

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

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## ABSTRACT

Bangladesh, a nation with a high population density, gets all of the protein it needs from river fish. 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].

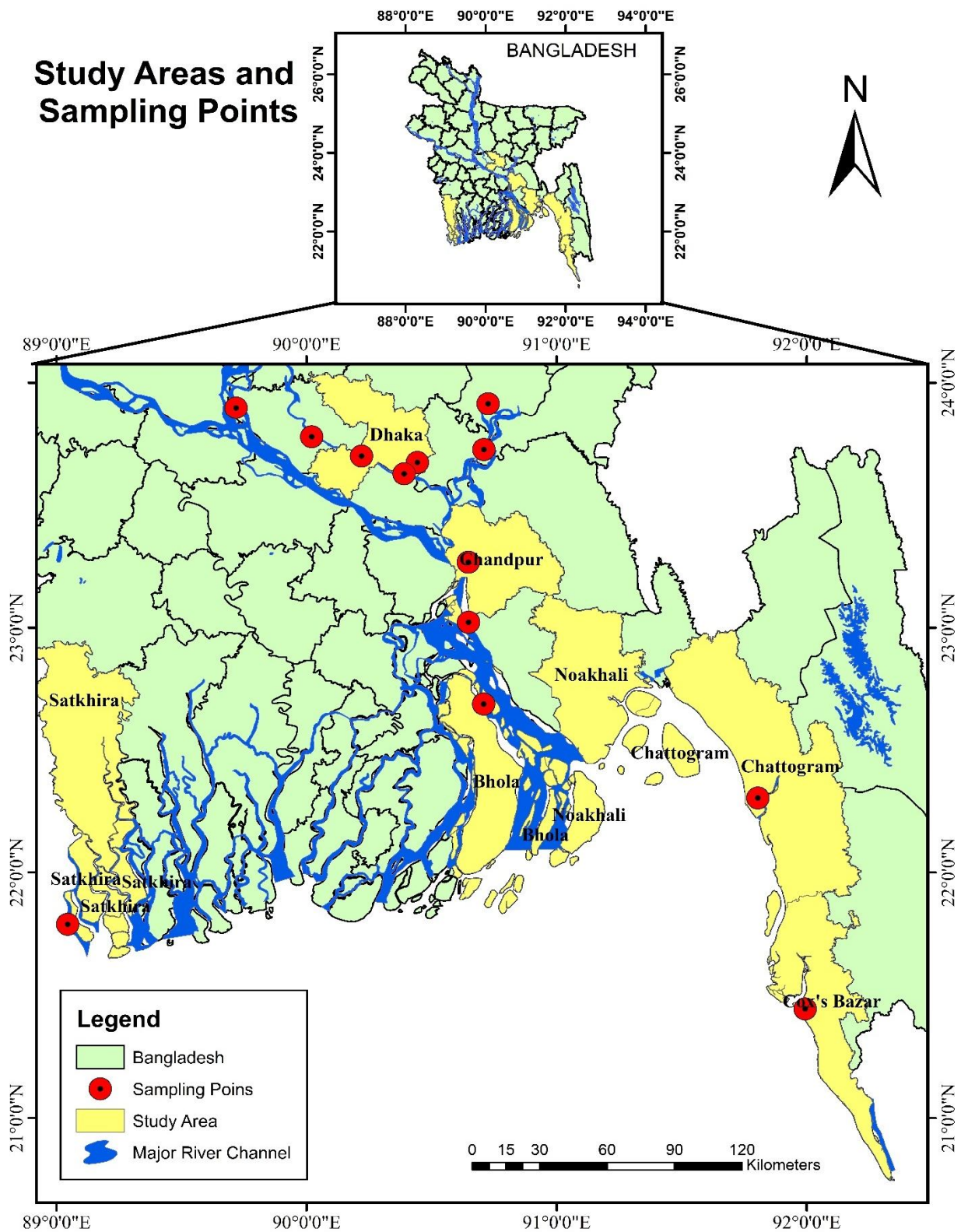
On the contrary, fish is usually ingested owing to its lipid, protein, vitamin and mineral constituents and primarily the existence of long-chain omega-3 polyunsaturated fatty acids (PUFAs) [18]. Moreover, alongside long-chain omega-3 PUFAs, researchers have identified numerous other components of fish 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. Material and Method**

### **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



**Fig. 1.** The map showing the study area and sampling points

## 2.2 Research Sample Collection

We investigate the study data for six (6.0) local fishes as *Heteropneustes fossilis* (stinging catfish), *Tenuilosailisha* (Ilish), *Channa punctatus* (Taki), *Trichogaster fasciata* (Kholsh), *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 °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 °C for 1.0 hour and then the temperature raising 200.0 °C, 300.0 °C and 400.0 °C gradually to avoid the loss of the sample and maintaining each temperature for an hour and lastly the temperature raised to 550.0 °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 °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 °C for 2.0 to 3.0 hours after that cooled. The sample was taken in volumetric flask for rinse with distilled water. The flask 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].

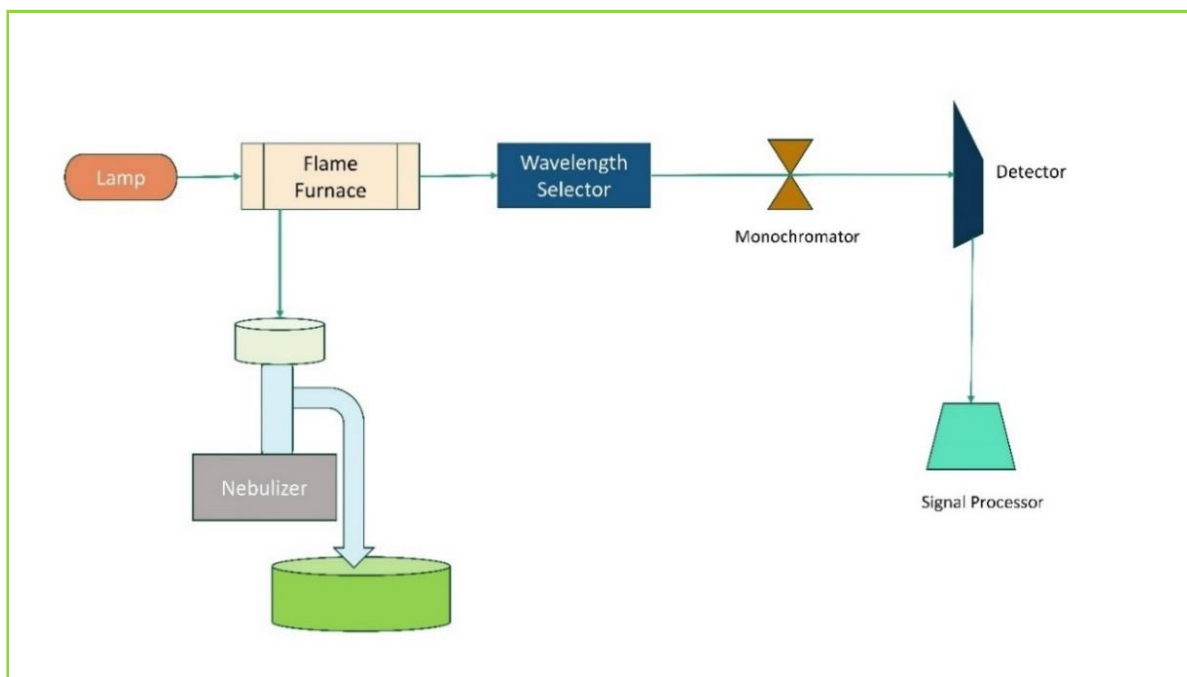
For the analysis of Hg and As required relatively low boiling point, about 20.0 g of fish samples were taken in cleaned and dried beakers and then 20.0 ml of concentrated nitric acid and 10.0 ml of concentrated perchloric acid were added to each sample into the beakers [36]. The sample in beakers is boiled for digestion on the hot plate at 180.0 - 200.0 °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 flask, 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].

### **3. Characterization**

#### **3.1 Basic Principle of Detection and Determination of Heavy Metal**

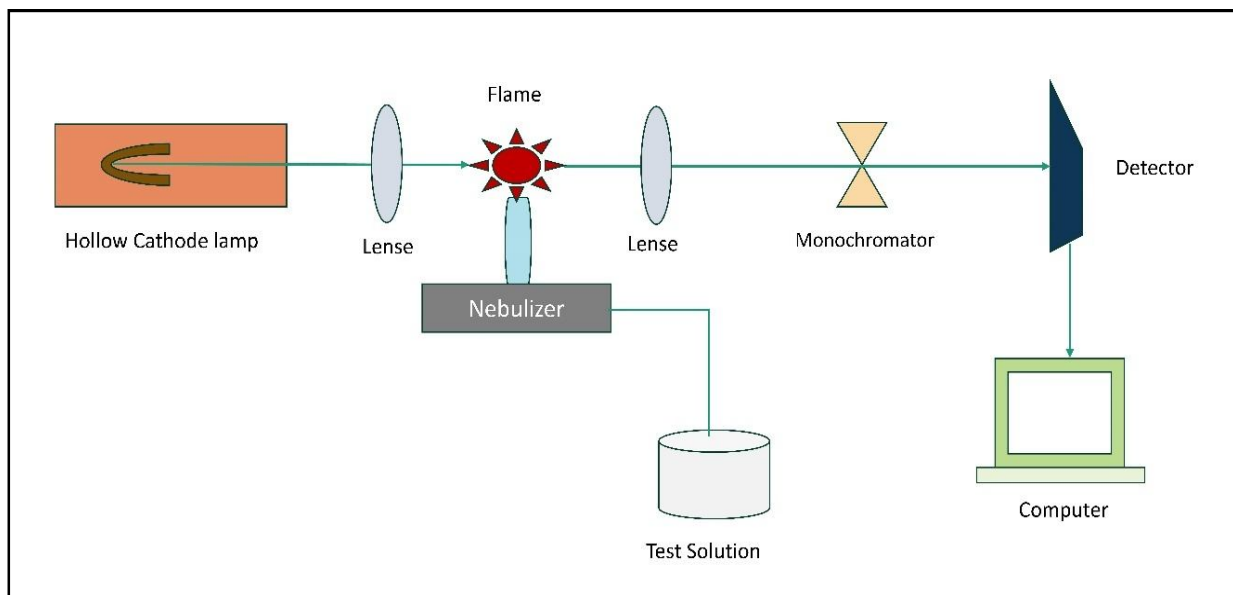
Atomic Absorption Spectroscopy (AAS) is a method in Spectro analysis employed for the precise determination of chemical elements by fixing the absorption of optical radiation, specifically light through free atoms in the gaseous phase state [35]. Block diagram of an atomic absorption spectrometer in 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].



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

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) [35-36]. 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.



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

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  $\mu\text{g L}^{-1}$ , 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.

**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 pre-concentration using Aspergillus niger-activated charcoal as Biosorbent	ETAAS	$1.0\mu\text{g L}^{-1}$	[39]
	pre-concentration using ion exchange media (N. Zhang, et al., 2008) Separation on a Dionex AS4A	EDXRFS	$0.40\text{ mg L}^{-1}$	[40]

Cr	anion exchange column			
	Pyrolysis and atomization using rhodium permanent modifier	ETAAS	0.20 $\mu\text{g L}^{-1}$	[41]
	Solid-phase extraction	ICP-MS	4.43 $\text{ng L}^{-1}$	[42]
	Separation on a Dionex AS4A anion exchange column	CL	0.05 $\mu\text{g L}^{-1}$	[43]
Zn	Preconcentration on a microcolumn of immobilized Alizarin Red S on alumina	FAAS	0.20 $\mu\text{g L}^{-1}$	[44]
	Chelating with 5,7 dichloro-oxine	AAS	0.50 $\mu\text{g L}^{-1}$	[45]
	In situ pre-concentration with the dual silica tube atom trap	AAS	0.30 $\mu\text{g L}^{-1}$	[46]
	CPE pre-concentration	FAAS	0.095 $\mu\text{g L}^{-1}$	[47]
	DLLME pre-concentration	Spectrophotometric	0.50 $\mu\text{g L}^{-1}$	[48]
Cu	CPE pre-concentration	FAAS	1.50 $\mu\text{g L}^{-1}$	[49]
		ICP-AES	0.014 mM	[50]
	Chelating 1,10-phenanthroline	CL	0.40 mM	[51]
	solid-phase extraction	FAAS	0.20 $\mu\text{g L}^{-1}$	[52]

## 4. Result and discussion

### 4.1 The 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.

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

Fish	Name of the river	Concentrations (mg/kg) of heavy metal	References
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species	and location	Cu	Cr	Zn	As	Pb	Cd	
<i>Heteropneustes fossilis</i> (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]

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).

**Table 3.** Heavy metal concentration (mg/kg) in *Tenulosailisha* 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	

	Meghna Estuary River, Noakhali	4.06	0.64	-	0.82	3.33	0.10	[23]
<i>Tenua- losailish</i> a (Ilish)	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]

Bangladeshi most popular fish *Tenualosailisha* (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).

**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	
<i>Channa punctatus</i> (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]

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±0.041mg/kg)>Cr (0.032±0.007mg/kg)> As (0.016±0.003mg/kg) >Cd (0.011±0.002mg/kg).

**Table 5.** Heavy metal concentration (mg/kg) in *Trichogasterfasciata* 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	
<i>Trichogasterfas</i>	Turag River, Dhaka	2.20	2.30	-	0.28	0.85	-	[23]
<i>ciata</i> (K holshe)	Buriganga River, Dhaka	4.10	2.50	-	0.36	1.20	-	[23]
	Shitalakha River, Narayanganj	3.80	1.40	-	0.22	0.69	-	[23]

For *Trichogasterfasciata*(Kholshhe) in Table 5, the heavy metal intake quantity highest (Cu 4.1 mg/kg, Cr 2.50 mg/kg, As 0.36mg/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 0.36mg/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).

**Table 6.** Heavy metal concentration (mg/kg) in *mastacembelusarmatusis* 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	
<i>Mastacembelusarmatus</i> (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]

For *mastacembelusarmatus*(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 (0.79mg/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).

**Table 7.** Heavy metal concentration (mg/kg) in *Anabas testudineusis* 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	
<i>Anabas testudin</i>	Upper Meghna River, Chandpur	0.65	1.27	1.85	0.41	0.09	0.02	[23]
	River in	32.49	7.86	107.22	-	0.68	-	[61]

<i>eus</i> (Koi	Noakhali							
)	Meghna River, Narsingdi	0.82	0.19	15.61	-	-	-	[55]

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 (0.68mg/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.

**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	15.0	0.30	-	0.50	60.0	-	[72]

#### 4.1.1 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].

#### 4.1.2 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.

#### 4.1.3 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 *Heteropneustesfossilis* (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].

#### **4.1.4 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 *Mastacembelusarmatus* (Bain) fish is 309.47 mg/kg at Bangshi River, Savar [60] also for *Heteropneustesfossilis* (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 *Heteropneustesfossilis* (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.

#### **4.1.5 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 *Heteropneustesfossilis* (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,

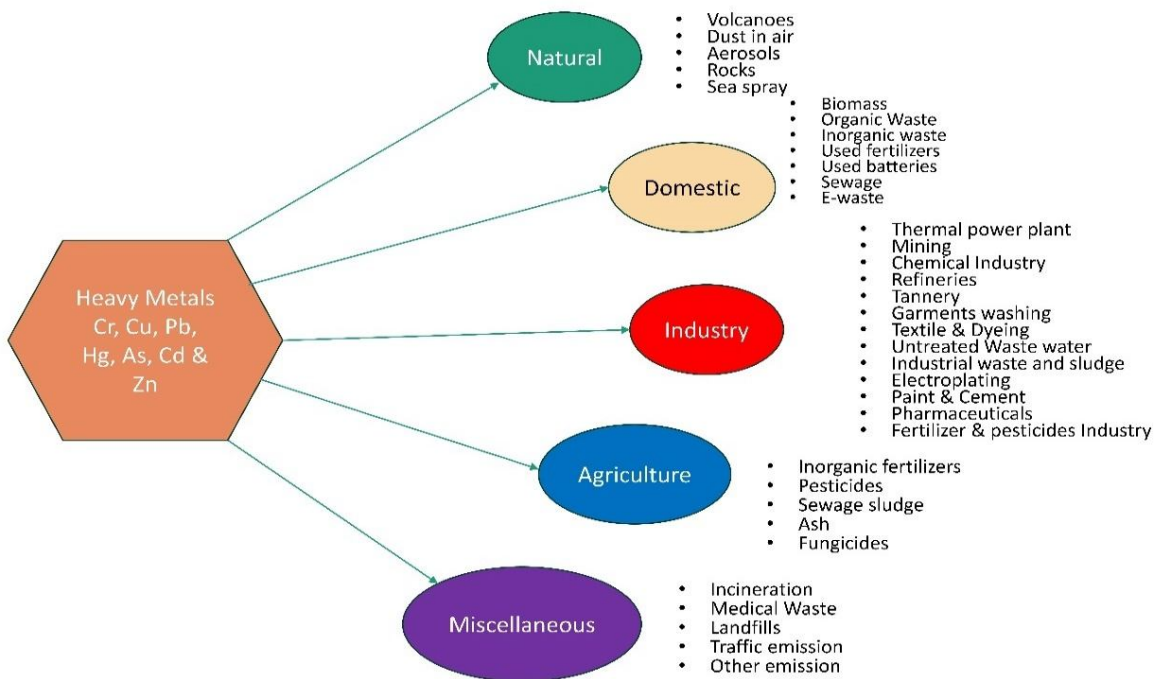
FDA [28] 1.50 mg/kg, India [69] 0.30 mg/kg, Malaysia [70] 0.30 mg/kg, China [71] 3.0 mg/kg respectively.

#### **4.1.6 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].

#### **4.2 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, canal 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].

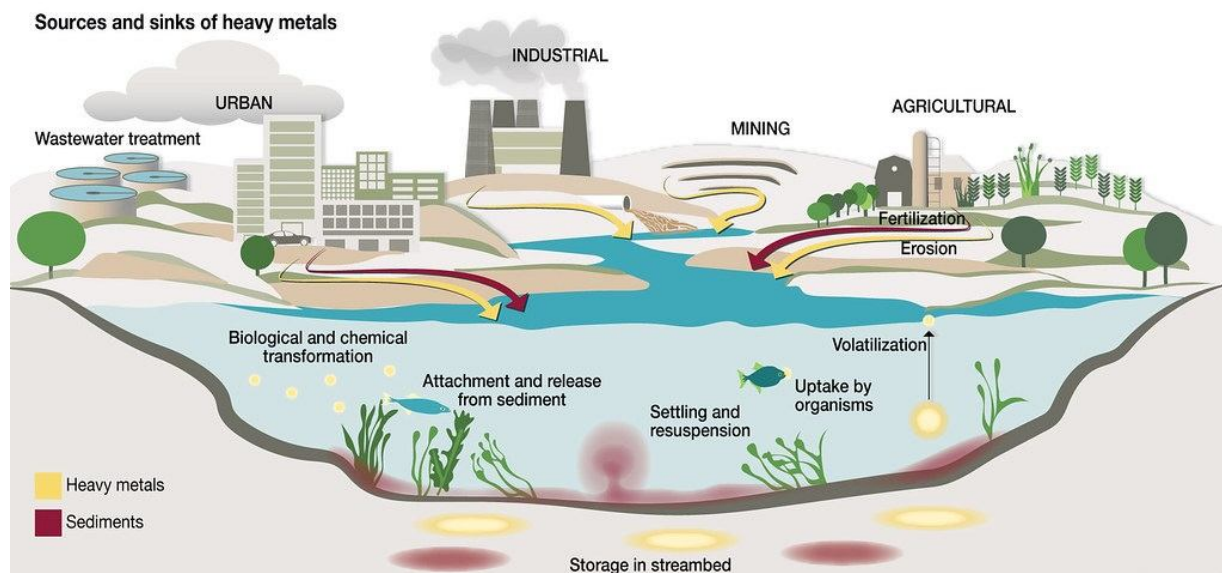


**Fig. 4.** Sources of heavy metal [73-78]

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].



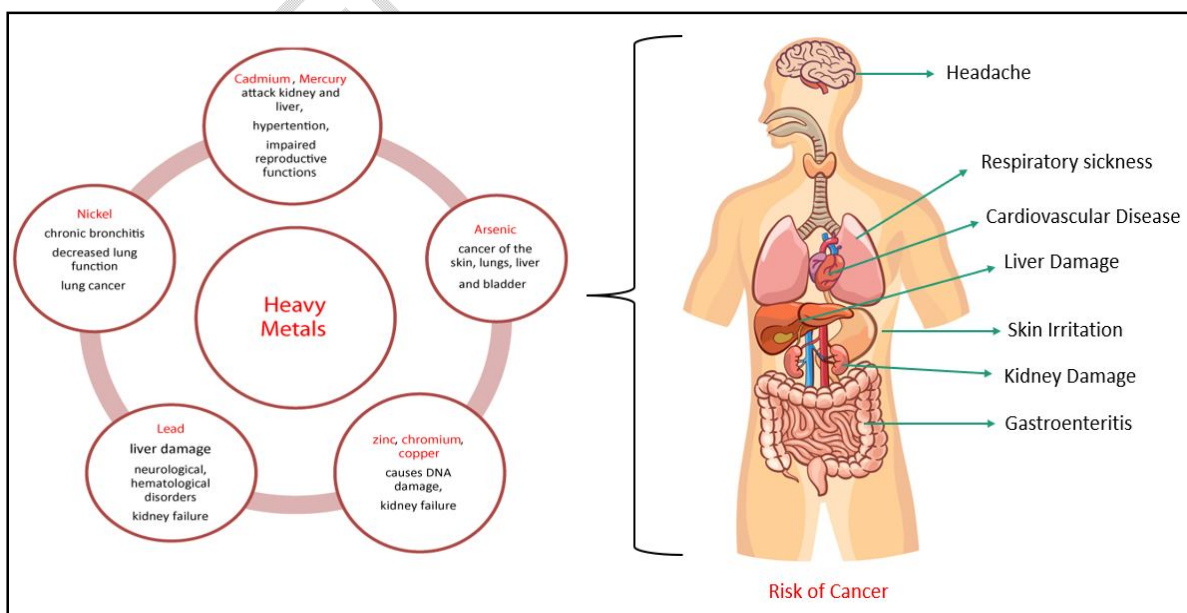
**Fig. 5.** Water pollution by heavy metals from different sources and contamination of fish and aquatic life [82].

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].

### 4.3 Toxicity of heavy metals and 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.



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

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]. The health hazards that are correlated with heavy metal toxicity have been succinctly presented in Table 9 [74, 111].

**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	Different health issues may arise, including dermatitis, asthma and cancer of the respiratory tract. Causes	[74,111-114]

magnetic materials, different health issues such as numismatics, non-ferrous Anemia, cerebral dysfunction, metallurgies, catalytic inflammatory liver disease, converters, microphone pulmonary disease, dysentery, renal capsules, rechargeable cells, dysfunction, abdominal discomfort, plumbing fixtures plating and idiopathic lung scarring, edema of dentures. the kidney, cutaneous inflammation and dysfunction of the central nervous system.

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**Pb** PVC pipes used in sanitation, It accumulates in the body and [74,111,115-119] damages the central nervous system. 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. 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.

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**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 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]

metallurgical processes.

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<b>Cd</b>	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]
<b>Hg</b>	Fungicidal agents, metallurgical plating laboratories, leather processing industries or tanneries, pharmaceutical industries, soldering workshops, light bulbs which contain mercury, chemical compositions, volcanic emissions, dental amalgam fillings, catalyzing agents, rectifying machinery, coal mining, incineration of both solid and urban refuse and mining process.	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 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.	[74,111,127-128]
<b>Cu</b>	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]

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## 5. 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 deathcausing 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.

### **Acknowledgement**

We apologize to the authors of the works for which we were unable to quote as many references as we were able to and we have included as many as we could. We apologize to the other writers that we may have inadvertently omitted but who have worked on various percepts of heavy metals. Our sincere gratitude also goes to Dr. Debasish Sarkar, Professor, Department of Ceramic Engineering, NIT, Rourkela, Odisha, India for his mentorship; Dr. Samina Ahmed, CSO and Director (Addl. charge), IGCRT, BCSIR, Bangladesh and Dr. Shirin Akter Jahan, PSO, BCSIR, Bangladesh for using the PC, software.

### **COMPETING INTERESTS**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

## References

- [1] Khatun, M., Kobir, M. M., Miah, M. A. R., Sarkar, A. K., & Alam, M. A. (2024). Technologies for remediation of heavy metals in environment and ecosystem: A critical overview of a comparison study. *Asian Journal of Environment & Ecology*, 23(4), 61-80.
- [2] Ganges, P. A. S. (2019). Seasonal variation and ecological risk assessment of heavy metal contamination in surface waters of the Ganges River (northwestern Bangladesh). *Malaysian Journal of Analytical Sciences*, 23(2), 300-311.
- [3] Kobir, M. M., Ali, M. S., Ahmed, S., Sadia, S. I., & Alam, M. A. (2024). Assessment of the physicochemical characteristic of wastewater in Kushtia and Jhenaidah Municipal Areas Bangladesh: A Study of DO, BOD, COD, TDS and MPI. *Asian Journal of Geological Research*, 7(1), 21-30.
- [4] Fu, J., Zhao, C., Luo, Y., Liu, C., Kyzas, G. Z., Luo, Y., ... & Zhu, H. (2014). Heavy metals in surface sediments of the Jialu River, China: their relations to environmental factors. *Journal of hazardous materials*, 270, 102-109.
- [5] Krishna, A. K., Satyanarayanan, M., & Govil, P. K. (2009). Assessment of heavy metal pollution in water using multivariate statistical techniques in an industrial area: a case study from Patancheru, Medak District, Andhra Pradesh, India. *Journal of hazardous materials*, 167(1-3), 366-373.
- [6] Islam, M. M., Karim, M. R., Zheng, X., & Li, X. (2018). Heavy metal and metalloid pollution of soil, water and foods in bangladesh: a critical review. *International journal of environmental research and public health*, 15(12), 2825.
- [7] Islam, M. S., Han, S., AHMED, M. K., & Masunaga, S. (2014). Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. *Journal of water and environment technology*, 12(2), 109-121.
- [8] Gan, Y., Wang, L., Yang, G., Dai, J., Wang, R., & Wang, W. (2017). Multiple factors impact the contents of heavy metals in vegetables in the high natural background areas of China. *Chemosphere*, 184, 1388-1395.

- [9] Hossain, M. B., Ahmed, A. S. S., & Sarker, M. S. I. (2018). Human health risks of Hg, As, Mn, and Cr through consumption of fish, Ticto barb (*Puntius ticto*) from a tropical river, Bangladesh. *Environmental Science and Pollution Research*, 25(31), 31727-31736.
- [10] 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 & Management*, 5, 27-35.
- [11] Banu, Z., Chowdhury, M. S. A., Hossain, M. D., & Nakagami, K. I. (2013). Contamination and ecological risk assessment of heavy metal in the sediment of Turag River, Bangladesh: an index analysis approach.
- [12] Hasan, I., Rajia, S., Kabir, K. A., & Latifa, G. A. (2009). Comparative study on the water quality parameters in two rural and urban rivers emphasizing on the pollution level. *Global Journal of Environmental Research*, 3(3), 218-222.
- [13] Zakir, H. M., Sharmin, S., & Shikazono, N. (2006). Heavy metal pollution in water and sediments of Turagriver at Tongi area of Bangladesh.
- [14] Kawser Ahmed, M., Baki, M. A., Kundu, G. K., Saiful Islam, M., Monirul Islam, M., & Muzammel Hossain, M. (2016). Human health risks from heavy metals in fish of Buriganga river, Bangladesh. *SpringerPlus*, 5, 1-12.
- [15] Ahmad, M. K., Islam, S., Rahman, S., Haque, M., & Islam, M. M. (2010). Heavy metals in water, sediment and some fishes of Buriganga River, Bangladesh.
- [16] Rakib, M. A., Ali, M., Akter, M. S., & Bhuiyan, M. A. (2014). Assessment of heavy metal (Pb, Zn, Cr and Cu) content in roadside dust of Dhaka Metropolitan City, Bangladesh. *Int. Res. J. Environ. Sci*, 3(1), 1-5.
- [17] Hezbullah, M., Sultana, S., Chakraborty, S. R., & Patwary, M. I. (2016). Heavy metal contamination of food in a developing country like Bangladesh: An emerging threat to food safety. *Journal of Toxicology and Environmental Health Sciences*, 8(1), 1-5.
- [18] Ashraf, S. A., Adnan, M., Patel, M., Siddiqui, A. J., Sachidanandan, M., Snoussi, M., & Hadi, S. (2020). Fish-based bioactives as potent nutraceuticals: Exploring the therapeutic perspective of sustainable food from the sea. *Marine drugs*, 18(5), 265.
- [19] Khalili Tilami, S., & Sampels, S. (2018). Nutritional value of fish: lipids, proteins, vitamins, and minerals. *Reviews in Fisheries Science & Aquaculture*, 26(2), 243-253.
- [20] Ahmed, A. T. A., Mandal, S., Chowdhury, D. A., Tareq, A. R. M., & Rahman, M. M. (2012). Bioaccumulation of some heavy metals in Ayre Fish (*SperataAor* Hamilton, 1822), sediment and water of Dhaleshwari River in dry season. *Bangladesh Journal of Zoology*, 40(1), 147-153.

- [21] Chakraborty, P., Babu, P. R., Acharyya, T., & Bandyopadhyay, D. (2010). Stress and toxicity of biologically important transition metals (Co, Ni, Cu and Zn) on phytoplankton in a tropical freshwater system: An investigation with pigment analysis by HPLC. *Chemosphere*, 80(5), 548-553.
- [22] Mansour, S. A., & Sidky, M. M. (2002). Ecotoxicological studies. 3. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt. *Food chemistry*, 78(1), 15-22.
- [23] Sarker, M. J., Polash, A. U., Islam, M. A., Rima, N. N., & Farhana, T. (2020). Heavy metals concentration in native edible fish at upper Meghna River and its associated tributaries in Bangladesh: a prospective human health concern. *SN Applied Sciences*, 2, 1-13.
- [24] Magu, M. M., Keriko, J. M., Kareru, P. G., & Chege, C. W. (2016). „Burdens“ of selected heavy metals in common fish species from specific Kenyan freshwaters. *International Journal of Fisheries and Aquatic Studies*, 4(3), 173-179.
- [25] Frisbie, S. H., Mitchell, E. J., & Sarkar, B. (2013). World Health Organization increases its drinking-water guideline for uranium. *Environmental Science: Processes & Impacts*, 15(10), 1817-1823.
- [26] Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Subcommittee on Interpretation, & Uses of Dietary Reference Intakes. (2003). *Dietary reference intakes: applications in dietary planning*.
- [27] Dearwent, S. M., Mumtaz, M. M., Godfrey, G., Sinks, T., & Falk, H. (2006). Health effects of hazardous waste. *Annals of the New York Academy of Sciences*, 1076(1), 439-448.
- [28] Additives, F. (2001). *Evaluation of certain food additives and contaminants*.
- [29] Joint, F. A. O., WHO Expert Committee on Food Additives, & World Health Organization. (1989). *Evaluation of certain food additives and contaminants: thirty-third report of the Joint FAO. World Health Organization*.
- [30] Schneider, K., Ollroge, I., Clauberg, M., & Schuhmacher-Wolz, U. (2007). Analysis of risk assessment and risk management processes in the derivation of maximum levels for environmental contaminants in food. *Food additives and contaminants*, 24(7), 768-776.
- [31] Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, clinical and environmental toxicology: volume 3: environmental toxicology*, 133-164.
- [32] National Research Council, Division on Earth, Life Studies, Board on Environmental Studies, Water Science, Technology Board, & Committee on Drinking Water Contaminants. (2001). *Classifying drinking water contaminants for regulatory consideration*.

- [33] Forti, E., Salovaara, S., Cetin, Y., Bulgheroni, A., Tessadri, R., Jennings, P., ... & Prieto, P. (2011). In vitro evaluation of the toxicity induced by nickel soluble and particulate forms in human airway epithelial cells. *Toxicology in vitro*, 25(2), 454-461.
- [34] Alipour, H., Pourkhabbaz, A., & Hassanpour, M. (2015). Estimation of potential health risks for some metallic elements by consumption of fish. *Water Quality, Exposure and Health*, 7, 179-185.
- [35] Paudel, S., Kumar, S., & Mallik, A. (2021). Atomic absorption spectroscopy: a short review. *EPRA Int. J. Res. Dev.(IJRD)*, 6, 322-327.
- [36] Ahsan, M. A., Siddique, M. A. B., Munni, M. A., Akbor, M. A., Bithi, U. H., & Mia, M. Y. (2018). Analysis of major heavy metals in the available fish species of the Dhaleshwari River, Tangail, Bangladesh. *Int J Fish Aquat Stud*, 6(4), 349-354.
- [37] Fu, F., & Wang, Q. (2011). Removal of heavy metal ions from wastewaters: a review. *Journal of environmental management*, 92(3), 407-418.
- [38] He, S., Niu, Y., Xing, L., Liang, Z., Song, X., Ding, M., & Huang, W. (2024). Research progress of the detection and analysis methods of heavy metals in plants. *Frontiers in Plant Science*, 15, 1310328.
- [39] Shahlaei, M., & Pourhossein, A. (2014). Determination of arsenic in drinking water samples by electrothermal atomic absorption spectrometry after preconcentration using the biomass of *Aspergillus niger* loaded on activated charcoal. *Journal of Chemistry*, 2014.
- [40] Menéndez-Alonso, E., Hill, S. J., Foulkes, M. E., & Crighton, J. S. (1999). Speciation and preconcentration of Cr III and Cr VI in waters by retention on ion exchange media and determination by EDXRF. *Journal of Analytical Atomic Spectrometry*, 14(2), 187-192.
- [41] de Almeida Pereira, L., de Amorim, I. G., & da Silva, J. B. B. (2004). Development of methodologies to determine aluminum, cadmium, chromium and lead in drinking water by ET AAS using permanent modifiers. *Talanta*, 64(2), 395-400.
- [42] Zhang, N., Suleiman, J. S., He, M., & Hu, B. (2008). Chromium (III)-imprinted silica gel for speciation analysis of chromium in environmental water samples with ICP-MS detection. *Talanta*, 75(2), 536-543.
- [43] Beere, H. G., & Jones, P. (1994). Investigation of chromium (III) and chromium (VI) speciation in water by ion chromatography with chemiluminescence detection. *Analytica chimica acta*, 293(3), 237-243.
- [44] Shabani, A. M., Dadfarnia, S., Moosavinejad, T., & Ahmadi, S. H. (2009). On-line preconcentration system using a microcolumn packed with Alizarin Red S-modified alumina for zinc determination by flame atomic absorption spectrometry. *Quimica Nova*, 32, 1202-1205.

- [45] Tony, K., Rao, T., & Iyer, C. P. (1999). Flow injection on-line preconcentration and flame atomic absorption spectrometric determination of iron, cobalt, nickel, manganese and zinc in sea-water. *Analyst*, 124(2), 191-195.
- [46] Matusiewicz, H., Sturgeon, R., Luong, V., & Moffatt, K. (1991). Determination of copper, iron, manganese and zinc in river and estuarine water by atom trapping-flame atomic absorption spectrometry. *Fresenius' journal of analytical chemistry*, 340, 35-40.
- [47] Chen, J., & Teo, K. C. (2001). Determination of cadmium, copper, lead and zinc in water samples by flame atomic absorption spectrometry after cloud point extraction. *Analytica Chimica Acta*, 450(1-2), 215-222.
- [48] Wen, X., Yang, Q., Yan, Z., & Deng, Q. (2011). Determination of cadmium and copper in water and food samples by dispersive liquid-liquid microextraction combined with UV-vis spectrophotometry. *Microchemical Journal*, 97(2), 249-254.
- [49] Lemos, V. A., Santos, M. S., dos Santos, M. J. S., Vieira, D. R., & Novaes, C. G. (2007). Determination of copper in water samples by atomic absorption spectrometry after cloud point extraction. *Microchimica Acta*, 157, 215-222.
- [50] Rahil-Khazen, R., Henriksen, H., Bolann, B. J., & Ulvik, R. J. (2000). Validation of inductively coupled plasma atomic emission spectrometry technique (ICP-AES) for multi-element analysis of trace elements in human serum. *Scandinavian Journal of Clinical and Laboratory Investigation*, 60(8), 677-686.
- [51] Coale, K. H., Johnson, K. S., Stout, P. M., & Sakamoto, C. M. (1992). Determination of copper in sea water using a flow-injection method with chemiluminescence detection. *Analytica chimica acta*, 266(2), 345-351.
- [52] Yu, H. M., Song, H., & Chen, M. L. (2011). Dithizone immobilized silica gel on-line preconcentration of trace copper with detection by flame atomic absorption spectrometry. *Talanta*, 85(1), 625-630.
- [53] Uzun Ozel, H., Gemici, B. T., Gemici, E., Ozel, H. B., Cetin, M., & Sevik, H. (2020). Application of artificial neural networks to predict the heavy metal contamination in the Bartın River. *Environmental Science and Pollution Research*, 27, 42495-42512.
- [54] Mukherjee, S., Bhattacharyya, S., Ghosh, K., Pal, S., Halder, A., Naseri, M., ... & Bhattacharyya, N. (2021). Sensory development for heavy metal detection: A review on translation from conventional analysis to field-portable sensor. *Trends in Food Science & Technology*, 109, 674-689.

- [55] Bhuyan, M. S., Bakar, M. A., Islam, M. S., & Akhtar, A. (2016). Heavy metals status in some commercially important fishes of Meghna River adjacent to Narsingdi District, Bangladesh: health risk assessment. *Am J Life Sci*, 4, 60-70.
- [56] Islam, G. R., Khan, F. E., Hoque, M. M., & Jolly, Y. N. (2014). Consumption of unsafe food in the adjacent area of Hazaribag tannery campus and Buriganga River embankments of Bangladesh: heavy metal contamination. *Environmental monitoring and assessment*, 186, 7233-7244.
- [57] Raknuzzaman, M., Ahmed, M. K., Islam, M. S., Habibullah-Al-Mamun, M., Tokumura, M., Sekine, M., & Masunaga, S. (2016). Trace metal contamination in commercial fish and crustaceans collected from coastal areas of Bangladesh and health risk assessment. *Environmental Science and Pollution Research*, 23, 17298-17310.
- [58] Islam, M. S., Ahmed, M. K., Habibullah-Al-Mamun, M., & Masunaga, S. (2015). Assessment of trace metals in fish species of urban rivers in Bangladesh and health implications. *Environmental toxicology and pharmacology*, 39(1), 347-357.
- [59] Fakhri, Y., Bjørklund, G., Bandpei, A. M., Chirumbolo, S., Keramati, H., Pouya, R. H., ... & Ghasemi, S. M. (2018). Concentrations of arsenic and lead in rice (*Oryza sativa* L.) in Iran: a systematic review and carcinogenic risk assessment. *Food and chemical toxicology*, 113, 267-277.
- [60] Gorell, J. M., Johnson, C. C., Rybicki, B. A., Peterson, E. L., Kortsha, G. X., Brown, G. G., & Richardson, R. J. (1997). Occupational exposures to metals as risk factors for Parkinson's disease. *Neurology*, 48(3), 650-658.
- [61] Hossain, M. B., Tanjin, F., Rahman, M. S., Yu, J., Akhter, S., Noman, M. A., & Sun, J. (2022). Metals bioaccumulation in 15 commonly consumed fishes from the lower Meghna River and adjacent areas of Bangladesh and associated human health hazards. *Toxics*, 10(3), 139.
- [62] Adams, M. A. (1993). Guidance document for arsenic in shellfish.
- [63] Ficklin, D. L., Luo, Y., Luedeling, E., & Zhang, M. (2009). Climate change sensitivity assessment of a highly agricultural watershed using SWAT. *Journal of hydrology*, 374(1-2), 16-29.
- [64] Ahmed, M. K., Ahamed, S., Rahman, S., Haque, M. R., & Islam, M. M. (2009). Heavy metals concentration in water, sediments and their bioaccumulations in some freshwater fishes and mussel in Dhaleshwari River, Bangladesh. *Terr Aquat Environ Toxicol*, 3(1), 33-41.
- [65] Epa, U. S. (2011). Regional screening level (RSL) summary table. United States Environmental Protection Agency, Washington.

- [66] Pastorok, P. (1987). Guidance manual for assessing human health risks from chemically contaminated fish and shellfish. PTI Environmental Service's submission to Battelle New England for EPA, Washington, DEC PTI Environ Draft Report C737-01 Bellevue, Washington, 91.
- [67] ISLAND, N. (2005). Food and Agriculture Organization of the United Nations, Rome.
- [68] World Health Organization. (2002). Guidelines for drinking-water quality. World Health Organization.
- [69] Heikens, A. (2006). Arsenic contamination of irrigation water, soil and crops in Bangladesh: Risk implications for sustainable agriculture and food safety in Asia.
- [70] Gavrilesco, M. (2004). Removal of heavy metals from the environment by biosorption. *Engineering in life sciences*, 4(3), 219-232.
- [71] Demirbas, A. (2008). Heavy metal adsorption onto agro-based waste materials: a review. *Journal of hazardous materials*, 157(2-3), 220-229.
- [72] Lupea, M., Bulgariu, L., & Macoveanu, M. (2012). Biosorption of Cd (II) from aqueous solution on marine green algae biomass. *Environmental Engineering & Management Journal (EEMJ)*, 11(3).
- [73] Yang, L., Zhang, M., Wei, J., & Qi, J. (2022). Pollution load estimation and control countermeasures of Zhangze reservoir. *Frontiers in Environmental Science*, 10, 874124.
- [74] Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., ... & Ru, J. (2023). Water quality degradation due to heavy metal contamination: health impacts and eco-friendly approaches for heavy metal remediation. *Toxics*, 11(10), 828.
- [75] Lancaster, M. *Green Chemistry: An Introductory Text*; RSC Paperbacks Ser.; RSC: Cambridge, UK, 2007.
- [76] Zacchaeus, O. O., Adeyemi, M. B., Adedeji, A. A., Adegoke, K. A., Anumah, A. O., Taiwo, A. M., & Ganiyu, S. A. (2020). Effects of industrialization on groundwater quality in Shagamu and Ota industrial areas of Ogun state, Nigeria. *Heliyon*, 6(7).
- [77] Chen, B., Wang, M., Duan, M., Ma, X., Hong, J., Xie, F., ... & Li, X. (2019). In search of key: Protecting human health and the ecosystem from water pollution in China. *Journal of Cleaner Production*, 228, 101-111.
- [78] Wu, H., Gai, Z., Guo, Y., Li, Y., Hao, Y., & Lu, Z. N. (2020). Does environmental pollution inhibit urbanization in China? A new perspective through residents' medical and health costs. *Environmental Research*, 182, 109128.
- [79] Singh, V., Singh, M. P., & Mishra, V. (2020). Bioremediation of toxic metal ions from coal washery effluent. *Desalin. Water Treat*, 197, 300-318.

- [80] John, N. U., & Chimka, E. I. (2017). Effect of discharge of partially treated refinery effluent on the Okrika River. *J. Environ. Stud*, 3, 1-6.
- [81] Koul, B., Yadav, D., Singh, S., Kumar, M., & Song, M. (2022). Insights into the domestic wastewater treatment (DWWT) regimes: a review. *Water*, 14(21), 3542.
- [82] <https://www.grida.no/resources/13718>
- [83] Alvarez, S., Asci, S., & Vorotnikova, E. (2016). Valuing the potential benefits of water quality improvements in watersheds affected by non-point source pollution. *Water*, 8(4), 112.
- [84] Straškraba, M. (1996). Ecotechnological methods for managing non-point source pollution in watersheds, lakes and reservoirs. *Water Science and Technology*, 33(4-5), 73-80.
- [85] Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics*, 9(3), 42.
- [86] Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, 13(19), 2660.
- [87] Moghal, A. A. B., Lateef, M. A., Abu Sayeed Mohammed, S., Ahmad, M., Usman, A. R., & Almajed, A. (2020). Heavy metal immobilization studies and enhancement in geotechnical properties of cohesive soils by EICP technique. *Applied Sciences*, 10(21), 7568.
- [88] Pal, D., & Maiti, S. K. (2020). An approach to counter sediment toxicity by immobilization of heavy metals using waste fish scale derived biosorbent. *Ecotoxicology and Environmental Safety*, 187, 109833.
- [89] Bhattacharya, P., Banerjee, P., Mallick, K., Ghosh, S., Majumdar, S., Mukhopadhyay, A., & Bandyopadhyay, S. (2013). Potential of biosorbent developed from fruit peel of *Trewia nudiflora* for removal of hexavalent chromium from synthetic and industrial effluent: Analyzing phytotoxicity in germinating *Vigna* seeds. *Journal of Environmental Science and Health, Part A*, 48(7), 706-719.
- [90] Sari, A., & Tuzen, M. (2008). Biosorption of total chromium from aqueous solution by red algae (*Ceramium virgatum*): equilibrium, kinetic and thermodynamic studies. *Journal of hazardous materials*, 160(2-3), 349-355.
- [91] Pujol, L., Evrard, D., Groenen-Serrano, K., Freyssinier, M., Ruffien-Cizsak, A., & Gros, P. (2014). Electrochemical sensors and devices for heavy metals assay in water: the French groups' contribution. *Frontiers in chemistry*, 2, 19.
- [92] Roy, S. P. (2010). Overview of heavy metals and aquatic environment with notes on their recovery. *Ecoscan*, 4(2-3), 235-240.
- [93] Lollar, B. S. (Ed.). (2005). *Environmental geochemistry* (Vol. 9). Elsevier.

- [94] Musarrat, J., Zaidi, A., Khan, M. S., Siddiqui, M. A., & Al-Khedhairi, A. A. (2011). Genotoxicity assessment of heavy metal-contaminated soils. *Biomangement of metal-contaminated soils*, 323-342.
- [95] Prabhakar, S., Singh, A. K., & Pooni, D. S. (2012). Effect of environmental pollution on animal and human health: a review. *Indian Journal of Animal Sciences*, 82(3), 244.
- [96] Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, clinical and environmental toxicology: volume 3: environmental toxicology*, 133-164.
- [97] Masindi, V., & Muedi, K. L. (2018). Environmental contamination by heavy metals. *Heavy metals*, 10(4), 115-133.
- [98] Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary toxicology*, 7(2), 60-72.
- [99] Fernandez-Luqueno, F., Lopez-Valdez, F., Gamero-Melo, P., Luna-Suarez, S., Aguilera-Gonzalez, E. N., Martínez, A. I., ... & Pérez-Velázquez, I. R. (2013). Heavy metal pollution in drinking water-a global risk for human health: A review. *African Journal of Environmental Science and Technology*, 7(7), 567-584.
- [100] Sasakova, N., Gregova, G., Takacova, D., Mojziso, J., Papajova, I., Venglovsky, J., ... & Kovacova, S. (2018). Pollution of surface and ground water by sources related to agricultural activities. *Frontiers in Sustainable Food Systems*, 2, 42.
- [101] Ji, L., Li, Y., Zhang, G., & Bi, Y. (2021). Anthropogenic disturbances have contributed to degradation of river water quality in arid areas. *Water*, 13(22), 3305.
- [102] Jabeen, F., Aslam, A., & Salman, M. (2018). Heavy metals toxicity and associated health risks in vegetables grown under soil irrigated with sewage water. *Univers. J. Agric. Res*, 6, 173-180.
- [103] Rahman, Z., & Singh, V. P. (2019). The relative impact of toxic heavy metals (THMs)(arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. *Environmental monitoring and assessment*, 191, 1-21.
- [104] Boufekane, A., & Saighi, O. (2019). Assessing groundwater quality for irrigation using geostatistical method—Case of Wadi Nil Plain (North-East Algeria). *Groundwater for sustainable development*, 8, 179-186.
- [105] Yan, G., Gao, Y., Xue, K., Qi, Y., Fan, Y., Tian, X., ... & Liu, J. (2023). Toxicity mechanisms and remediation strategies for chromium exposure in the environment. *Frontiers in Environmental Science*, 11, 1131204.

- [106] Valko, M. M. H. C. M., Morris, H., & Cronin, M. T. D. (2005). Metals, toxicity and oxidative stress. *Current medicinal chemistry*, 12(10), 1161-1208.
- [107] Cao, W., Wang, Z., Ao, H., & Yuan, B. (2018). Removal of Cr (VI) by corn stalk-based anion exchanger: the extent and rate of Cr (VI) reduction as a side reaction. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 539, 424-432.
- [108] Dinari, M., & Haghghi, A. (2018). Ultrasound-assisted synthesis of nanocomposites based on aromatic polyamide and modified ZnO nanoparticle for removal of toxic Cr (VI) from water. *Ultrasonics sonochemistry*, 41, 75-84.
- [109] Dayan, A. D., & Paine, A. J. (2001). Mechanisms of chromium toxicity, carcinogenicity and allergenicity: a review of the literature from 1985 to 2000. *Human & experimental toxicology*, 20(9), 439-451.
- [110] Kumar Dey, S., & Roy, S. (2009). Effect of chromium on certain aspects of cellular toxicity. *Iranian Journal of Toxicology*, 2(4), 260-267.
- [111] Okpara, E. C., Fayemi, O. E., Wojuola, O. B., Onwudiwe, D. C., & Ebenso, E. E. (2022). Electrochemical detection of selected heavy metals in water: a case study of African experiences. *RSC advances*, 12(40), 26319-26361.
- [112] Genchi, G., Carocci, A., Lauria, G., Sinicropi, M. S., & Catalano, A. (2020). Nickel: Human health and environmental toxicology. *International journal of environmental research and public health*, 17(3), 679.
- [113] Zhang, X., & Wang, X. (2015). Adsorption and desorption of nickel (II) ions from aqueous solution by a lignocellulose/montmorillonite nanocomposite. *PloS one*, 10(2), e0117077.
- [114] Hoseinian, F. S., Rezai, B., Kowsari, E., & Safari, M. (2018). Kinetic study of Ni (II) removal using ion flotation: Effect of chemical interactions. *Minerals Engineering*, 119, 212-221.
- [115] Collin, M. S., Venkatraman, S. K., Vijayakumar, N., Kanimozhi, V., Arbaaz, S. M., Stacey, R. S., ... & Swamiappan, S. (2022). Bioaccumulation of lead (Pb) and its effects on humans: A review. *Journal of Hazardous Materials Advances*, 7, 100094.
- [116] Liu, J., Mwamulima, T., Wang, Y., Fang, Y., Song, S., & Peng, C. (2017). Removal of Pb (II) and Cr (VI) from aqueous solutions using the fly ash-based adsorbent material-supported zero-valent iron. *Journal of Molecular Liquids*, 243, 205-211.
- [117] Patrick, L. (2006). Lead toxicity part II: the role of free radical damage and the use of antioxidants in the pathology and treatment of lead toxicity. *Alternative medicine review*, 11(2).
- [118] Ettinger, A. S., & Wengrovitz, A. M. (2010). Guidelines for the identification and management of lead exposure in pregnant and lactating women.

- [119] Liu, C., Bai, R., & San Ly, Q. (2008). Selective removal of copper and lead ions by diethylenetriamine-functionalized adsorbent: behaviours and mechanisms. *Water Research*, 42(6-7), 1511-1522.
- [120] Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., ... & Ru, J. (2023). Water quality degradation due to heavy metal contamination: health impacts and eco-friendly approaches for heavy metal remediation. *Toxics*, 11(10), 828.
- [121] Elkhatib, E., Mahdy, A., Sherif, F., & Hamadeen, H. (2015). Evaluation of a novel water treatment residual nanoparticles as a sorbent for arsenic removal. *Journal of Nanomaterials*, 2015, 5-5.
- [122] Caporale, A. G., Punamiya, P., Pigna, M., Violante, A., & Sarkar, D. (2013). Effect of particle size of drinking-water treatment residuals on the sorption of arsenic in the presence of competing ions. *Journal of Hazardous Materials*, 260, 644-651.
- [123] Valko, M. M. H. C. M., Morris, H., & Cronin, M. T. D. (2005). Metals, toxicity and oxidative stress. *Current medicinal chemistry*, 12(10), 1161-1208.
- [124] Rahimzadeh, M. R., Rahimzadeh, M. R., Kazemi, S., & Moghadamnia, A. A. (2017). Cadmium toxicity and treatment: An update. *Caspian journal of internal medicine*, 8(3), 135.
- [125] Chen, Y. Y., Yu, S. H., Jiang, H. F., Yao, Q. Z., Fu, S. Q., & Zhou, G. T. (2018). Performance and mechanism of simultaneous removal of Cd (II) and Congo red from aqueous solution by hierarchical vaterite spherulites. *Applied Surface Science*, 444, 224-234.
- [126] Ercal, N., Gurer-Orhan, H., & Aykin-Burns, N. (2001). Toxic metals and oxidative stress part I: mechanisms involved in metal-induced oxidative damage. *Current topics in medicinal chemistry*, 1(6), 529-539.
- [127] Johnson, K., Tefera, E., & Farrell Jr, J. (2021). Characteristics and treatment of elemental mercury intoxication: A case series. *Health Science Reports*, 4(2), e293.
- [128] Dubey, R., Bajpai, J., & Bajpai, A. K. (2016). Chitosan-alginate nanoparticles (CANPs) as potential nanosorbent for removal of Hg (II) ions. *Environmental Nanotechnology, Monitoring & Management*, 6, 32-44.
- [129] Hu, H., Li, X., Huang, P., Zhang, Q., & Yuan, W. (2017). Efficient removal of copper from wastewater by using mechanically activated calcium carbonate. *Journal of Environmental Management*, 203, 1-7.
- [130] Witkowska, D., Słowik, J., & Chilicka, K. (2021). Heavy metals and human health: Possible exposure pathways and the competition for protein binding sites. *Molecules*, 26(19), 6060.

- [131] Kumar, U., & Garg, A. P. (2018). Bisorption of heavy metals oxides by heavy metals Resis-Tant microorganism in liquid Culture-ICP-MS Technique. *Progressive Agriculture*, 18(1), 66-72.
- [132] Hart, E. B., Steenbock, H., Waddell, J., Elvehjem, C. A., Van Donk, E., & Riising, B. M. (1928). Iron in nutrition: VII. Copper as a supplement to iron for haemoglobin building in the rat. *Journal of Biological Chemistry*, 77(2), 797-812.
- [133] Baki, M. A., Hossain, M. M., Akter, J., Quraishi, S. B., Shojib, M. F. H., Ullah, A. A., & Khan, M. F. (2018). The concentration of heavy metals in seafood (fishes, shrimp, lobster and crabs) and human health assessment in Saint Martin Island, Bangladesh. *Ecotoxicology and environmental safety*, 159, 153-163.
- [134] Vu, C. T., Lin, C., Yeh, G., & Villanueva, M. C. (2017). Bioaccumulation and potential sources of heavy metal contamination in fish species in Taiwan: assessment and possible human health implications. *Environmental Science and Pollution Research*, 24, 19422-19434.
- [135] Gorell, J. M., Johnson, C. C., Rybicki, B. A., Peterson, E. L., Kortsha, G. X., Brown, G. G., & Richardson, R. J. (1997). Occupational exposures to metals as risk factors for Parkinson's disease. *Neurology*, 48(3), 650-658.
- [136] Roels, H. A., Lauwerys, R. R., Buchet, J. P., Bernard, A., Chettle, D. R., Harvey, T. C., & Al-Haddad, I. K. (1981). In vivo measurement of liver and kidney cadmium in workers exposed to this metal: its significance with respect to cadmium in blood and urine. *Environmental Research*, 26(1), 217-240.
- [137] Sarkar, T., Alam, M. M., Parvin, N., Fardous, Z., Chowdhury, A. Z., Hossain, S., ... & Biswas, N. (2016). Assessment of heavy metals contamination and human health risk in shrimp collected from different farms and rivers at Khulna-Satkhira region, Bangladesh. *Toxicology reports*, 3, 346-350.
- [138] Shishir, M. K. H., Sadia, S. I., Ahmed, S., Aidid, A. R., Rana, M. M., Hasan, M. M., ... & Alam, M. A. (2024). Transmission Electron Microscopic and X-ray Diffraction Based Study of Crystallographic Bibliography Demonstrated on Silver, Copper and Titanium Nanocrystals: State of the Art Statical Review. *Asian Journal of Applied Chemistry Research*, 15(3), 1-19.
- [139] Haque, N. N., Alam, M. A., Baidya, A. S., Zenat, E. A., Rahman, M. Z., Roy, C. K., & Munshi, J. L. (2024). Bioremedial capacity of indigenous hydrophytes and microalgae of Bangladesh: A comparative study on their potential in tannery effluent treatment. *Asian Journal of Environment & Ecology*, 23(6), 53-65.
- [140] Ahamed, M. S., Ali, M. S., Ahmed, S., Sadia, S. I., Islam, M. R., Rahaman, M. A., & Alam, M. A. (2024). Synthesis of Silver Nanomaterials Capping by Fruit-mediated Extracts and

Antimicrobial Activity: A Critical Review. *International Research Journal of Pure and Applied Chemistry*, 25(1), 45-60.

[141] Zenat, M., Akther, E., Haque, N. N., Hasan, M. R., Begum, M., Munshi, J. L., ... & Alam, M. A. (2024). Antifungal Activity of Various Plant Extracts against *Aspergillus* and *Penicillium* Species Isolated from Leather-Borne Fungus. *Microbiology Research Journal International*, 34(1), 10-23.

[142] Sarkar, A. K., Ahmed, S., Sadia, S. I., Kobir, M. M., Tabassum, S., Islam, M. R., & Alam, M. A. (2024). Overview of the skeleton significance of toothpaste formulation, evaluation and historical perspectives: Insights from Bangladesh's toothpaste industry. *Journal of Materials Science Research and Reviews*, 7(1), 80-101.

[143] Kobir, M. M., Tabassum, S., Ahmed, S., Sadia, S. I., & Alam, M. A. (2024). Crystallographic benchmarking on diffraction pattern profiling of Polymorphs-TiO<sub>2</sub> by WPPF for Pigment and Acrylic Paint. *Archives of Current Research International*, 24(1), 62-70.

[144] Ali, M. S., Ahmed, S., Islam, M. R., Ahamed, M. S., Rahaman, M. A., Khatun, M., & Alam, M. A. (2024). Diabetes mellitus control including fruits in diet: Exhaustive review and meta-analysis. *Asian Journal of Food Research and Nutrition*, 3(1), 43-59.

[145] Islam, M. R., Ahmed, S., Sadia, S. I., Sarkar, A. K., & Alam, M. A. (2023). Comprehensive review of phytochemical content and applications from *cestrum nocturnum*: A Comparative Analysis of Physicochemical Aspects. *Asian Journal of Research in Biochemistry*, 13(4), 43-58.

[146] Moulick, S. P., Hossain, M. S., Al Mamun, M. Z. U., Jahan, F., Ahmed, M. F., Sathee, R. A., ... & Islam, F. (2023). Characterization of waste fish bones (*Heteropneustes fossilis* and *Otolithoides pama*) for photocatalytic degradation of Congo red dye. *Results in Engineering*, 20, 101418.

[147] Rahman, M. M., Maniruzzaman, M., Yeasmin, M. S., Gafur, M. A., Shaikh, M. A. A., Alam, M. A., ... & Quddus, M. S. (2023). Adsorptive abatement of Pb<sup>2+</sup> and crystal violet using chitosan-modified coal nanocomposites: A down flow column study. *Groundwater for Sustainable Development*, 23, 101028.

[148] Haque, N. N., Alam, M. A., Roy, C. K., Zenat, M., Akther, E., & Munshi, J. L. (2023). Cyanobacteria Mediated CO<sub>2</sub> Segregation: A Promising Alternative Method for Sustainable Bioremediation and Biomass Production. *Asian Journal of Research in Biochemistry*, 13(3), 28-43.

- [149] Alam, M. A., Mostafa, S., Bishwas, R. K., Sarkar, D., Tabassum, M., & Jahan, S. A. Low-Temperature Synthesis and Characterization of High Crystalline 3c-Ag Nanoparticle. Available at SSRN 4446717.
- [150] Alam, M. A., Bishwas, R. K., Mostofa, S., & Jahan, S. A. (2024). Crystallographic phase stability of nanocrystalline polymorphs  $\text{TiO}_2$  by tailoring hydrolysis pH. *South African Journal of Chemical Engineering*, 49, 73-85.
- [151] Tabassum, M., Alam, M. A., Mostofa, S., Bishwas, R. K., Sarkar, D., & Jahan, S. A. (2024). Synthesis and crystallinity integration of copper nanoparticles by reaction medium. *Journal of Crystal Growth*, 626, 127486.
- [152] Hasan, M. R., Abdur, R., Alam, M. A., Aziz, S., Sujana, A., Islam, D., ... & Hossain, M. (2024). + Exploring the effects of different parameters on the incorporation of K ions in eggshell derived CaO reveals highly variable catalytic efficiency for biodiesel conversion. *South African Journal of Chemical Engineering*, 47(1), 67-74.
- [153] Alam, M. A., Bishwas, R. K., Mostofa, S., & Jahan, S. A. (2024). Low-temperature synthesis and crystal growth behavior of nanocrystal anatase- $\text{TiO}_2$ . *Materials Letters*, 354, 135396.
- [154] Bishwas, R. K., Mostofa, S., Alam, M. A., & Jahan, S. A. (2023). Removal of malachite green dye by sodium dodecyl sulfate modified bentonite clay: Kinetics, thermodynamics and isotherm modeling. *Next Nanotechnology*, 3, 100021.
- [155] Alam, M. A., Tabassum, M., Mostofa, S., Bishwas, R. K., Sarkar, D., & Jahan, S. A. (2023). The effect of precursor concentration on the crystallinity synchronization of synthesized copper nanoparticles. *Journal of Crystal Growth*, 621, 127386.
- [156] Alam, M. A., Mobashsara, M. T., Sabrina, S. M., Bishwas, R. K. B., Debasish, D. S., & Shirin, S. A. J. (2023). One-pot low-temperature synthesis of high crystalline Cu nanoparticles. *Malaysian Journal of Science and Advanced Technology*, 122-127.
- [157] Alam, M. A., Munni, S. A., Mostafa, S., Bishwas, R. K., & Jahan, S. A. (2023). An investigation on synthesis of silver nanoparticles. *Asian Journal of Research in Biochemistry*, 12(3), 1-10.
- [158] Opeyemi, I. E., & Olatunde, O. O. (2020). Determination of Heavy Metals in Water and Some Selected Fish Species in River Ofin, Ado-Ekiti. *Annual Research & Review in Biology*, 35(3), 52–62. <https://doi.org/10.9734/arrb/2020/v35i330200>
- [159] Akter, M., Zakir, H. M., Sharmin, S., Quadir, Q. F., & Mehrin, S. (2020). Heavy Metal Bioaccumulation Pattern in Edible Tissues of Different Farmed Fishes of Mymensingh Area,

Bangladesh and Health Risk Assessment. *Advances in Research*, 21(4), 44–55.  
<https://doi.org/10.9734/air/2020/v21i430200>

[160]Elnabris KJ, Muzyed SK, El-Ashgar NM. Heavy metal concentrations in some commercially important fishes and their contribution to heavy metals exposure in Palestinian people of Gaza Strip (Palestine). *Journal of the Association of Arab Universities for Basic and Applied Sciences*. 2013 Apr 1;13(1):44-51.

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