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Heavy Metal Intake by Fishes of Different River Locations in Bangladesh: A Comparative Statistical Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Bangladesh a nation with a high population density, gets all of the protein it needs from river fishes. The observation is very alarming that heavy metals polluted the major river water by the growing garment washing, dyeing and textile, fertilizer, cement, tannery, metal, electrochemical and pharmaceutical industries were the main culprits that don't have proper effective effluent treatment plants (ETP). High-value heavy metals in industrial area river fish as chromium (Cr) 164.73 mg/kg in *Heteropneustes fossilis* (stinging catfish) at Buriganga River, Hazaribagh, zinc (Zn) 309.47 mg/kg in *Mastacembelus armatus* (Bain) fish at Bangshi river, Savar, copper (Cu) 26.33 mg/kg in *Mastacembelus armatus* (Bain) at Bangshi river, Savar, arsenic (As) 5.64 mg/kg in *Heteropneustes fossilis* (stinging catfish) at Bangshi river, Savar, lead (Pb) 18.16 mg/kg in *Channa punctatus* (Taki) at Buriganga river, Hazaribagh and cadmium (Cd) 2.03 mg/kg in *Heteropneustes fossilis* (stinging catfish) at Buriganga river, Hazaribagh were observed. The two rivers are identified as most contaminated by heavy metals one is the Bangshi River, Savar, Gazipur and another one Buriganga River, Hazaribagh. The main reason for the contamination of these two rivers was uncontrolled industrialization around Dhaka and in Hazaribagh, a huge number of tanneries have grown that use a huge quantity of Cr creating a threat to the ecosystem and even a serious health risk for humans. Heavy metals that fish consume are contaminating river water ecosystems. This contamination spreads to human bodies and is the cause of many serious ailments.

Keywords: Eco-system; effluent; health effect; heavy metal; point and non-point source; toxicity.

1. INTRODUCTION

Heavy metals are generally characterized as metals with elevated densities, atomic weights or atomic numbers [1]. Heavy metals and metalloids are inherently non-biodegradable and possess the capacity to adversely impact human health, both by direct and indirect means [1]. Environmental contamination has become a global threat and heavy metals are regarded as one of the most significant polluting agents [2]. Heavy metal pollution in aquatic ecosystems is a primary apprehension due to the toxicity, permanence, non-biodegradable nature and abundance of these metals in the environment [3]. Also, the accumulation of heavy metals in aquatic habitats poses a severe threat [3,4]. The primary causes of heavy metal pollution in aquatic environments include industrialization, urbanization, agriculture, and natural processes [5]. The expeditious growth of industries, the proliferation of cities and sundry anthropogenic undertakings have led to the extensive dissemination of cadmium (Cd), lead (Pb) and chromium (Cr) in the ecosystem [6]. As a developing nation, the heavy metal concentration in the aquatic environment has escalated and intensified concerns in Bangladesh [7,8,158,159,160], in addition to the lethal toxicity, intrinsic persistence, non-biodegradability and accumulative nature of these metals [9]. The rivers around Dhaka and Chittagong, namely, the Buriganga, Turag, Shitalakhya, and Karnaphuli, are extensively contaminated with Cd, Pb and Cr [10-13]. The quality of river water can be adversely impacted by industrial discharge and sewage by the addition of heavy metals [14]. In addition, the species of fish from the contaminated river intake heavy metal in a high concentration [14,15]. The significant volume of traffic [16] also adds significantly to the heavy metal and metalloid concentrations in the soil and water that cause pollution. Aquatic species such as fish and invertebrates are susceptible to contamination from inadequately treated both point-source (industries) and non-point-source (agriculture) pollutants [17]. For instance, the contamination of surface water, the disposal of agricultural and industrial effluents and the application of chemical fertilizers and pesticides comprise the dominant sources of heavy metal contamination [17].

On the contrary, fish is usually ingested owing to its lipid, protein, vitamin and mineral constituents and primarily the existence of long-chain omega-3 polyunsaturated fatty acids (PUFAs) [18]. Moreover, alongside long-chain omega-3 PUFAs, researchers have identified numerous other components of fish that are beneficial to human health [19]. While certain trace metals are necessary for maintaining human metabolism, they may be toxic when present in excessive concentrations. Moreover, certain metals, namely Cadmium, Lead and Mercury, possess high toxicity [20]. As the concentrations of these metals reach the permissible optimal limit, they progressively mix in water, ultimately sediment into sedimentary strata [21]. Through feeding upon benthic and pelagic species-contaminated water, they accumulate within the bodies of fish, generating differences between their uptake and elimination rates [21,22]. The established maximum tolerance range for Cr is 0.1-1.0 mg/kg by the standards of FAO [24] (Food and Agriculture Organization), WHO (World Health Organization) [25] and MOFL [23] (Ministry of Fisheries and Livestock). The upper limit for Cu consumption in children aged 1.0 – 3.0 years is 1.0 mg/ per day while for adults aged 19.0-70.0, it is set at 10.0 mg per day [26]. The concentration of Pb, as set by FAO [24], is 0.5 mg/kg while the Joint Expert Committee on Food Additives (JECFA) [28] permits up to 3.0 mg/kg. In Bangladesh, the MOFL [23] has set the permissible limit for Pb at 0.3 mg/kg. The FAO/WHO [29] and EU (European Union) [30] have proposed a maximum permissible limit of 100.0 mg/kg and 30.0 mg/kg for Zn in fish and fish products, respectively. The established permissible limit for As is 1.0 mg/kg set by the California Environmental Protection Agency (CEPA) and FAO [24]. On the other hand, the accepted limit set by MOFL [23] in Bangladesh is 5.0 mg/kg. The acceptable limit for Cd 0.1 mg/kg is established by FAO and WHO [25]. Also, the limit for Cd set by MOFL [23] is 0.25 mg/kg. Prolonged exposure to heavy metals and metalloids can result in damage to multiple organs such as the kidneys, liver, lungs, brain and bones [31,32]. The higher concentration of Cr intake in food or fish and the most severe instances, it may give rise to pulmonary ailments [33] and inflict damage upon vital organs including the liver, lungs and kidneys [34] and cause cancer. Overconsumption of Cu may lead to injury in the liver and kidneys [27]. From this vantage point, the review ought to emphasize the harmful consequences that heavy metals have on human health as well as the possibility of various health problems and contaminated fish in various Bangladeshi river regions.

2. MATERIALS AND METHODS

2.1 Study Area

The location or area selected for this study is two different sites, site 1 is the industrial zone river and site 2 is the coastal zone river and available fishes of that area river. For example, in Fig.1. shows the taken Dhaka and surrounding Dhaka area river study data for analysis of industrial zone river fishes heavy metal contamination and for coastal zone like as Sundarbans, Noakhali, Chandpur, Chittagong Port, Bhola, Coxes bazar etc. area river fish's study on heavy metal contamination. Different locations of rivers in Bangladesh like as upper Meghna River, Chandpur, Bangshi River, Savar, Turag River, Dhaka, Buriganga River, Dhaka, Shitalakha River, Narayanganj, Meghna River adjacent to Narsingdi, Buriganga river, Hazaribagh Beside tannery, Dhaleshwari river, Tangail, Meghna Estuary River, Noakhali, Meghna Estuary River, Bhola, Chittagong Port, Cox's Bazar, Sundarbans, river in Chandpur and river in Noakhali samples were under-investigated.

2.2 Research Sample Collection

We investigate the study data for six (6.0) local fishes as *Heteropneustes fossilis* (stinging catfish), *Tenualosa ilisha* (Ilish), *Channa punctatus* (Taki), *Trichogaster fasciata* (Kholshe), *Mastacembelus armatus* (Bain) and *Anabas testudineus* (Koi) fish of Bangladesh and different locations of rivers in Bangladesh like as upper Meghna river, Chandpur, Bangshi river, Savar, Turag river, Dhaka, Buriganga river, Dhaka, Shitalakha river, Narayanganj, Meghna river Adjacent to Narsingdi, Buriganga river, Hazaribagh Beside tannery, Dhaleshwari river, Tangail, Meghna Estuary river, Noakhali, Meghna Estuary river, Bhola, Chittagong Port, Cox's Bazar, Sundarbans, river in Chandpur and river in Noakhali.

2.3 Sample Preparation

Firstly, the fish sample was washed with deionized water and soaked with tissue paper or soft cotton fabric aim is to remove the moisture and then gut and flesh separation and collection in a watch glass for each separated sample [36]. The identification and analysis of Pb, Cd and Cr required about 20.0 g of samples in cleaned beakers [36]. The samples dried in an oven at 105.0 ^{0}C daylong. From the dry oven, the beaker containing the sample was placed in a muffle covering with a watch glass remaining gap at 150.0 ^{0}C for 1.0 hour and then the temperature raising 200.0 ^{0}C, 300.0 ^{0}C and 400.0 ^{0}C gradually to avoid the loss of the sample and maintaining each temperature for an hour and lastly the temperature raised to 550.0 ^{0}C and kept for 4.0 to 5.0 hours for getting white colour ash and that is free from carbon [36]. After complete ashing, the beaker of the sample was removed from the furnace. After that, 1.0 to 3.0 ml of concentrated nitric acid and distilled water with a ratio of 1:1 is added to the beaker to remove the rest amount of the carbon from the sample and then heated on the hot plate at about 150.0 ^{0}C under the fume hood to remove the fume until dry [36]. The beaker was again taken in the furnace for heating at 550.0 ^{0}C for 2.0 to 3.0 hours after that cooled. The sample was taken in volumetric flux for rinse with distilled water. The flax was shaken well to mix uniformly then it was transferred in a black or non-transparent plastic bottle then it was filtered with filter paper and sample-making for heavy metal analysis [36].

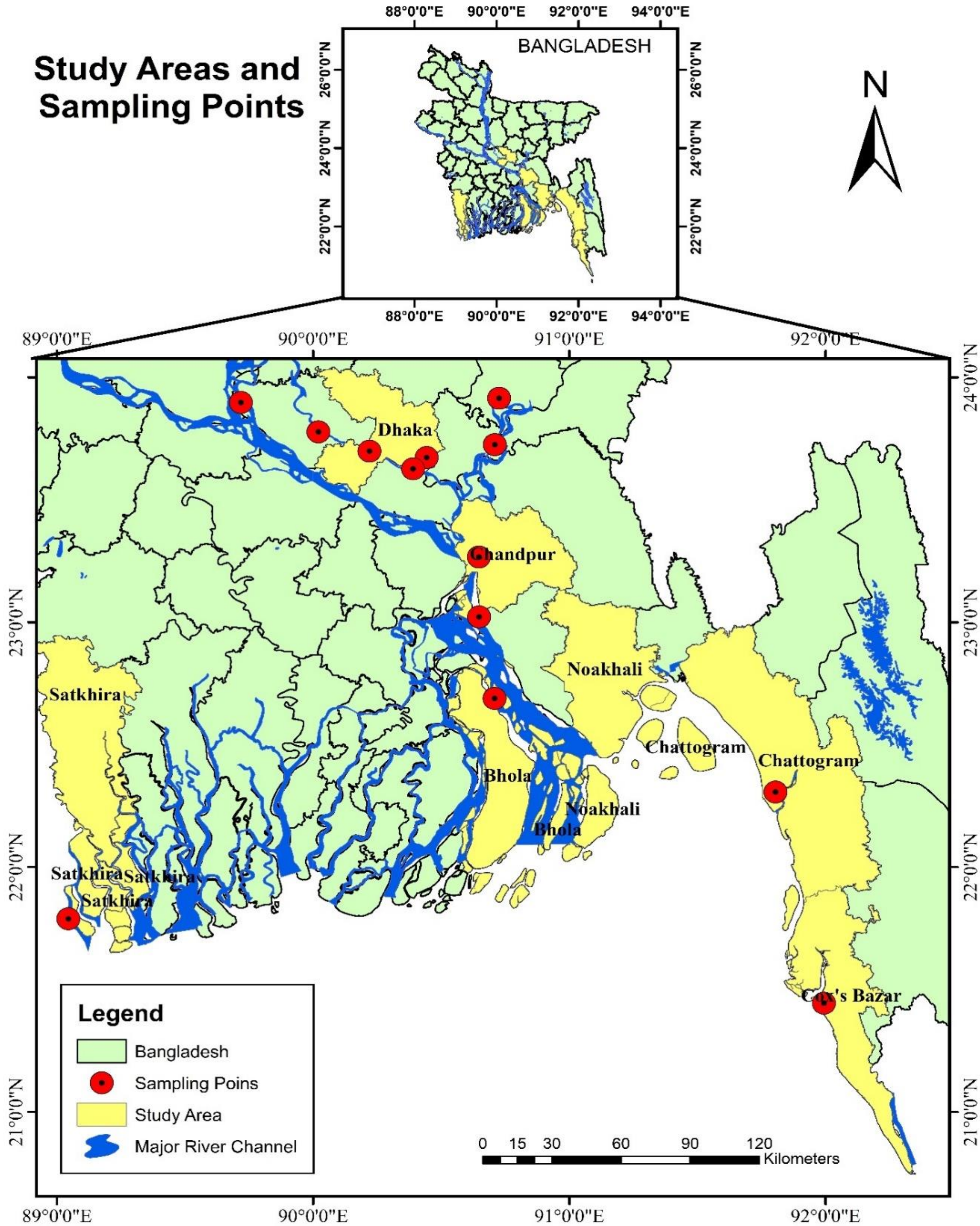

Fig. 1. The map showing the sampling points

For the analysis of Hg and as required relatively low boiling point, about 20.0 g of fish samples were taken in cleaned and dried beakers and then 20.0 ml of concentrated nitric acid and 10.0 ml of concentrated perchloric acid were added to each sample into the beakers [36]. The sample in beakers is boiled for digestion on the hot plate at 180.0 - 200.0 ^{0}C covering with a watch glass under a fume hood chamber to almost dryness [36]. The process is repeated until a colourless solution is obtained by evaporating the volatile organic matter after complete decomposition with oxidizing acids. After being taken in volumetric flux, the sample was rinsed with distilled water. After giving the flax, a good shake to ensure uniform mixing, it is put in a black or opaque plastic bottle, filtered using filter paper and then used as a sample for heavy metal analysis [36]. Three replicates are made for each fish sample preparation in both of the above processes. A sample blank is also prepared in both processes following the same procedure as described for quality control [36].

2.4 Characterization

2.4.1 Basic principle of detection and determination of heavy metal

Atomic Absorption Spectroscopy (AAS) is a method in Spectro analysis employed for the precise determination of chemical elements by fixing the absorption of optical radiation, specifically light through free atoms in the gaseous phase state [35]. Block diagram of an atomic absorption spectrometer in Fig. 2. To analyze a sample's atomic components, firstly it must be atomized using flame or electrothermal (graphite tube) atomizers, both of which are commonly used today. The resulting atoms are then exposed to optical radiation which may from a line or continuum radiation source specific to the element in question [35]. This radiation is then passed through a monochromator to distinguish it from any extraneous radiation generated by the source and is eventually quantified by a detector [35].

For the detection of Pb, Cr and Cd concentrations of samples for both water and fish use the GFAA method by electrothermal AAS (ET AAS) [35-38]. The concentration of Hg in the samples is analyzed by utilizing the cold vapour hydride generation technique in AAS [36]. Similarly, the electric hydride vapour generation technique in AAS is applied for the determination of the concentration of As in the samples [36]. A schematic diagram for AAS is shown in Fig. 3.

The Method Detection Limit (MDL) for heavy metals such as lead Pb, Cd, Cr, Hg and As to be 4.3411, 0.1986, 1.7963, 0.8071 and 0.0799 μgL^{-1}, correspondingly [36]. On the other hand, for the detection of heavy metal Cr, Ni, Pb, Cu and Zn in river water by AAS and using the 3.0 algorithms like MLP (Multilayer perceptron) for Ni, RBN (Radial basis function network) for Cu and Zn, ANFIS (Adaptive neuro-fuzzy inference system) for Pb [53]. Some conventional techniques are also used for the detection of heavy metals [54] described in Table 1.

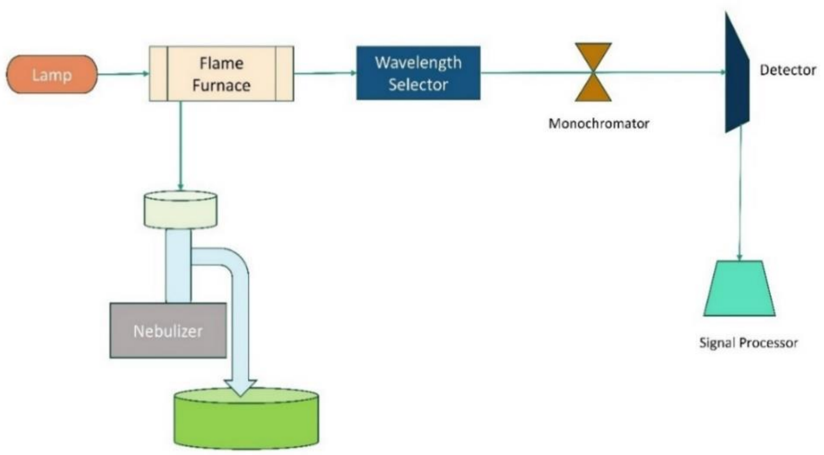

Fig. 2. Block diagram of single-beam instrument AAS [35,37]

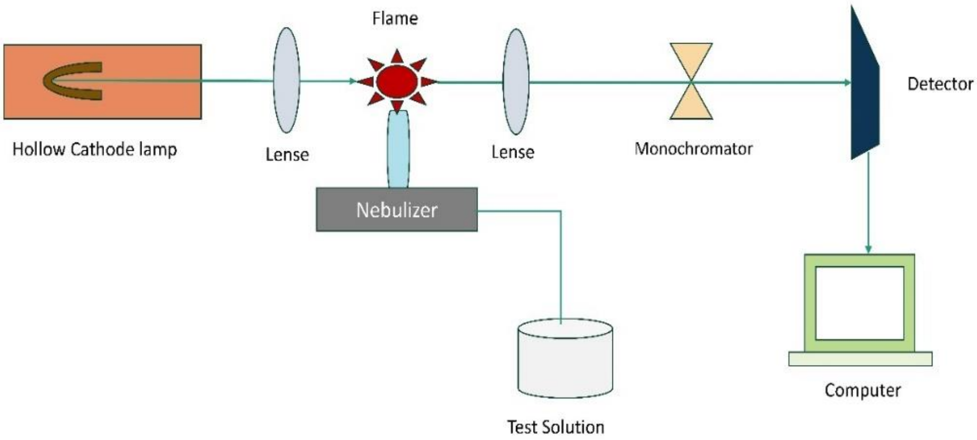

Fig. 3. Operating principals and schematic diagram of AAS [37,53-54]

Table1. Summary of conventional technique for the detection of heavy metal

Heavy metal	Sample pretreatment	Methods of detection	Detection limit	References
As	UV digestion and preconcentration using Aspergillus niger-activated charcoal as Biosorbent	ETAAS	1.0 µg L^{-1}	[39]
Cr	pre-concentration using ion exchange media (N. Zhang, et al., 2008) Separation on a Dionex AS4A anion exchange column	EDXRFS	0.40 mg L^{-1}	[40]
	Pyrolysis and atomization using rhodium permanent modifier	ETAAS	0.20 µg L^{-1}	[41]
	Solid-phase extraction	ICP-MS	4.43 ng L^{-1}	[42]
	Separation on a Dionex AS4A anion exchange column	CL	0.05 µg L^{-1}	[43]
Zn	Preconcentration on a microcolumn of immobilized Alizarin Red S on alumina	FAAS	0.20 µg L^{-1}	[44]
	Chelating with 5,7 dichloro-oxine	AAS	0.50 µg L^{-1}	[45]
	In situ pre-concentration with the dual silica tube atom trap	AAS	0.30 µg L^{-1}	[46]
	CPE pre-concentration	FAAS	0.095 µg L^{-1}	[47]
	DLLME pre-concentration	Spectrophotometric	0.50 µg L^{-1}	[48]
Cu	CPE pre-concentration	FAAS	1.50 µg L^{-1}	[49]
		ICP-AES	0.014 mM	[50]
	Chelating 1,10-phenanthroline	CL	0. 40 mM	[51]
	solid-phase extraction	FAAS	0.20 µg L^{-1}	[52]

3. RESULTS AND DISCUSSION

3.1 Heavy Metal Concentration in Fish

Fish contamination with heavy metals poses a serious risk to both human and aquatic life [61]. The initial stage in assessing the scope of contamination in fish is to ascertain the concentration of heavy metals. Human health is at risk due to environmental contamination by heavy metals [59]. The presence of heavy metals Zn, Cd, Pb, Cu, As and Cr in six (6.0) different species of fish is investigated in different rivers of Bangladesh in different regions.

For *Heteropneustes fossilis* (stinging catfish), in Table 2 the heavy metal intake quantity observed highest Cr 164.73 mg/kg, Zn 184.06 mg/kg, Pb 11.05 mg/kg and Cd 2.03 mg/kg in Buriganga River, Hazaribagh [56] beside Tannery and the hierarchy of heavy metal as follow Zn (184.06 mg/kg) > Cr (164.73 mg/kg) > Pb (11.05 mg/kg) > Cd (2.03 mg/kg) and lowest concentration of heavy metal determined (Cr 0.102±0.021 mg/kg, As 0.035±0.006 mg/kg, Pb 0.183±0.057 mg/kg and Cd 0.063 ± 0.012 mg/kg) in Dhaleshwari River, Tangail [36] and by hierarchy of heavy metal array as follow Pb 0.183±0.057 mg/kg > Cr 0.102±0.021 mg/kg > As 0.035±0.006 mg/kg > Cd 0.063 ± 0.012 mg/kg. On the other hand, in Bangshi River, Savar, Gazipur [23] fish also intake a high volume of heavy metal (Cr 1.14 mg/kg, Zn 176.98 mg/kg, Pb 8.29 mg/kg, Cu 16.04 mg/kg, As 5.64 mg/kg and Cd 0.46 mg/kg) that is also reported as follow Zn (176.98 mg/kg) > Cu (16.04 mg/kg) > Pb (8.29 mg/kg) > Cr (1.14 mg/kg) > Cd (0.46 mg/kg).

Bangladeshi most popular fish *Tenualosa ilisha* (Ilish) in Table 3, used for the sample analysis is more easily found in coastal areas than in other regions. From the study, the heavy metal intake highest quantity is Cu 14 mg/kg, Cr 2.2 mg/kg, Zn 138 mg/kg, As 13 mg/kg, Pb 0.63 mg/kg, Cd 0.075 mg/kg. in Cox's Bazar [23] and the hierarchy of heavy metals as follows Zn (138.0 mg/kg) > Cu (14 mg/kg) > As (13 mg/kg) > Cr (2.2 mg/kg) > Pb (0.63 mg/kg) > Cd (0.075 mg/kg). The lowest concentration of heavy metal determined in Meghna River Narsingdi [55] as follows as Zn (11.31 mg/kg), Cu (1.21 mg/kg), Pb (0.67 mg/kg), Cd (0.092 mg/kg) [2] and the hierarchy of heavy metal array as follow as Zn (11.31 mg/kg) > Cu (1.21 mg/kg) > Pb (0.67 mg/kg) > Cd (0.092 mg/kg).

For *Channa punctatus* (Taki) in Table 4, the heavy metal intake quantity highest (Cr 49.36 mg/kg, Zn 184.46 mg/kg, As below description level, Pb 18.16 mg/kg, Cd 0.717 mg/kg.) in Buriganga River, Hazaribagh Beside Tannery [56] and the hierarchy of heavy metal array as follows Zn (184.46 mg/kg) > Cr (49.36 mg/kg) > Cu > As (13.0 mg/kg) >, Pb (18.16 mg/kg) > Cd (0.717 mg/kg) and lowest concentration of heavy metal determined in Dhaleshwari River, Tangail [36] as follows Pb (0.133 ± 0.041 mg/kg) >Cr (0.032 ± 0.007 mg/kg) > As (0.016 ± 0.003 mg/kg) > Cd (0.011 ± 0.002 mg/kg).

For *Trichogaster fasciata* (Kholshe) in Table 5, the heavy metal intake quantity highest (Cu 4.1 mg/kg, Cr 2.50 mg/kg, As 0.36 mg/kg, Pb 1.20 mg/kg) in Buriganga River, Dhaka [23] and the hierarchy of heavy metal as follow Cu 4.10 mg/kg > Cr 2.50 mg/kg > Pb 1.20 mg/kg > As 0.36 mg/kg and lowest concentration of heavy metal determined in Shitalakha River, Narayanganj [23] as follows Cu (3.80 mg/kg), Cr (1.4 mg/kg), and As (0.22 mg/kg), Pb (0.69 mg/kg) and the array as follow Cu (3.80 mg/kg) > Cr (1.4 mg/kg) > Pb (0.69 mg/kg) > As (0.22 mg/kg).

For *mastacembelus armatus* (Bain) in Table 6, the heavy metal intake quantity highest (Cu 26.33 mg/kg, Cr 0.79 mg/kg, Zn 309.47 mg/kg, As 2.11 mg/kg, Pb 2.64 mg/kg, Cd 0.19 mg/kg) in Bangshi River, Savar [60] and the hierarchy of heavy metal array as follow Zn (309.47 mg/kg) > Cu (26.33 mg/kg) > Pb (2.64 mg/kg) > As (2.11 mg/kg) > Cr (0.79 mg/kg) > Cd 0.19 mg/kg. The lowest concentration of heavy metal determined in Dhaleshwari River, Tangail [36] as follows Cr (0.159 ± 0.033 mg/kg), As (0.027 ± 0.004 mg/kg), Pb (0.091 ± 0.028 mg/kg), Cd (0.005 ± 0.001 mg/kg) and the array as follow Cr (0.159 ± 0.033 mg/kg) > Pb (0.091 ± 0.028 mg/kg) > As (0.027 ± 0.004 mg/kg) > Cd (0.005 ± 0.001 mg/kg).

Among the studied values for *Anabas testudineus* (Koi) in Table 7, the heavy metal intake quantity highest (Cu 32.49 mg/kg, Cr 7.86 mg/kg, Zn 107.22 mg/kg, Pb 0.68 mg/kg) at River in Noakhali [61] and the hierarchy of heavy metal as follow Zn (107.22 mg/kg) > Cu (32.49 mg/kg) > Cr (7.86 mg/kg) > Pb (0.68 mg/kg). The lowest concentration of heavy metal determined in Meghna River, Narsingdi as follow Cu (0.82 mg/kg), Cr (0.19 mg/kg), Zn (15.61 mg/kg) [55] and the array as follows Zn (15.61 mg/kg) > Cu (0.82 mg/kg) > Cr (0.19 mg/kg). For the determination and risk-free heavy metal intake in food, some international organizations and countries have set the standard limit value for heavy metals in Table 8. which shows the limit values set by FAO [30], WHO [62], FDA [28], EU [64], FSG [67], Bangladesh [68], India [69], Malaysia [70], China [71], International Criterion [30] etc.

3.1.1 Chromium (Cr)

The main sources of Cr contamination in fish are tannery and poultry waste that is used as a source of fish feed in Bangladesh which significantly increases the contamination in fish [137]. Cr causes acute and chronic toxicity in the living organism. It is carcinogenic and causes cancer [74, 111]. The different locations of the river and six (6.0) fish sample data in which the majority are exceeding the limit of national [68] and international [67] guidelines. The highest value of Cr found in Buriganga River, Hazaribagh [56] beside tannery and for fishes *Heteropneustes fossilis* (stinging catfish) is 164.0 mg/kg and *Channa punctatus* (Taki) is 49.36 mg/kg, another relatively high value observed in the River in Noakhali [61] for the fish *Anabas testudineus* (Koi) is 7.86 mg/kg. The maximum tolerance limit for Cr is 0.1-1.0 mg/kg by the standards of FAO [24], WHO [25] and MOFL [23].

3.1.2 Copper (Cu)

Copper is an essential element that benefits sound health by adding iron to form haemoglobin [132]. However limitless intake of Cu may cause liver and kidney damage [133,134]. From the observation the highest intake of Cu 32.49 mg/kg in *Anabas testudineus* (Koi) fish at the River in Noakhali [61]. On the other hand, at the Bangshi River, Savar [60] found the fish *Mastacembelus armatus* (Bain) intake amount of Cu is 26.33 mg/kg and *Heteropneustes fossilis* (stinging catfish) is 16.40 mg/kg. The upper limit for copper (Cu) consumption in children aged 1.0 – 3.0 years is 1.0 mg per day, while for adults aged 19-70.0, it is set at 10.0 mg per day [26]. The maximum standard limit for Cu is 30.0 mg/kg by FAO [24], WHO [25], FSG [67], India [69] and Malaysia [70] but in Bangladesh [68] the set limit is 5.0 mg/kg.

3.1.3 Arsenic (As)

As contamination in water is difficult to stop because it is caused by natural and man-made sources [111]. It has the risk of cancer and causes skin lesions [74,111]. The recordable value for As obtained in a fish sample of *Heteropneustes fossilis* (stinging catfish) is 5.64 mg/kg at Bangshi River, Savar [60] exceeds the set limit value by MOFL [23] in Bangladesh is 5.0 mg/kg. The established permissible limit for As is 1.0 mg/kg set by the California Environmental Protection Agency (CEPA) and FAO [24].

3.1.4 Zinc (Zn)

Zinc plays an important role in the physiology and metabolic processes of various organisms in the human body but excess concentrations of this element can be poisonous and result in Parkinson's disease [135]. The highest value of Zn from analyzed data obtained in *Mastacembelus armatus* (Bain) fish is 309.47 mg/kg at Bangshi River, Savar [60] also for *Heteropneustes fossilis* (stinging catfish) is 176.98 mg/kg. On the other hand, at the Buriganga River, Hazaribagh [56] the intake amount of Zn in fishes was 184.46 mg/kg and 186.06 mg/kg respectively for *Channa punctatus* (Taki) and *Heteropneustes fossilis* (stinging catfish). The FAO/WHO [29] and EU (European Union) [30] have proposed a maximum permissible limit is 100.0 mg/kg and 30.0 mg/kg for Zn in fish and fish products, respectively.

3.1.5 Lead (Pb)

Lead is a very toxic element that accumulates in the body and damages the central nervous system. The riskiest relative to children and pregnant women [74,111,115]. Among the analyzed data at Buriganga River, Hazaribagh [56] the two fishes sample *Channa punctatus* (Taki) and *Heteropneustes fossilis* (stinging catfish) intake high amounts of Pb as 18.16 mg/kg and 11.05 mg/kg respectively which observed exceeding the maximum standard value in Bangladesh, the MOFL [23] has set the permissible limit for Pb at 0.30 mg/kg. Also, international organizations and countries set their permissible limit as like FAO [24] set 2.00 mg/kg, WHO [25] 0.50 mg/kg, FDA [28] 1.50 mg/kg, India [69] 0.30 mg/kg, Malaysia [70] 0.30 mg/kg, China [71] 3.0 mg/kg respectively.

3.1.6 Cadmium (Cd)

Cadmium is a type of element which creates chronic toxicity even if a trace amount is 1.0 mg/kg in food or fish samples [135]. The highest intake of Cd found in *Heteropneustes fossilis* (stinging catfish) is 2.03 mg/kg at Buriganga River, Hazaribagh [56] which exceeds the limit value of the standard. The acceptable limit for Cd 0.10 mg/kg is established by FAO and WHO [25]. Also, the limit for Cd set by MOFL [23] is 0.25 mg/kg. It is observed that highly industrialized and highly urbanized area rivers are highly contaminated by heavy metals that are generated from different industries, sewage, untreated wastewater and point and non-point sources [9,74,75].

3.2 Water Pollution by Heavy Metal from Different Sources and Intake by Fish

Heavy metal contamination is responsible for two distinct sources in water, one is pointing sources and another is non-point sources Fig. 4. [9,74]. The point source contaminates the surface water source like rivers, lakes, cannel and ponds by direct discharge or overflow. Non-point source contaminants pollute surface water by rainwater [73]. The anthropogenic/man-made/artificial sources of water contamination are called heavy metal contamination which is caused by human activity. Heavy metal contamination in water is caused by different industrial activities, Agriculture and domestic sources [75].

In the past period, there was a significant increase in the contamination of heavy metals in the surface and groundwater [76]. Different industries cause pollution by harmful heavy metals like Cu, Cr, Pb, Zn, As, Hg and Cd in surface water [77]. Due to rapid industrialization, the production of industrial effluent progressively increased [78]. Industries including Ceramic application, plastic manufacturing, tanning, chrome plating, coal mining, metalworking, plastic manufacturing, food production, cement industry and agrochemical wastes are responsible for the pollution of dangerous heavy metals in water sources Fig. 5 both surface and groundwater [79].

Industrial discharge effluent is partially treated or untreated wastewater containing heavy metals polluting water which is a significant factor for health issues for both humans and other animals like fish and phytoplankton [80]. The principal constituents of domestic waste are living microorganisms and biodegradable substances [81]. Out of this constituent, domestic waste also provides nitrates, chlorides, nutritive elements, surfactants, lubricants, sewage and noxious metallic compounds [81]. From a previous study in India, the Yamuna River is polluted by domestic waste. The main culprits of domestic contamination are densely populated urban settlements that are polluted by dumping of waste into the river [81].

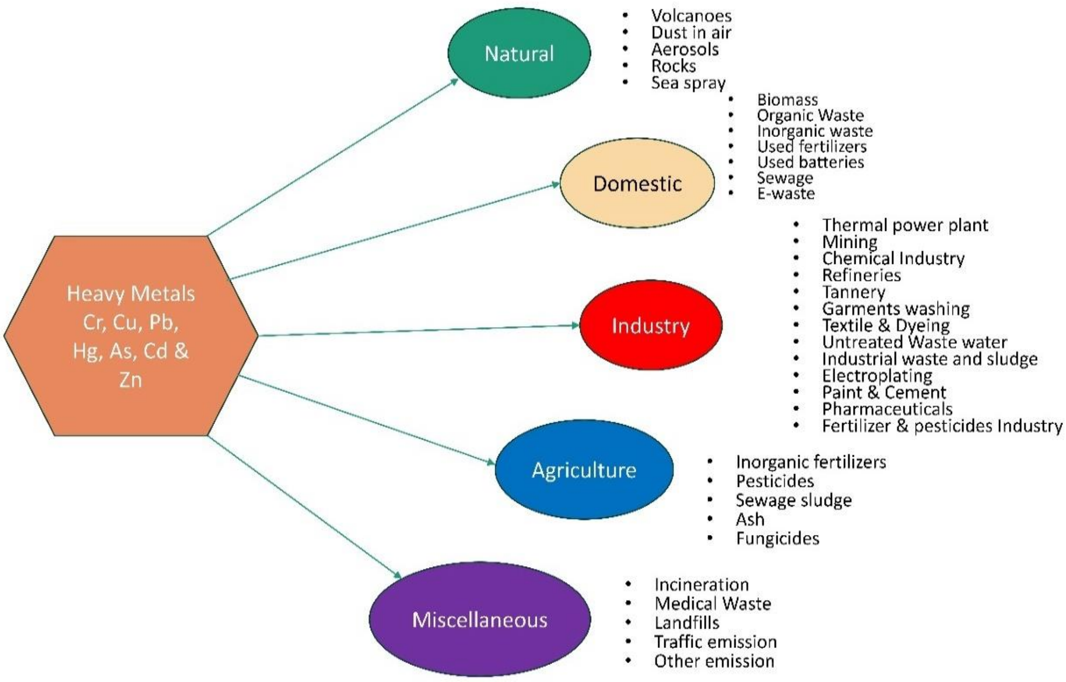

Fig. 4. Sources of heavy metals [73-78].

Table 2. Heavy metal concentration (mg/kg) in *Heteropneustes fossilis* that are intake from the different rivers in Bangladesh

Fish species	Name of the river and location	Concentrations (mg/kg) of heavy metal						References
		Cu	Cr	Zn	As	Pb	Cd	
Heteropneustes fossilis (stinging catfish)	Upper Meghna River,Chandpur	1.22	1.30	1.10	0.14	0.85	0.25	[23]
	Bangshi River, Savar	16.04	1.14	176.98	5.64	8.29	0.46	[23]
	Turag River,Dhaka	3.40	1.15	-	0.14	0.65	-	[23]
	Buriganga River, Dhaka	4.40	2.10	-	0.24	1.0	-	[23]
	Shitalakha River, Narayanganj	3.60	1.10	-	0.22	1.0	-	[23]
	Meghna River Adjacent to Narsingdi	1.76	3.01	13.10	-	1.56	-	[55]
	Buriganga River, Hazaribagh Beside Tannery	-	164.73	184.06	-	11.05	2.03	[56]
	Dhaleshwari River, Tangail	-	0.102±0.021	-	0.035±0.006	0.183±0.057	0.063 ± 0.012	[36]

Table 3. Heavy metal concentration (mg/kg) in *Tenualosa ilisha* is consumed from the different coastal rivers in Bangladesh

Fish species	Name of the river and location	Concentrations (mg/kg) of heavy metal						References
		Cu	Cr	Zn	As	Pb	Cd	
Tenualosa ilisha (Ilish)	Meghna Estuary River, Noakhali	4.06	0.64	-	0.82	3.33	0.10	[23]
	Meghna Estuary River, Bhola	1.60	0.32	34.0	0.76	0.25	0.051	[57]
	Chittagong Port	5.90	1.10	53.0	2.70	0.51	0.06	[23]
	Cox's Bazar	14.0	2.20	138.0	13.0	0.63	0.075	[23]
	Sundarbans	1.30	0.15	3.0	0.76	0.06	0.033	[23]
	Meghna River, Narsingdi	1.21	0.05	11.31	-	0.67	0.092	[55]

Table 4. Heavy metal concentration (mg/kg) in *Channa punctatus* is an intake from the different rivers in Bangladesh

Fish species	Name of the river and location	Concentrations (mg/kg) of heavy metal						References
		Cu	Cr	Zn	As	Pb	Cd	
Channa punctatus (Taki)	Upper Meghna River, Chandpur	0.59	1.12	1.23	0.42	0.16	0.13	[23]
	Turag River, Dhaka	1.20	1.30	-	0.093	0.13	-	[58]
	Buriganga River, Dhaka	2.70	1.40	-	0.092	0.81	-	[58]
	Shitalakha River, Narayanganj	2.50	1.10	-	0.12	0.16	-	[58]
	Meghna River, Narsingdi	0.32	-	12.40	-	-	-	[55]
	Buriganga River, Hazaribagh Beside Tannery	-	49.36	184.46	-	18.16	0.717	[56]
	Dhaleshwari River, Tangail	-	0.032±0.007	-	0.016±0.003	0.133±0.041	0.011±0.002	[36]

Table 5. Heavy metal concentration (mg/kg) in *Trichogaster fasciata* is consumed from the different rivers in Bangladesh

Fish species	Name of the river and location	Concentrations (mg/kg) of heavy metal						References
		Cu	Cr	Zn	As	Pb	Cd	
Trichogaster fasciata (Kholshe)	Turag River, Dhaka	2.20	2.30	-	0.28	0.85	-	[23]
	Buriganga River, Dhaka	4.10	2.50	-	0.36	1.20	-	[23]
	Shitalakha River, Narayanganj	3.80	1.40	-	0.22	0.69	-	[23]

Table 6. Heavy metal concentration (mg/kg) in *mastacembelus armatus* is taken from the different rivers in Bangladesh

Fish species	Name of the river and location	Concentrations (mg/kg) of heavy metal						References
		Cu	Cr	Zn	As	Pb	Cd	
Mastacembelus armatus (Bain)	River in Chandpur	0.66	1.05	1.45	0.69	0.78	0.85	[23]
	Bangshi River, Savar	26.33	0.79	309.47	2.11	2.64	0.19	[60]
	Meghna River, Narsingdi	1.98	-	14.99	-	-	-	[55]
	Dhaleshwari River, Tangail	-	0.159±0.033	-	0.027±0.004	0.091±0.028	0.005±0.001	[36]

Table 7. Heavy metal concentration (mg/kg) in *Anabas testudineus* is consumed from the different rivers in Bangladesh

Fish species	Name of the river and location	Concentrations (mg/kg) of heavy metal						References
		Cu	Cr	Zn	As	Pb	Cd	
Anabas testudineus (Koi)	Upper Meghna River, Chandpur	0.65	1.27	1.85	0.41	0.09	0.02	[23]
	River in Noakhali	32.49	7.86	107.22	-	0.68	-	[61]
	Meghna River, Narsingdi	0.82	0.19	15.61	-	-	-	[55]

Table 8. Heavy metal concentration (mg/kg dry weight) by international guidelines

Standard	Cu (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Hg (mg/kg)	Zn (mg/kg)	Cr (mg/kg)	References
FAO	30.0	2.0	55.0	0.50	-	0.1-1.0	[30]
WHO	30.0	0.50	30.0	0.50	-	-	[62]
ROPME	0.5-19.5	0.01-1.28	0.01-0.75	1.0	-	-	[63]
FDA	-	1.70	70.0	0.5-1.0	-	-	[28]
European Commission	-	1.0	40.0	0.5-1.0	-	-	[64]
NOAA	149.0	128.0	52.0	0.50	-	-	[65]
FAO/WHO Limits	30.0	-	-	0.50	100.0	-	[66]
FSG	30.0	2.0	80.0	-	30.0	12.0-13.0	[67]
Bangladesh	5.0	0.30	-	-	-	1.0	[68]
India	30.0	0.30	-	0.50	50.0	-	[69]
Malaysia	30.0	0.30	-	-	100.0	-	[70]
China	50.0	2.0	-	0.30	-	-	[71]
International Criterion	15.0	0.30	-	0.50	60.0	-	[72]

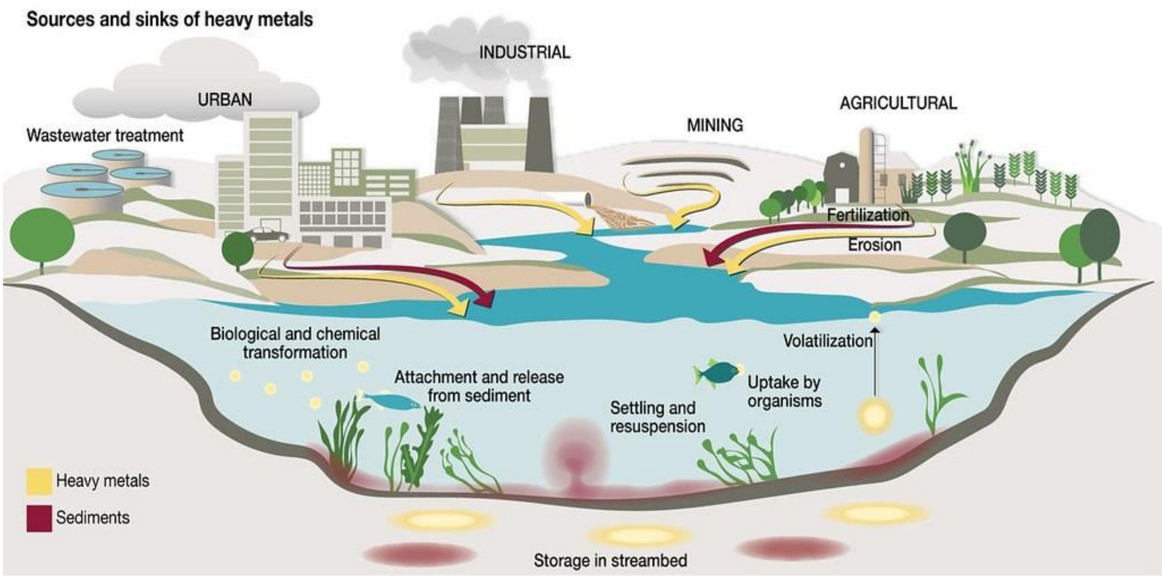

Fig. 5. Water pollution by heavy metals from different sources and contamination of fish and aquatic life [82]

The non-point sources are declared as the pollutants are flow into the river in any way like rain or flood [83]. When run-off the source of pollutants like fertilizer and pesticides contains heavy metals and passes through by stream from the field [83,84] as well as materials have a great impact on different functional approaches [138-149] and crystalline approaches also [150-157] investigation. Agriculture-related heavy metal pollution of the water is responsible by different sources including fertilizers, herbicides, pesticides and agricultural residues as well as high salts brought about by irrigation water application [85]. The produced agricultural waste in the river basin or neighbouring water resources such as ponds, and lakes is naturally decomposed and leaching poisonous heavy metals and contaminate water [86,87]. Furthermore, the heavy metal contamination attributed to the surface water by the use of agrochemicals. Some heavy metals contained in used fertilizers, pesticides and nutrients are as listed Cd, Pb, Cr, As, Hg, Ni, Cu and Zn [88]. The main allocated location for the removal of solid waste is landfilling and it is the reason for extreme ecological degradation and transmissible disease [89,90].

3.3 Toxicity of Heavy Metals and their Adverse Effect on Human Health

Almost fifty (50.0) elements are under the classification of heavy metals and they consist of some metalloids, transition metals and lanthanides. Among them, it was studied seventeen (17.0) elements are categorized as extremely harmful, toxic and easier to obtain [91]. The easy availability and release of this extremely harmful heavy metal create a threat to the ecology and the cancer-causing metals found in research [92,93], environment [94,95] and health concerns [96-98]. From the previous research, it was noted approximately 1.60 million children die in a year due to contaminated water [99]. The decline of surface water sources and groundwater quality due to industrial wastes, urban sewage and agricultural discharge is a concerning issue [74]. The evaluation of groundwater's suitable uses for particular purposes, including irrigation, public water supply, industrial applications and power generation, is significantly reliant on groundwater [100]. Different health risks are shown in Fig. 6. due to water and fish contamination by heavy metals.

The Caliber of groundwater is gradually but progressively deteriorating on a global scale. Hydrological, physical, chemical and biological aspects are all crucial determinants of groundwater quality [101]. Some trace metals affect the phytochemical and biochemical mechanisms of plants, animals and humans, even other trace metals in small quantities can also be hazardous [102]. The high concentration of trace metals interacts with the human body via three pathways namely inhalation, ingestion and dermal absorption. Humans are contaminating through drinking water, food and dermal contact [103,104]. Through food or water, heavy metals when entering the human body initiate diverse processes in the human body. Heavy metals called Cr, Pb and As obstruct the metabolic pathway or restrict enzymatic activity [130]. Among them, Cr easily passes the cell membrane enters the intermolecular area and reduces due to their lower oxidative stage. For that reason, the reduction process causes oxidative stress within the cell which is also accountable for harming DNA, RNA and proteins [131,136]. The health hazards that are correlated with heavy metal toxicity have been succinctly presented in Table 9 [74,111].

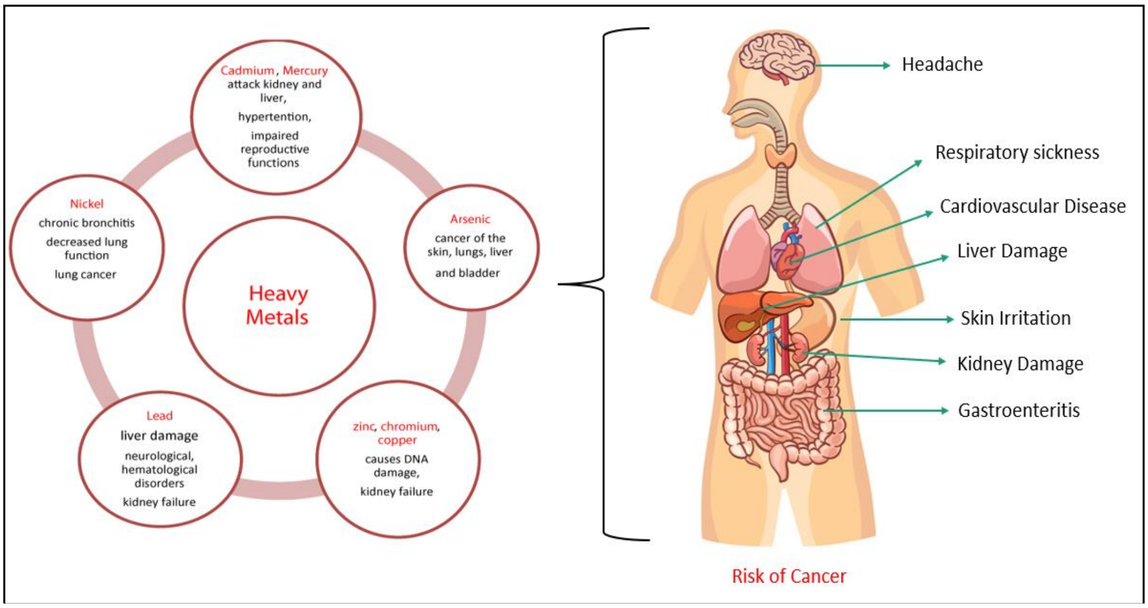

Fig. 6. Water and fish are contaminated by heavy metals and effect on human health [74]

Table 9. Harmful heavy metals, sources and different health effects

Heavy metals	Anthropogenic Source	Health Impacts	References
Cr	Chemical processing, maritime activities, information retention, textile production, hide preparation, dye compounds, timber preservation, metalworking, decolorizing agents and electrochemical industries.	Causes acute and chronic toxicity in the living organism. It is carcinogenic and causes cancer. Also responsible for Skin rash and ulcers, irritations and bleedings in the nasal cavity, weakened immune system, genetic material mutation, impaired liver and renal functions, teratogenicity, reproductive toxicity, embryotoxicity, mutagenicity and carcinogenicity, dermatitis, septum perforation and untoward reactions.	[74,105-111]
Ni	Surgical prosthetics, nickel-based steel, super alloys, electrodepositing, alnico magnetic materials, numismatics, non-ferrous metallurgies, catalytic converters, microphone capsules, rechargeable cells, plumbing fixtures plating and	Different health issues may arise, including dermatitis, asthma and cancer of the respiratory tract. Causes different health issues such as Anemia, cerebral dysfunction, inflammatory liver disease, pulmonary disease, dysentery, renal dysfunction, abdominal discomfort, idiopathic lung scarring, edema of the kidney,	[74,111-114]

Heavy metals	Anthropogenic Source	Health Impacts	References
	dentures.	cutaneous inflammation and dysfunction of the central nervous system.	
Pb	PVC pipes used in sanitation, high lead batteries, different types of fuels and even lunch boxes with lead-painted designs are all sources of contamination. The recycling industry, along with electronics manufacturing, metal processing, pigment creation for painting, electroplating, mining operations, leather tanning, agriculture, jewellery making, and lead battery production are all activities that contribute to this issue.	It accumulates in the body and damages the central nervous system. The riskiest relative to children and pregnant women. It causes reproductive system dysfunction, Central nerve system damage, renal and hepatic disorders and impediments to the protective blood-brain barrier which signifies a causative factor for the occurrence of Alzheimer's disease in conjunction with senile dementia. Furthermore, there is a decrease in IQ, diminished bone growth, aberrant behaviour disorders, heightened irritability, catatonic states and ataxia.	[74,111,115-119]
As	Waste materials obtained or generated from industrial processes like, mining operations, insect extermination agents, ceramic manufacturing, herbicides and pesticides, electronic components, additives containing arsenic, electricity production, organic solids derived from sewage treatment, leather tanning, fertilizers, iron sulfide oxidation (FeS), arsenic-containing iron sulfide (FeAsS), compounds used in animal feed, textiles, veterinary medicine and metallurgical processes.	It has the risk of cancer and causes skin lesions. This toxicity is also associated with cardiovascular diseases and diabetes. Affects in gastrointestinal tract, haemopoietic system, and genitourinary system, as well as impacts on the skin, fetus and teratogenic effects.	[74,111,120-123]
Cd	Electrochemical enterprises, nickel and cadmium-based batteries, coal combustion, plastic stabilizing agents, alloy manufacturing plants, fabricated rubber industry, photographic and engraving techniques, petroleum refinement procedures, photoconductive materials, coatings, colourants, photovoltaic cells, plated components and polymers.	This exposure causes reproductive, cardiovascular, pulmonary and gastrointestinal disorders. On the other hand, Pulmonary fibrosis, pulmonary hypertension, skeletal dysplasia, lymphocytic proliferation, type 2 diabetes, renal toxicity, cachexia, microcytic hypochromic anaemia and chronic obstructive pulmonary disease.	[74,111,124-126]
Hg	Fungicidal agents, metallurgical plating laboratories, leather processing industries or tanneries, pharmaceutical industries, soldering workshops, light bulbs which contain mercury, chemical	It causes harmful effects on the living system, including headaches, anorexia and rash. It causes reproductive system dysfunction, affects the digestive system, kidney, and respiratory system, Central Nervous System impairment, liver	[74,111,127-128]

Heavy metals	Anthropogenic Source	Health Impacts	References
	compositions, volcanic emissions, dental amalgam fillings, catalyzing agents, rectifying machinery, coal mining, incineration of both solid and urban refuse and mining process.	damage, aberrant neuronal development, adverse effects on the gastrointestinal and immunological systems, renal complications, respiratory distress, ocular impairments and dermal disorders, all being consequences of toxic heavy metal exposure. Such pernicious substances are responsible for devastating occurrences like the Minamata and acrodynia incidents, as well as debilitating conditions that entail surges in salivation, hypertension, and hypotonia.	
Cu	Mining operations, kitchenware, pharmaceutical and chemical equipment and paper production.	Alzheimer's disease, seizures, Parkinson’s disease, Wilson’s disease with liver and ocular manifestations, Muscle spasms, nausea and vomiting, as well as Menkes disease.	[111,129]

4. CONCLUSION

The heavy metal contamination overview is so alarming in industrial areas and uses six (6.0) fish samples from different regions of rivers in Bangladesh. High-value heavy metals in industrial area river fish as chromium (Cr) 164.73 mg/kg in, zinc (Zn) 309.47 mg/kg, copper (Cu) 26.33 mg/kg, arsenic (As) 5.64 mg/kg, lead (Pb) 18.16 mg/kg and cadmium (Cd) 2.03 mg/kg were observed. The obtained value of heavy metals in studied samples for both industrial and urbanized areas was found so high in fish that it exceeded the local and international standards. The contamination of river water and fishes that affects an entire ecosystem. Human health is in big threat regarding heavy metal contamination that is affecting the food chain and groundwater. Different death causing diseases occur due to this contamination. We have identified the different sources that contaminate the water sources both surface and ground water. This review enables us and enrich our knowledge regarding heavy metal sources and different health concerns. We determined to develop the pathway of proper management and disposal system of heavy metal and proper management system of waste to protect against water pollution.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

The authors have declared that they have no known competing financial or non-financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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