metals (As, Cd, Pb, Cr) in samples K6 and K7, as well as in several other samples. The level of arsenic in K1, K2, and K10 was relatively lower than that of the other metals, but all samples had arsenic concentrations that were higher than allowable limits for human consumption. None of the winter samples meet the requirements for human consumption. In the winter, the order of contamination was as follows:

Arsenic K6 > K4 > K7 > K5 > K3 > K9 > K2 > K10 > K8 > K1 (Figure: 7a),

Cadmium K6 > K7 > K4 > K10 > K9 > K3 = K8 > K5 > K1 > K2 (Figure:7b),

Lead K6 > K7 > K3 > K5 > K4 = K8 = K9 > K10 > K2 > K1 (Figure:7c),

Chromium K6 > K7 > K3 > K5 > K4 > K9 > K2 > K10 > K8 > K1 (Figure:7d).

The consistent elevated levels in the winter (increased 15% to 25% compared to summer) can be attributed to the lack of water, which has impacted dilution capacity and biogeochemical conditions associated with the dry season.

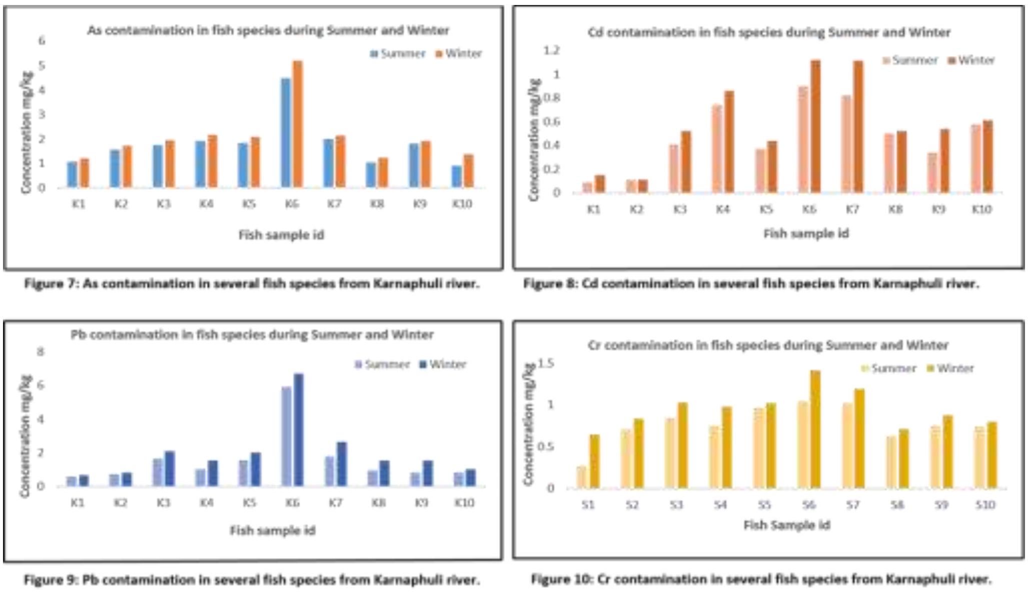

Figure 7. Seasonal Variation of Heavy Metal Concentration in Fish Species from the Karnaphuli River, Chittagong (mg/kg).

3.5. Health Risk Assessment and Public Safety

A comprehensive evaluation of heavy metal levels in marine samples F2, F3, F5, C1, C2, C3, C6, C7, D3, D4, D5, and all of Karnaphuli River's samples (K1-K9 in summer; K1-K10 in winter) against WHO standards suggests that they are unfit for human consumption (See Table 2). Health risks from eating fish that have arsenic, lead, cadmium, and chromium are severe due to their inability to degrade and bio-accumulate in human body fat as well as their carcinogenic and systemic toxic properties [46]. Eating fish with arsenic increases the chances of developing skin lesions, heart problems, and cancer of the skin, lung, or bladder. Eating fish contaminated with lead affects the central nervous system, kidneys, and reproductive organs; it causes anemia and developmental problems, particularly in children. Eating fish with cadmium primarily affects the kidneys/bones, causing kidney dysfunction (renal failure), bone damage, and pulmonary disease. Eating cadmium-contaminated fish has also been shown to be cancer-causing. Eating fish that contain chromium, especially hexavalent chromium (Cr VI), will damage the liver and kidneys, cause skin ulcers, and irritation to the lungs. Chronic consumption of heavy metal-contaminated fish has serious cumulative effects on health, even when low concentrations are consumed [46].

Table 2. Seasonal Variation in Heavy Metal Concentration in Fish Samples from the Karnaphuli River, Chittagong, Bangladesh (mg/kg).

Season	Fish species	Sample id	As	Cd	Pb	Cr	Ref.
Summer	*Tenualosa ilisha*	K1	1.07	0.09	0.57	0.27	[21]
	Gudusia chapra	K2	1.57	0.11	0.74	0.71	
	Otolithoides pama	K3	1.75	0.41	1.67	0.85	
	Polynemus paradiseus	K4	1.92	0.74	1.02	0.75	
	Harpadon nehereus	K5	1.83	0.37	1.56	0.97	
	Mystus vittatus	K6	4.50	0.90	5.91	1.05	[44]
	Sillaginopsis panijus	K7	2.00	0.82	1.78	1.02	
	Lates calcarifer	K8	1.06	0.50	0.95	0.63	
	Cynoglossus arel	K9	1.80	0.34	0.82	0.75	
	Pseudapocryptes elongates	K10	0.90	0.58	0.83	0.74	
Winter	*Tenualosa ilisha*	K1	1.22	0.15	0.67	0.65	[21]
	Gudusia chapra	K2	1.73	0.11	0.82	0.84	
	Otolithoides pama	K3	1.96	0.52	2.10	1.03	
	Polynemus paradiseus	K4	2.16	0.86	1.52	0.98	
	Harpadon nehereus	K5	2.1	0.44	2.0	1.02	
	Mystus vittatus	K6	5.19	1.12	6.72	1.42	[53]
	Sillaginopsis panijus	K7	2.13	1.11	2.64	1.19	
	Lates calcarifer	K8	1.23	0.52	1.52	0.71	
	Cynoglossus arel	K9	1.92	0.54	1.52	0.88	
	Pseudapocryptes elongates	K10	1.37	0.61	1.02	0.80	
Safe limit by WHO (mg/kg)			1.0	1.0	2.0	1.0	[36]

3.6. Ecosystem-Level Impacts

The impact of heavy metal pollution on ecologies extends well beyond the impacts on human health (and pathogens). The accumulation of metals in aquatic organisms has disrupted trophic relationships, resulting in biomagnification through food chains. This continues to threaten the diversity of aquatic life and, in turn, compromises the growth and reproductive capabilities of fish populations [47]. Heavy metals coming from industrial and urban sources have seriously impacted the quality of both sediment and water bodies (as well as degrading the integrity of ecosystems). The high levels of metals observed during winter months in this study demonstrate that there are serious seasonal risks to the public health of aquatic organisms. When consuming fish that are contaminated with high levels of arsenic or lead, individuals may experience long-term health effects, such as cancer, neurological impairments, or impairments to their heart and cardiovascular systems. Ecologically, heavy metal pollution has caused reproductive failure, reduced populations, and diminished biodiversity for marine organisms. It promotes pollution-tolerant organisms, changes the structure of food webs, and alters the nutrient cycles within marine systems. By disrupting these processes, heavy metal pollutants have reduced ecosystem resilience, productivity, and stability, while increasing their vulnerability to other stressors, including overfishing and climate variability [47].

4. Conclusion and Future Recommendations

The results from this comparative assessment of heavy metal pollution in the Karnaphuli River and the Bay of Bengal illustrate that both ecosystems are under tremendous threat to public health as well as the overall health of the environment. Large fish such as hilsa, shrimp, and crabs in both freshwater and brackish water habitats reportedly accumulate high levels of heavy metals. Systematic contamination through heavy metals is not just limited to individual types of fish or other aquatic organisms; it is present throughout the entire aquatic food chain. The threat from heavy metal contamination is immediate and significant, and affects millions of people who depend upon these fish or other aquatic resources for dietary protein. As the commercial epicenter of Chittagong continues to develop without regulation of industrial processes, both the river and the marine environments receive increasingly higher levels of contamination from inadequate waste disposal practices and discharges from hazardous industrial processes. The extent and severity of this problem necessitate immediate action by providing comprehensive monitoring, rigorous industrial regulations, and enforcement of a zero-tolerance policy. In order for Bangladesh to resolve and address environmental crises, it is necessary that the government and socially responsible parties come together to provide solutions through coordinated policies, develop technology that improves upon the detection of pollution, remediation of pollution, and provide community support in preserving both public and aquatic ecosystems. Only through an integrated approach and sustaining the current efforts will we be able to help Bangladesh meet the challenges of our environment and provide a viable means of protecting and preserving vulnerable populations and their aquatic resources for generations to come.

1) A real-time, ongoing heavy metal monitoring network that covers the Karnaphuli River and the coastal Bay of Bengal should be made available so that significant contamination events can be identified quickly, and a trend analysis of contamination over time can be done.

2) Stricter regulations on the treatment of industrial effluent should be enforced, and manufacturers that are located along the banks of the rivers in the Chattogram region should be subjected to periodic audits to decrease the number of point-source heavy metal releases into the rivers.

3) Fisheries science research should be done on fish species that are commercially important in order to make evidence-based guidelines for the safe consumption of these fish by local residents, particularly vulnerable groups, such as children and pregnant women.

4) Research into biomarkers of oxidative stress and histopathological changes of sentinel species of fish should be expanded in order to develop early warning indicators of the degradation of ecosystems.

5) Bioremediation technologies, such as phytoremediation or microbial-assisted remediation, should be piloted and implemented at sites along the Karnaphuli River that are heavily contaminated.

6) AI (artificial intelligence) assisted detection and remote sensing technologies should be developed to provide cost-effective and rapid real-time monitoring of heavy metal contamination in both freshwater and marine environments throughout Bangladesh.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not–for–profit sectors.

Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally

Informed Consent

Not applicable for this study.

Availability of data and material

Supplementary information is available from the authors upon reasonable request.

Institutional Review Board Statement

Not applicable for this study.

Ethical Approval

Not applicable for this study.

Acknowledgements

We, the authors, would like to express our heartfelt gratitude to Research Buddy AI platform for providing a great opportunity to carry out this work. We are also grateful to Md. Abadat Hossain for his great supervision, insightful guidance, and continuous encouragement throughout this study. His expertise and patience in this field were crucial in bringing this manuscript to successful completion.

References

Wang, A., Kawser, A., Xu, Y., Ye, X., Rani, S., & Chen, K. (2016). Heavy metal accumulation during the last 30 years in the Karnaphuli River estuary, Chittagong, Bangladesh. SpringerPlus, 5(1): 2079.

Rakib, M.R.J., et al. (2022). A comprehensive review of heavy metal pollution in the coastal areas of Bangladesh: abundance, bioaccumulation, health implications, and challenges. Environmental Science and Pollution Research, 29(45): 67532–67558.

Aziz, K.H.H., Mustafa, F.S., Omer, K.M., Hama, S., Hamarawf, R.F., & Rahman, K.O. (2023). Heavy metal pollution in the aquatic environment: efficient and low-cost removal approaches to eliminate their toxicity: a review. RSC Advances, 13(26): 17595–17610.

Ali, M.M., Ali, M.L., Islam, M.S., & Rahman, M.Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Environmental Nanotechnology, Monitoring and Management, 5: 27–35.

Dey, S., Das, J., & Manchur, M.A. (2015). Studies on heavy metal pollution of Karnaphuli River, Chittagong, Bangladesh. IOSR Journal of Environmental Science, Toxicology and Food Technology, 9(8): 79–83.

Sakib, S., et al. (2024). Heavy metal accumulation in fish, sediment and water from three riverine ecosystems in the south-western Bangladesh and nexus to human health. Biological Trace Element Research, 203(4): 1839–1858.

Biswas, A., Kanon, K.F., Rahman, M.A., Alam, M.S., Ghosh, S., & Farid, M.A. (2023). Assessment of human health hazard associated with heavy metal accumulation in fishes from Bangladesh. Heliyon, 9(10): e20514.

Dey, M., et al. (2021). Assessment of contamination level, pollution risk and source apportionment of heavy metals in the Halda River water, Bangladesh. Heliyon, 7(12): e08625.

Kamal, A., Kibria, M.M., Hossain, S., Mahmud, C.K., Roy, R., & Resma, N.S. (2024). Analysis of heavy metal pollution in the water of the Halda River. Veterinary Medicine and Science, 10(6): 70078.

Kundu, S., Keya, R.R., & Ali, H. (2024). Impacts assessment on the Karnaphuli River water qualities due to industrial wastes.

Ahmed, A.S.S., et al. (2019). Bioaccumulation of heavy metals in fishes and health risk. PLOS ONE, 14(10): e0219336.

Barua, P., & Barua, C. (2024). Assessment of heavy metals in fish organs in Bangladesh. BioResearch Science Pollution and Community Health Effects, 2(1): 1–15.

Rashid, T., Hoque, S., & Akter, S. (2015). Pollution in the Bay of Bengal: impact on marine ecosystem. Open Journal of Marine Science, 5(1): 55–63.

Shaika, N.A., Khan, S., Awal, S., Haque, M.M., Bashar, A., & Simsek, H. (2025). Aquatic pollution in the Bay of Bengal. Hydrology, 12(7): 191.

Hasan, M.R., et al. (2016). Heavy metals distribution in surface water of the Bay of Bengal coast. Cogent Environmental Science, 2(1): 1140001.

Rahman, M.S., et al. (2019). Assessment of heavy metals contamination in marine fish species. Environmental Nanotechnology, Monitoring and Management, 11: 100210.

Islam, M.S. (2003). Perspectives of coastal and marine fisheries of the Bay of Bengal. Ocean and Coastal Management, 46(8): 763–796.

Islam, A.A.M.S., Hossain, M.M., Ahmed, M., Hossain, S., & Khandaker, M.U. (2021). Terrestrial radionuclides in river sediments and hazards. International Journal of Environmental Analytical Chemistry, 103(16): 3779–3789.

Roy, S.K., & Chowdhury, M.A. (2023). Morphometric analysis of Karnaphuli river basin. River, 3(4): 426–437.

Islam, F., Rahman, M., Khan, S.S.A., Ahmed, B., Bakar, A., & Halder, M. (2013). Heavy metals in water, sediment and fishes. Pollution Research, 32(4): 715–721.

Ali, M.M., et al. (2020). Heavy metal concentrations in fishes with health risk. Human and Ecological Risk Assessment, 26(10): 2646–2662.

Mukut, S., Rahaman, M.M., Azim, M.R., Hossain, M.M., & Uddin, M.H. (2023). Water quality assessment using CCME-WQI method. Asian Journal of Environment and Ecology, 20(14): 1–11.

Tacon, A.G.J., & Metian, M. (2013). Fish matters: importance of aquatic foods. Reviews in Fisheries Science, 21(1): 22–38.

Tidwell, J.H., & Allan, G.L. (2001). Fish as food: aquaculture contribution. EMBO Reports, 2(11): 958–963.

Einarsson, H., Emerson, W., & Emerson, W.K. (Eds.) (2009). International seafood trade: challenges and opportunities. Rome: FAO.

Shahjahan, M., Taslima, K., Rahman, M.S., Al-Emran, M., Alam, S.I., & Faggio, C. (2022). Effects of heavy metals on fish physiology. Chemosphere, 300: 134519.

Zeitoun, M.M., & Mehana, E.S.E. (2014). Impact of water pollution with heavy metals on fish health. Global Veterinaria, 12(2): 219–231.

Hossain, M.B., Shanta, T.B., Ahmed, A.S., Hossain, M.K., & Semme, S.A. (2019). Heavy metal contamination in Sangu River estuary. Marine Pollution Bulletin, 140: 255–261.

Shahjahan, M., et al. (2022). Effects of heavy metals on fish physiology: a review. Chemosphere, 300: 134519.

Ray, S., & Vashishth, R. (2024). Bioaccumulation of heavy metals and human health risks. Emerging Contaminants, 10(4): 100358.

Ray, S., & Vashishth, R. (2024). Bioaccumulation of heavy metals in fish and health risks. Emerging Contaminants, 10(4): 100358.

Zahran, E., et al. (2025). Impact of heavy metal pollution in fish. Aquaculture International, 33(5): 371.

Das, M., Paul, M., Das, J., & Mandal, B. (2022). Effect of heavy metals in fish reproduction. Journal of Ecobiology, 34(3): 637–642.

Alam, M., Haque, M., Chowdhury, M., Hossain, M., & Khatun, M. (2025). Heavy metals contamination in water, soil and fishes. Journal of Public Health and Community Medicine, 4(4): 145.

Alam, M., Rohani, M.F., & Hossain, M.S. (2023). Heavy metals accumulation in fish species. Emerging Contaminants, 9(4): 100254.

Hussein, M.A., et al. (2023). Risk assessment of toxic residues in fish. Frontiers in Veterinary Science, 10.

Hossain, M.B., et al. (2022). Heavy metals in marine fish and shrimp. Biology, 11(12): 1780.

Reksten, A.M., et al. (2021). Metal contents in fish from Bay of Bengal. Foods, 10(5): 1147.

Akter, S., et al. (2019). Heavy metals in dried fish of Bangladesh. Bangladesh Journal of Zoology, 47(2): 293–304.

Kar, M., et al. (2020). Monitoring heavy metals in marine dried fish. Grassroots J. of Nat. Resources, 3(2): 30–41.

Baki, M.A., et al. (2018). Heavy metals in seafood and human health assessment. Ecotoxicology and Environmental Safety, 159: 153–163.

Khatun, N., Nayeem, J., Deb, N., Hossain, S., & Kibria, M.M. (2021). Heavy metals contamination and health risk. Toxicology and Environmental Health Sciences, 13(4): 375–388.

Hoque, M.S., et al. (2022). Public health risks from heavy metals in dried fish. Environmental Science and Pollution Research, 29(14): 20112–20127.

Ali, M.M., Ali, M.L., Proshad, R., Islam, S., Rahman, Z., & Kormoker, T. (2020). Trace elements in demersal fishes. Thalassas, 36(2): 641–655.

Biswas, K.P., et al. (2021). Pollution risks in marine fish and crustaceans. Environments, 8(2): 13.

Amirah, M.N., Afiza, A.S., Faizal, W.I.W., Nurliyana, M.H., & Laili, S. (2013). Human health risk assessment of metal contamination through fish consumption. Journal of Environmental Pollution and Human Health, 1(1): 1–5.

Oros, A. (2025). Bioaccumulation and trophic transfer of heavy metals in marine fish. Journal of Xenobiotics, 15(2): 59.

Islam, M.S., Proshad, R., & Ahmed, S. (2022). Ecological risk of heavy metals in sediments. Human and Ecological Risk Assessment, 28(1): 1–18.

Hossain, M., Jamil, M., Mia, M., Uddin, M., & Mansur, M. (2017). Heavy metal concentration in dried marine fish. Journal of Environmental Science and Natural Resources, 10(1): 25–32.

Hoque, M.M.M., Khatun, S., Islam, M.S., Klanti, M.S.M., Adnen, K.S., Kabir, M.H., Hoq, M.E., & Tusher, T.R. (2026). Toxic metals in dried marine fish. Food Safety and Health, 1: 1–15.

Rahaman, M.A., Jahan, I., Alam, S.S., Shill, L.C., Dihan, A.M., & Mamun, A.A. (2026). Heavy metal contamination in marine fish. MedRxiv.