ECOLOGICAL AND HEALTH RISK ASSESSMENTS OF FISHES IN INDUSTRIAL CONTAMINATED WATER OF BANGLADESH

By

Md. Abdullah-Al-Mamun

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CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma

Mamun

....

(Md. Abdullah-Al-Mamun)

Signature of the candidate

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET),

DHAKA -1000

Department of Chemistry

Certification of Thesis

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Md. Abdullah-Al-Mamun

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Board of Examiners

1. **Dr. Md. Abdul Goni**
   Assistant Professor
   Department of Chemistry
   BUET, Dhaka-1000

   31-01-2021
   ……………………
   Supervisor and Chairman

2. **Dr. Md. Shakhawat Hossain Firoz**
   Head and Professor
   Department of Chemistry
   BUET, Dhaka-1000

   31-01-21
   ……………………
   Member (Ex-officio)

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   Department of Chemistry
   Dhaka University of Engineering and Technology (DUET), Gazipur

   ……………………
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To

MY Beloved

Parents

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Abstract

Heavy and toxic metals contamination in various environmental segments in the vicinity of industrial areas is one of the most serious problems to maintain the environmental quality and sustainability in Bangladesh. Heavy and toxic metals are being discharged with wastewater from industrial and agricultural activities into Lakes and Rivers and their rates of mobilization and transportation into the surrounding environment have greatly accelerated in Bangladesh in recent years. In this study, water, sediments, and different fishes were collected during the winter season in 2019 from the aquatic ecosystems of Dhaka Export Processing Zone (DEPZ) Lake and Bangshi River in Savar, Dhaka which is considered as highly contaminated sites (HCS). Similarly, the representative water, sediments, and typical fishes were collected from long range contaminated sites (LCS) located at Kalihati Upazila in Tangail District. The sediment, water, and fishes samples have been digested with the acid mixtures following the standard procedures and then analyzed for determining the heavy and toxic metal contamination status, using the Flame-AAS and HG-AAS methods. A total of eight heavy and toxic metals such as Cr, Cu, Ni, Fe, Mn, Pd, Cd and As have been studied in all fish, sediment, and water samples. Different metal concentrations determined in fish, sediments, and water samples were compared with standard permissible/tolerable values set up by WHO, USEPA, and other countries such as China, India. Water pollution indices, sediment quality indices and metal contamination data in various fish species revealed that the entire highly contaminated sites (HCS) are severely polluted. In the long range contaminated sites (LCS), Mn in fishes; Fe, Mn, and Pb in water; Cu, Ni and Cr concentrations in sediments have been found considerably higher than the corresponding permissible levels of WHO, USEPA, India, and China. The highest concentration of metals appeared in fishes living in the middle and demersal layers. The estimated daily intake (EDI) data of different fishes in the highly contaminated sites, revealed that the analyzed fish species are not safe for human consumption as per the recommended daily dietary allowance limit set by USEPA. The Targeted Hazard Quotient (THQ) values for all metals studied were below 1 (except As and Pb for some species), which suggested that people would not experience significant health hazards immediately if they consume metal contaminated fishes. However, the total metal THQ (TTHQ) data pointed out the potential non-carcinogenic health hazards risks to the highly-exposed consumers in the polluted study area. The excessive consumption of metals contaminated fishes over a long period of time might cause the developments of severe carcinogenic effects in people as the calculated Target Cancer Risk (TR) values were found much higher than the USEPA threshold levels.

KEYWORDS: Fishes, Water, Sediments, Heavy Metals, Bioconcentration Factor, Health Risks.

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List of Abbreviations of Technical Symbols and Terms

1. Atomic Absorption spectrometer (AAS)
2. Hydride generator (HG)
3. Arsenic (As)
4. Cadmium (Cd)
5. Chromium (Cr)
6. Copper (Cu)
7. Nickel (Ni)
8. Lead (Pb)
9. Manganese (Mn)
10. Iron (Fe)
11. World Health Organization (WHO)
12. Department of Environment (DoE)
13. Canadian Council of Ministers of the Environment (CCME)
14. Ministry of Health of the People‘s Republic of China (MHPRC)
15. United States Environmental Protection Agency (USEPA)
16. Toxicity Reference Value (TRV)
17. Lowest Effect Level (LEL)
18. Highly Contaminated Sites (HCS)
19. Long Range Contaminated Sites (LCS)

CHAPTER-1

INTRODUCTION

1. Introduction

1.1. General remarks

Heavy metals are generally considered as hazardous component of environment due to their poisonous, bio accumulative and non-degradable nature [1-2]. Heavy metals such as Copper, Iron, Manganese, Calcium, Magnesium, and others are essential metals as they have a significant important role in biological systems, whereas Nickel, Chromium, Lead, Arsenic, Mercury, Cadmium and others are non-essential metals, as they are toxic, even in trace amounts. These essential and non-essential metals can cause toxic effects when the metal intake level is highly excessive [3]. Heavy metals are entered into the surface waters by different means and processes (e.g. runoff, precipitation, atmospheric deposition, migration, adsorption, point spills, etc.) and then settled down into the sediments [4]. Thus sediments could play an important role in moving and accumulating metals impurities [5]. Fishes are one of the most significant living organisms in aquatic ecosystem because of having their economic and aesthetic qualities. Channa punctata, Punctius sophore, Oreochromis niloticus, Trichogaster fasciata, Magrognathus pancalus and Aplocheilus panchax are popular and usually grown into different water bodies in Bangladesh.

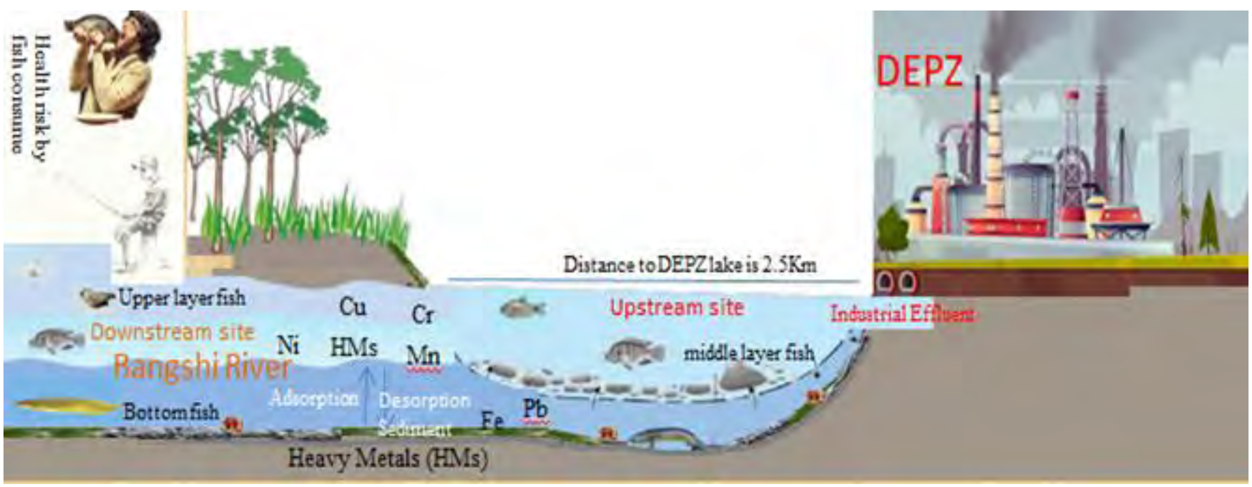


Figure 1.1: Sources and impact of pollution in the environments in and around Dhaka export processing zone industrial systems.

For the common metabolism of the fishes, the essential and nonessential metals must be taken up from water, food or sediment. Heavy metals could be accumulated by fishes through different paths like as from water passing through the gills which is being considered as the most direct potential route, from food that affecting their intestines, the metabolic organs, and finally from the environmental contact with the skin [6].

1.2. Environmental contamination

Environmental pollution is one of the most serious global challenges now a days in terms of environmental and economical sustainability. A natural environment could be polluted or contaminated due to different human activities or natural activities. Pollution could be differed depending on the contamination sources; however, irrespective of the types of pollutants, any pollution could pose a detrimental impact on the environment. From literature, pollution is defined as the introduction by man, directly or indirectly, of substances or energy into the environment which results very deleterious and harmful effects to living resources and are hazardous to human health, hindrance to environmental activities and impairment of quality for the use of environment and reduction of amenities [7]. Contamination on the other hand describes the presence of elevated concentrations of substances in the environment above the natural background level for the area and for the organism. Environmental pollution can be referred to undesirable and unwanted change in physical, chemical and biological characteristics of air, water, and soil which are severely harmful for living organisms—both animal and plants. Pollution could also occur in the form energy, such as noise, heat or light [8]. Pollutants, the elements of pollution, can either be foreign substances/energies or naturally occurring contaminants.

1.2.1. Types of pollutants

Environmental pollutants have been a constant growing concern in the world in recent years and one of the greatest challenges faced by the global society now a days. Pollutants can be naturally occurring compounds or foreign matters which when in contact with the environment cause adverse effects to the surrounding environments. There are different types of pollutants we encounter every day, namely inorganic, organic, and biological. Irrespective of pollutants falling under different categories, they all receive considerable attention due to their severe impacts they introduce and convey to the environment and consequently deteriorate environmental quality and sustainability. The relationship between environmental pollution and world population has become a directly proportional relationship as it is being observed that the amount of potentially toxic substances released into the environment is continuously increasing with the dramatic rise of global population [9].

1.2.2. Inorganic pollutants

Industrial, agricultural, and domestic wastes contribute to environmental pollution, which consequently cause adverse impacts to human and animal health. Inorganic pollutants are usually substances of mineral origin, with metals, and salts. Studies have reported inorganic pollutants as materials found naturally but have been altered by human production to increase their number in the environment. Inorganic substances enter into the environment through different anthropogenic activities such as sewerage drainage, various activities, mine drainage, smelting, metallurgical and chemical processes, as well as natural processes [10]. These pollutants could be toxic due to the large and longtime accumulation in the food chains

1.2.3. Organic pollutants

Organic pollution can be briefly defined as biodegradable contaminants in an environment [11]. The common sources of organic pollutant are being observed naturally and caused by the environment, but anthropogenic activities have also been contributing to their intensive production to meet the needs of human beings. Some of the common organic pollutants which have been noted to be of special concern are human waste, food waste, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), pesticides, petroleum and organochlorine pesticides (OCPs). Organic pollutants have drawn considerable attention in recent years because of having their pernicious effects in the environment. Properties of organic pollutants may include high lipid solubility, stability, lipophilicity and hydrophobicity which have recently made organic pollutants to be recognized as persistent pollutants [12]. These properties provide organic pollutants the ability to easily bioaccumulate in the different spheres of the environment, thus causing toxicological effects.

1.2.4. Biological pollutants

Biological pollutants described as contaminants result from human activities, pose negative impacts on the quality of aquatic and terrestrial environment. This type of pollutants include bacteria, viruses, molds, mildew, animal dander and cat saliva, house dust, mites, cockroaches and pollen [13]. Studies have reported different sources of these types of pollutants, including pollens originating from plants; viruses that are being transmitted by people and animals; bacteria which are carried out by people, animals, and soil and plant debris.

1.3. Heavy metals

Although there is no specific definition of a heavy metal is clearly reported, literature study identified the heavy metals as naturally occurring element having a high atomic weight and high density which is five times greater than that of water [14]. Among all the pollutants, heavy metals have received a paramount attention to environmental chemists due to their toxic nature. Heavy metals are usually present in trace amounts in natural waters but many of them are considered as toxic even at very low concentrations [15]. Metals such as arsenic, lead, cadmium, nickel, mercury, chromium, cobalt, zinc and selenium are highly toxic even with a minor quantity. Constant increasing of heavy metals into our global resources due to different activities including anthropogenic and natural, has become a great concern in recent years, especially since a large number of industries are continuously discharging their metal containing effluents into fresh water bodies without any prior and adequate treatment. Heavy metals arise naturally in rocks and soils, however, anthropogenic actions have caused in elevated concentrations of them in the environment, particularly in aquatic networks. Metals are mutual contaminants in urban lakes which are being released from agricultural activities, industrial establishments, and urban development, as well as from natural sources and thus are being entered into water bodies and into the sediment by punctual or wordy ways [16]. Heavy metals become toxic when they are not metabolized by the body and thus accumulate in the soft tissues. They may enter into the human body through food, water, air or absorption through the skin when they come in very close contact with agricultural activities and work in manufacturing, pharmaceutical, industrial or residential settings for a long time [17]. Industrial emissions account for a common route of exposure of heavy and toxic metals for adults. Ingestion is the most common route of heavy and toxic metals exposure in children. A wide variety of natural and human activities are continuously contaminating the environment and its resources with the discharging of toxic pollutants more than what the environment could handle and manage. Sources of heavy metals can emanate from both natural and anthropogenic processes and later these heavy and toxic metals find their ultimate destination in different environmental segments (soil, water, air and their interfaces)

1.3.1. Natural processes

Many studies have reported different natural sources of heavy metals. Under different environmental conditions, natural emissions of heavy metals could be occurred. Such types of emissions include volcanic eruptions, sea-salt sprays, forest fires, rock weathering, biogenic sources, and wind-borne soil particles [18]. Natural weathering processes can lead to the release of different metals from their endemic spheres to various environmental components. Heavy metals can be found in the form of hydroxides, oxides, sulfides, sulphates, phosphates, silicates and as metal-organic compounds. The most common heavy metals are lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd), arsenic (As), iron (Fe), manganese (Mn) and copper (Cu). Although the aforementioned heavy metals can be found in trace level, they still could cause serious health problems to human and other mammals.

Surface mineralization

Volcanic eruption

Natural oil spillage

Metal ore

Figure 1.2: Natural sources of heavy metals

1.3.2. Anthropogenic processes

Anthropogenic processes include industrial activities, agricultural runoffs, wastewater discharge , mining and metallurgical processes which release a wide range of pollutants to different components of natural environmental. Anthropogenic processes of heavy metals have been noted to go beyond the natural fluxes for some metals [19]. Sometimes metals can be emitted and carried out with wind-blown dusts mostly originated from industrial areas. Some important anthropogenic sources which significantly contribute to the heavy metal contamination in the environment include automobile exhaust which releases lead; smelting processes which releases arsenic, copper and zinc; application of insecticides which release arsenic and burning of fossil fuels which liberate nickel, vanadium, mercury, selenium and tin.

Emission of industrial effluents

Waste disposal from Mines or mills

Agricultural use of metal containing compounds

Waste disposal through drainage systems

Figure 1.3: Anthropogenic sources of heavy metals

Human activities have been found to contribute more to environmental pollution with their activities involve in the manufacturing of different kinds of products to meet the demands of the large population around the world. Figure 1.3 shows the contamination of our environmental caused by different anthropogenic sources.

1.4. Sources of heavy metal exposure to humans

Heavy metals are naturally present in our environment. They are present in the different layers of our environment such as atmosphere, lithosphere, hydrosphere, and biosphere. During the mining activities, heavy metals are being released from the ore and scattered in the open environment; deposited in the soil, transported by air and water to other areas. Moreover, when these heavy metals are used in the industries for various industrial purposes, some of these elements are released into the air during combustion or into the soil or water bodies as effluents. In addition, different industrial products such as paints, cosmetics, pesticides, and herbicides also serve as sources of heavy metals. Heavy metals could also be transported through erosion, run-off or acid rain to different locations in soils and water bodies. This type of pollution can be recognized as long range contamination. Detailed information regarding the different sources of specific heavy metals are described below.

1.4.1. Arsenic

Arsenic associated with arsenide of copper, lead, gold, iron hydroxides and sulfides is stored in geological bedrocks (sedimentary rocks) or in the arsenic-rich aquifer matrices in many regions of the world such as Bangladesh, Australia, Canada, India, Vietnam, and Latin America [20]. The inorganic forms arsenic such as arsenite and arsenate compounds are lethal to humans and other organisms in the environment. Humans get in contact with arsenic through several means which include industrial sources such as smelting and microelectronic industries. Phosphate fertilizers, paints materials, textile products; pharmaceutical products; pesticides; smelting of gold, lead, copper and nickel and others [21]

1.4.2. Lead

Lead is a slightly bluish, bright silvery metal. Natural lead pollution occurs from volcanic explosions and forest fires [22]. The main sources of lead exposure include drinking water, food, cigarette, industrial processes and domestic sources. The industrial sources of lead pollution include gasoline combustion, house painting, plumbing of lead pipes, uses of lead bullets, lead storage batteries, pewter pitchers, toys and faucets. Lead is released into the atmosphere from industrial processes as well as from vehicle exhausts [23]. Therefore, it may get into the soil and flow into water bodies which can be taken up by plants and hence human exposure of lead occurs through the consumption of food or drinking water.

1.4.3. Cadmium

This metal is mostly used in different industries for the production of paints, pigments alloys, coatings, batteries as well as plastics. Majority of cadmium, about three fourths is used as electrode component in producing alkaline batteries [24]. Cadmium is emitted from various industrial processes and from cadmium smelters into sewage sludge, fertilizers, and groundwater which could remain in soils and sediments for several decades and consequently taken up by plants [25]. The possible pathways of human exposure to Cd are through the food chain. Cd is a common contaminant found in most of the human foodstuffs due to the high metal transfer factor properties of plants. The bioaccumulation of Cd from soil to the foodstuffs makes diet a primary source of Cd exposure among non-smoking, non-occupationally exposed populations. Certain foods such as shellfish, kidney, liver, mushrooms and root crops contain high levels of cadmium [26].

1.4.4. Chromium

Chromium is present in petroleum and coal, chromium steel, pigment oxidants, fertilizers, catalyst, oil well drilling and metal plating tanneries. Chromium is extensively used in the industries such as wood preservation, electroplating, metallurgy, production of paints and pigments, chemical production, tanning, and pulp and paper production [27]. These industries play a major role in chromium pollution with an adverse effect on biological and ecological species. Following the anthropogenic activities by humans, disposal of sewage and use of fertilizers may also lead to the release of chromium into the environment. Chromium pollution in the environment has been occurred mostly with presence of hexavalent chromium species and both industrial and agricultural practices increase the contamination of water, sediment, and aquatic organism with chromium.

1.4.5. Copper

Heavy metal, Copper is used in the industries to produce copper pipes, cables, wires, copper cookware, plating, rayon, electrical and electronics waste, pesticides, paints, and pigments. Copper is also used in textile industries. Copper contents in foodstuff vary according to the local conditions. Copper concentration in soil, slurry/manure spreading, use of copper compounds as bactericides or fungicides on many crops and copper emissions from melting and casting industries may affect the copper contents in cereals, fruit and vegetables and to a lesser extent, meat and animal products [28].

1.4.6. Manganese

Manganese is the 12th most abundant element in the earth‘s crust. Ocean spray, forest fires, vegetation, and volcanic activities are other major natural atmospheric sources of manganese. The major anthropogenic sources of environmental manganese include emission from manganese ore mining, manganese alloy production, welding, coke ovens, dry alkaline battery manufacturing, and manganese salt production. Its widespread application in ceramics production and in the manufacture of glass, aluminum cans, and electronic components must also notable. Manganese-containing agrochemicals such as fungicides and fertilizers are still being used extensively in some countries [29]. Municipal waste water discharges and sewage sludge are also substantial sources of manganese.

1.4.7. Nickel

Nickel normally occurs at a very low concentration in the environment. It is used in the production of batteries, nickel-plated jewelry, machine parts, nickel plating on metallic objects, manufacture of steel, cigarette smoking, wire, electrical parts, etc. [30].

1.4.8. Iron

Iron is an attractive transition metal for various biological redox processes due to its inter-conversion between ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions. The sources of iron in surface water are anthropogenic and are related to different mining activities. The production of sulphuric acid as well as the discharge of ferrous (Fe^{2+}) takes place due to the oxidation of iron pyrites (FeS_2) that are common found in coal seams [31]. The following equations represent the simplified oxidation reactions involve with ferrous and ferric iron:

$$2FeS_2 + 7O_2 \rightarrow 2FeSO_4 + H_2SO_4 \text{ (ferrous)}$$

$$4FeSO_4 + O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 4H_2SO_4 \text{ (ferric)}$$

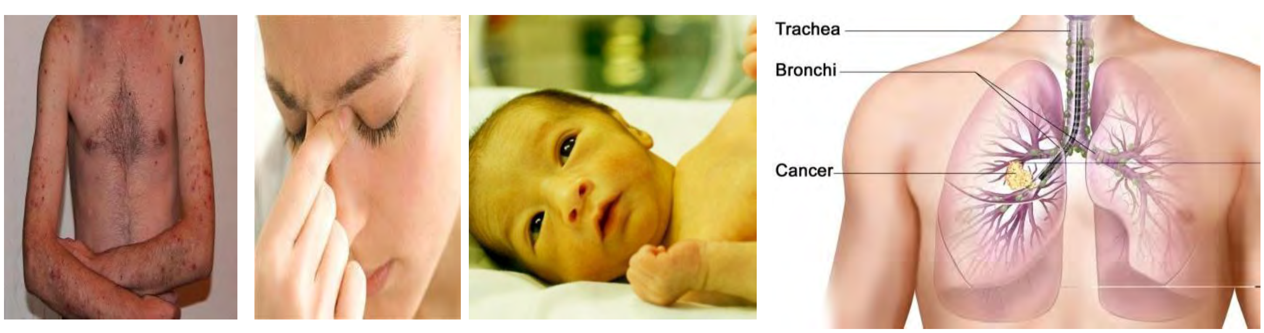
1.5. Effects of heavy metals on the human health

In addition to deteriorate the quality of natural waters, heavy metals could also cause several serious health problems in humans, affecting the nervous system, kidney, liver, and respiratory functions. Most metal trace elements (MTEs) are strongly carcinogenic.

Acute poisoning

Abdominal pain Vomiting Skin Kidney

Chronic poisoning



Hyperpigentation Hypertension Jaundice Cancer

Figure 1.4: Effects of heavy metals on human health

MTEs could also cause the delays in the human growth and development, and disruption of bioregulatory systems responsible for functional or psychosomatic disorders, like chronic fatigue syndrome, and neurodegenerative pathologies, such as the Parkinson‘s and Alzheimer‘s diseases [32]. Intoxication by some heavy metals, such as mercury and lead, can also lead to autoimmunity phenomena, in which the immune system of the patient attacks his own cells. This could cause the development of joint diseases, such as rheumatoid arthritis, and kidney, circulatory, or nervous problems in the human bodies. Figure 1.4 shows the development of different diseases in human bodies for the long time exposure of heavy and toxic metals to humans from various sources.

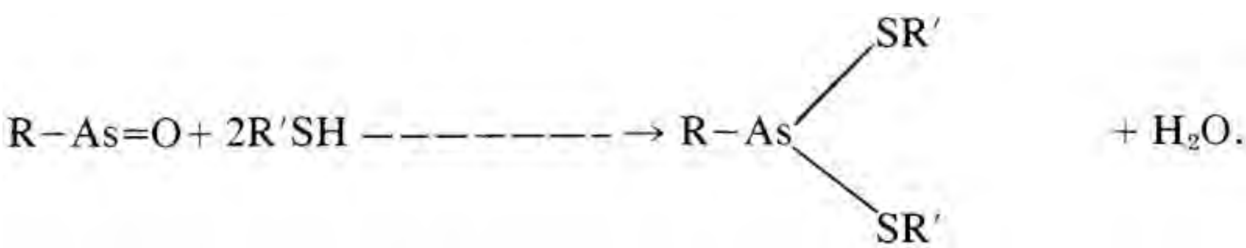
1.5.1. Impact and toxicity of chromium

The toxicity of chromium varies strongly, according to its chemical form (particle, nanoparticle, ion, oxide, hydroxide, valence 2 to valence 6). For example, the Cr^{6+} ions are extremely toxic, about 1000 times more toxic than the Cr^{3+} ions. Cr (VI) ions can enter into the cells through the ion transport system and constitute an increasing health concern for aquatic organisms [33]. Besides the positive role of Cr (III) in metabolism of glucose, fats and proteins in animals and humans it has distinct toxicological features. The presence of high level of chromium (VI) in drinking water causes tumors in stomach of humans and animals. Cr (VI) can be reduced to Cr (III). This form of chromium is not found highly toxic since it cannot be transported inside the cells. Cr (VI) enters into many types of cells under various physiological conditions and produces reactive intermediates that may interrupt cellular integrity and numerous functions. In general, chromium does not accumulate in the fish body, however the presence of higher concentrations of chromium in surface water resulting from excessive release of this metal due to industrial activities could damage the fish gills near the discharge points [34]. In animals, chromium could cause respiratory problems, the decrease of ability to fight diseases, genetic defects, infertility, or the formation of tumors. In humans, chronic chromium poisoning could yield skin lesions and mucous membranes, as well as respiratory problems, even bronchopulmonary cancers [35].

1.5.2. Impact and toxicity of Arsenic

Figure 1.5: Toxic effects of Arsenic on human body

The difference in toxicities between trivalent and pentavalent arsenic compounds can be understood by considering the biochemical mechanisms of actions of these two distinct families of compounds. Organic arsenicals exert their toxic effects in vivo by first being metabolized to the trivalent arsenoxide form and then reacting with sulfhydryl groups of tissue proteins and enzymes to form an aryl bis (organylthio) arsine [36]:



Arsenic can enter the water bodies, air, and land by transportation through water runoffs and wind-blown dust etc. [37]. The presence of arsenic causes various toxicity in different organs of humans and animals bodies such as: Neurotoxicity, Hepatotoxicity, Cardiotoxicity, Renal toxicity, Testicular toxicity , Carcinogenicity , Oxidative stress, Cell proliferation, Diabetes[38]. Arsenic exposure can also cause hand and foot lesions, and may extend to cause disability in some cases [39].

1.5.3. Impact and toxicity of lead

Lead is considered as one of the most toxic heavy metals. Its long-term toxicity is commonly known as lead poisoning. It could have serious effects on the nervous, hematopoietic, and cardiovascular human systems. At high doses, lead can cause neurological, hematological, and renal disorders. In children, it can also produce brain development disorders, with psychological disturbances and learning difficulties. Lead poisoning results in decreasing fertility, death of fetuses and spontaneous abortion, and neurological, cardiovascular, and gastrointestinal disorders and may have also mutagenic and carcinogenic effects [40]. Lead salts are poorly soluble in saltwater and in hard water, and the presence of other salts reduces the availability of lead in organisms due to the lead precipitation. In aqueous medium, the lead toxicity varies with fish species. Eggs and very young fishes are most vulnerable to lead toxicity. Bird spinal deformity and blackening of the caudal region are symptoms of lead intoxication [41].

1.5.4. Impact and toxicity of cadmium

Cadmium is very toxic, almost as much as lead and mercury. In 1993 the International Agency for Research on Cancer (IARC) has classified cadmium in group 1 as ―carcinogenic agent (or mixture) for humans”. Various studies have been conducted in workplaces regarding cadmium pollution and corresponding inhalation exposures to cadmium have shown a significant increase of lung cancer mortality in the presence of cadmium [42]. In humans, cadmium can produce kidney problems and increase blood pressure. Moreover, direct inhalation of cadmium is severely harmful to humans. Chronic exposure to cadmium is the origin of a disease called ―itai-itai,” which causes irreversible nephropathy, possibly leading to kidney failure. Cadmium is toxic even at low doses for many animal and plant species, aquatic as well as terrestrial. In addition, like other heavy metals, cadmium can induce oxidative stress in algae and disturb the germination of seeds in certain plants. Cadmium induces the alteration of steroidogenesis, disorders of the menstrual cycle and reproductive hormones, the delay in puberty and menarche, causes pregnancy loss, premature birth, and reduced birth weight [43].

1.5.5. Impact and toxicity of nickel

Although nickel in its metallic form, constitutes one of the lightest heavy metals, its prolonged contact with skin and mucous membranes can cause itching and sometimes produce allergies. In general, contact dermatitis from skin exposure to nickel is the most common effect nickel contamination. In addition, ingestion of nickel salts can yield nausea, vomiting, and diarrhea, whereas chronic inhalation of nickel as the monoxide or metallic forms can generate certain cases of asthma and tubular dysfunction. Moreover, some nickel organic compounds, such as tetra-carbonyl-nickel, are known to be very toxic and highly carcinogenic (lung cancer) [44]. The IARC has classified nickel as a potentially carcinogenic substance.

1.5.6. Impact and toxicity of copper

The effects of chronic exposure to excess copper are badly understood in individuals that do not suffer the genetic disease. Neither the copper dose nor the time of exposure necessary to induce adverse effects is known [45]. As for copper deficiency, the effects associated with excess copper are best described in a severe disease state such as Wilson disease, an autosomal and recessive genetic condition due to the mutation of the Wilson protein. The gene is expressed mainly in the liver. It‘s defect results in the accumulation of copper in the liver because it cannot be incorporated to ceruloplasmin and exported into the bile system. In most cases, copper induces acute nausea, vomiting and diarrhea. In addition, multiple organs failure, shock and death have also been described in individuals that ingest very high doses [46].

1.5.7. Impact and toxicity of Manganese

Manganese is an important metal for human health, being necessary for the development, metabolism, and antioxidant system. Nevertheless, excessive exposure or intake of manganese may lead to develop a condition known as Manganism, a neurodegenerative disorder that causes dopaminergic neuronal death and parkinsonian- like symptoms. Manganese has a paradoxical effect in animals as a Janus-faced metal. There are different diseases such as neurodegenerative disease, Parkinson‘s disease, Alzheimer‘s disease, Huntington‘s disease, Molecular mechanisms of toxicity etc. due to the excessive accumulation of manganese in human bodies [47].

1.5.8. Impact and toxicity of Iron

It is well-known that deficiency or over exposure to various elements has noticeable effects on human health. The effects of an element in human bodies are determined by several characteristics, including absorption, metabolism, and degree of interaction with physiological processes [48]. Iron is an essential element for almost all living organisms as it participates in a wide variety of metabolic processes, including oxygen transport, deoxyribonucleic acid (DNA) synthesis, and electron transport. However, as iron can form free radicals, its concentration in body tissues must be tightly regulated because the presence of excessive amounts iron can lead to tissue damage. Disorders of iron metabolism are among the most common diseases in humans and encompass a broad spectrum of diseases with diverse clinical manifestations, ranging from anemia to iron overload, and possibly to neurodegenerative diseases [49].

1.7. Literature Review

Abarshi *et al.* (2017) performed research on the accumulation of heavy metals in different fish species from oil spilled rivers of Niger Delta region and the metal concentration was found in the range 0.2 to 102 mg/kg for eight metals [50]. Pal *et al.* (2018) reported the heavy metals concentration in highly consumed cultured fishes (Labeo rohita and Labeo bata) and determined the potential health risk assessment in aquaculture pond of the coal city, Dhanbad (India) and the metal concentrations were observed to be in the range of 0.12 to 18.2 mg/kg of eight metals [51]. Jia *et al.* (2018) conducted a research on the different fish species in Xiang River at China and the metals concentrations were observed to be varied from 0.032 to 31.1 mg/kg for eight different metals [52]. Bi *et al.* (2018) carried out a research on the different fish species grown in Dongting Lake at China and they noticed the metals concentration varied from 0.01 to 0.48 mg/kg for seven metals [53]. Zhong *et al.* (2018) reported the health risk assessment of different heavy metals in freshwater fishes in the central and eastern North China. The results explained the possible development of non-carcinogenic health risks to humans by consuming fish products, no matter wild or farmed fish [54]. Huang *et al.* (2019) carried out research works on the different fish species in various lakes and rivers located in Northeast China and reported the metals concentration was in the range of 0.0012 to 0.27 mg/kg for seven metals [55]. Nisbet *et al.* (2010) performed their study on different fish species grown in the Middle Black Sea and realized the metal concentration to be varied from 0.024 to 25.97 mg/kg for six metals [56]. Ahmed *et al* (2019) carried out their research work on various fish species collected from Karnaphuli River at Chittagong and observed the concentration of five heavy metals in the range of 0.39 to 12.4 mg/kg [57]. Rahman, *et al.* (2020), conducted a research on the pollution of water, sediments, and fishes of Rupsha River and the metal contents were found to be in the range of 0.05 to 4.95 mg/kg in fish species, 0.56 to 508.18 mg/kg in sediments and 0.008 to 1.32 mg/L in surface water of seven metals [58]. Ahmed *et al.* (2010) performed their study on the water, sediment and fishes of Burigonga river and they reported the metal concentrations in the range of 0.96 to 9.96 mg/kg for fish species, 3.33 to 200.45 mg/kg for sediments and 0.0088 to o.5826 mg/L for water samples [59].

Mohanta *et al.* (2019) reported the accumulation of heavy metals in different fresh water fishes, sediment, and surface water. Metal concentrations in fishes, sediments, and water were observed to be BDL to 64.49 mg/kg, 1.44 to 256.23 mg/kg and BDL to 0.1649 mg/L respectively[60]. Jothi *et al.* (2018) found average and maximum concentrations of certain metals in sea fishes grown at different locations in Chittagong bay area as unacceptably higher that tolerable levels and observed the increasing trend of heavy metal pollution in the respective areas [61]. Ahmed *et al.* (2019) reported the accumulation and concentration of heavy metals in different fresh water fishes that were grown in the contaminated water bodies. The fish species studied were being exposed to cadmium (Cd), Arsenic (As), chromium (Cr), Copper (Cu) and lead (Pb) at sub lethal levels [62]. Ahmed et al. (2016) also studied on Human health risks from heavy metals through the consumption of contaminated fishes from Buriganga River [63]. Summary of the literature review has been shown below in the Table 1.1:

Table 1.1: Average metals concentrations in fishes (mg/kg) from different studies in the world and respective comparison with the findings of present study

Year	River	City	Country	Conc. of metal in fish(mg/Kg)								Reference
				Cd	As	Fe	Ni	Mn	Pb	Cr	Cu	
2020	Bangshi and DEPZ lake	Dhaka	Bangladesh	0.49	0.97	111.16	4.09	31.44	3.98	1.16	16.47	Present study
2020	Different Bil, Lake & river	Kalihati	Bangladesh	0.005	0.057	77.31	0.7	9.87	1.38	0.00	3.61	Present study
2017	Spilled	Delta region	Nigeria	ND	Na	102	5.33	9.34	0.2	NA	3.5	[50]
2018	Urban Pond	Dhanbad	India	0.12	0.24	–	–	18.3	5.24	3.89	–	[51]
2017	Xiang River	Yueyang & six cities	China	0.032	0.743	31.1	0.112	2.35	0.175	0.646	2.5	[52]
2018	Dongting Lake	northern Hunan province	China	0.01	0.08	–	0.14		0.08	0.9	0.46	[53]
2018	Freshwater fish	central and eastern North China	China	0.007	0.145	–	0.15	0.66	0.16	2.29	0.46	[54]
2019	Different lake & river	Northeast China	China	0.0012	0.052	–	0.019		0.034	0.018	0.27	[55]
2010	Middle Black Sea	Coast of Samsun, Sinop	Turkey	0.024	–	25.97	2.9	5.21	0.79	–	2.48	[56]
2019	Karnaphuli River	Chittagong	Bangladesh	0.39	4.89	–	–	–	13.88	3.36	12.1	[57]
2020	Rupsha	Khulna	Bangladesh	0.05	0.78	–	0.58	4.97	0.92	0.26	4.62	[58]
2010	Burigonga	Dhaka	Bangladesh	0.96	–	–	9.48	–	9.96	6.28	4.8	[59]
2019	Dhaleshwari	Tangail	Bangladesh	6.38	BDL	–	–	–	64.49	4.51	BDL	[60]
2018	Sea fish	Chittagong	Bangladesh	–	–	79.279	1.168	NA	1.67	5.7798	4.0548	[61]
2019	Meghna	Noakhali	Bangladesh	0.11	1.04	–	–	–	3.66	0.62	4.97	[62]
2016	Burigonga	Dhaka	Bangladesh	0.012	0.322	–	2.11	48.04	3.46	7.48	10.52	[63]

Rastmanesh *et al*. (2018) carried out research on the heavy metal enrichment and ecological risk assessments of surface sediments at Khorramabad River located in the West region of Iran. The results showed that sediments were moderately polluted with stations located in more densely populated areas and explained the ecological risk assessments for sediments as the category of low risk [64]. Jumbe *et al.* (2009) examined the heavy metals status and sediment Quality values in Urban Lakes, India and reported the seven metal concentrations in the range of 8.38 to 206.00 mg/kg for sediments [65]. Shanbehzadeh, *et al.* (2014) and Kader *et al*. (2018) conducted research on heavy Metals status in sediment at Iran and at India respectively and the seven metal concentration was found to be varied from 27.00 to 767.50 mg/kg and 1.77 to 1409.67 mg/kg respectively in those study areas [66-67]. Wei *et al.* (2019) studied the pollution assessment of heavy metals in the surface sediments of the Raohe Basin at China. The risk analysis of geo-accumulation index (Igeo) from that study suggested the heavy metals, copper and arsenic as the main pollution factors and each element of the pollution degree was found to follow the order of: Cu>As> Pb> Cd> Cr>Zn [70]. Khan *et al.* (2018) evaluated the bioaccumulation status of heavy metals in water, sediments, and tissues in Kabul River located at Khyber Pakhtunkhwa, Pakistan. The order of metal contents in water was found in the order of: Pb > Ni > Cu > Mn > Fe > Cr > Cd, and in the sediments samples the order was Fe > Cr > Ni > Mn > Pb > Cu > Cd, as well as the order was realized to be: Fe > Mn > Pb > Cu > Cr > Ni > Cd in tissues [71]. Khan, *et al.* (2020), Siddiqui *et al*. (2019) conducted research works on heavy metals pollution status in sediments of Ganges-Brahmaputra-Meghna basin at Bangladesh and Ganga basin at India and the metal concentrations were found to be in the range of 0.13 to 94.31 and 13.84 to 31878.00 mg/kg respectively for seven metals studied [73-74]. Hassan *et al.* (2015) studied the status of six heavy metals in water and sediment of the Meghna river in Narayangonj, Bangladesh and the metal concentration was found to be in the range of 0.23 to 1281.42 mg/kg for sediments, BDL to 1.0224 mg/L for surface water [68]. Bhuyan *et al.* (2019) reported heavy metal contamination in surface water and sediment of the old Brahmaputra river in Bangladesh and the metal concentration was found to be varied from 0.001to 126.2 mg/kg in sediments and 0.001 to 1.44 mg/L in surface water for six metals [69]. Summary of the literature review on heavy metal contamination in sediments has been displayed in the following Table 1.2

Table 1.2: Average metals concentrations in sediments (mg/kg) observed from different studies in the world and respective comparison with the present investigation

Year	River	City	Country	Conc. of metal in sediments(mg/kg)								Reference
				Cd	As	Fe	Ni	Mn	Pb	Cr	Cu	
2020	Bangshi and DEPZ lake	Dhaka	Bangladesh	1.50	8.21	5513.76	54.28	421.26	14.73	80.88	98.49	Present Study
2020	Different Bil, Lake & river	Kalihati	Bangladesh	0.06	2.70	1556.27	36.05	293.42	10.63	63.44	31.14	Present Study
2018	Khorramabad River	Khorramabad city	West Iran	–	5.80	24369.90	76.80	636.30	19.20	169.60	49.40	[64]
2009	Urban Lake	Bangalore City	India	8.38	–	Na	97.64	176.00	206.00	96.70	203.50	[65]
2014	Tembi River		Iran	27.00	–	265.00	128.50	767.50	255.00	65.50	85.00	[66]
2018	Sundarbans	West Bengal	India	1.77	–	1409.67	–	978.41	18.54	–	164.64	[67]
2015	Meghna	Narayangonj	Bangladesh	0.23	–	1281.42	76.12	442.60	9.47	31.74	52.56	[68]
2019	Brahmaputra	Narsingdi	Bangladesh	0.48	–	Na	12.80	126.20	7.60	6.60	6.20	[69]
2019	Changjiang River	Jingdezhen	China	0.42	177.89	–	55.83	–	22.49	51.63	58.88	[70]
2018	Kabul River	Khyber Pakhtunkhwa	Pakistan	5.35	–	396.97	76.42	78.86	42.92	69.09	13.62	[71]
2020	Yangtze River	Estuary	China	0.13	–	–	23.40	–	15.24	82.30	17.16	[72]
2020	Ganges-Brahmaputra-Meghna		Bangladesh	0.13	–	–	46.32	–	23.28	94.31	30.88	[73]
2019	Ganga River	Devprayag	India	1.60	–	31878.00	25.00	1182.00	13.84	64.54	35.57	[74]
2020	Rupsha river	Khulna	Bangladesh	0.56	2.22	NA	31.34	508.38	62.40	67.72	31.95	[58]
2010	Burogonga River	Dhaka	Bangladesh	3.33	Na	Na	200.45	Na	69.75	177.53	27.85	[63]

Islam *et al.* (2020) analyzed the quality of water in Shitolokha river at Dhaka and reported the metal concentrations in the range of BDL to 0.01134 mg/L found for eight metals studied [82]. Goher *et al.* (2014) evaluated the surface water quality and heavy metal indices in water of Ismailia Canal, Nile River at Egypt. Metal index (MI) and Pollution index (PI) values in that study demonstrated the dangerous pollution status of the canal water which was seriously described as a major source of water for drinking and fisheries utilizations in the respective area [75]. Mahato *et al.* (2017) carried out research works on the assessment of Mine Water Quality using the Heavy Metal Pollution Index in a Coal Mining area of Damodar River at India and the concentrations of eight metals in water were observed to be varied from 0.0003 to 0.34 mg/L [76]. Bhardwaj *et al.* (2017) studied the heavy metal contamination using environmental metrics and indexing approach in water of Yamuna River located at around Delhi, India and observed eight different metal concentrations to be varied from 0.0476 to 10.00. mg/L [77]. Okbah *et al.* (2018) demonstrated that water resources and aquatic biodiversity are intimately interrelated and interdependent and degradation of water quality, depletion of water resources and loss of aquatic biodiversity are prominent features of the environmental landscape which require urgent attention at global and national scales. Abadi *et al.* (2018) carried out research works on the water quality of Caspian coasts in Iran and they observed six different metal concentrations in the range 0.00029 to 0.00162 mg/L [79].

Summary of the literature review on heavy metals contamination in water bodies from different studies has been shown below in the Table 1.3:

Table 1.3: Average metals concentrations in surface water (mg/L) from different studies in the world and respective comparison with the findings of present study

Year	River	City	Country	Conc. of metal in surface water(mg/L								Reference
				Cd	As	Fe	Ni	Mn	Pb	Cr	Cu	
2020	Bangshi and DEPZ lake	Dhaka	Bangladesh	0.0158	0.035	2.43	0.295	0.7275	0.13	0.07	0.30	Present Study
2020	Different Bil, Lake & river	Kalihati	Bangladesh	0.0003	0.008	1.44	0.00	0.22	0.05	0.22	0.10	Present Study
2014	Nile	Ismailia Canal	Egypt	–	–	0.57	0.01	0.113	0.018	-	0.007	[75]
2017	Damodar	East Bokaro	India	0.0005	0.0003	0.34	0.0065	0.0065	0.002	0.0067	0.0023	[76]
2017	Yamuna	Delhi stretch	India	0.0476	–	10	0.3755	–	0.1164	0.1471	0.21518	[77]
2018	Edku lake	Alexandria	Egypt	0.00116	–	0.02929	0.00324	0.00989	–	0.00553	0.00135	[78]
2018	Caspian sea	Shouthern	Iran	0.00029	0.0023	–	0.0054	–	0.00033	–	0.00162	[79]
2014	Costal Marin ecosystem	Greece	Greece	0.0016	–	–	–	1.32	0.017	–	0.09	[80]
2020	Shitolokha	Dhaka	Bangladesh	0.0034	0.01134	1.13968	0.005	0.01882	0.0044	0.014	BDL	[81]
2020	Rupsha	Khulna	Bangladesh	0.008	0.027	–	0.048	0.088	0.136	0.058	1.32	[58]
2010	Burigonga	Dhaka	Bangladesh	0.00934	–	–	0.0088	Na	0.06545	0.5872	0.16309	[59]
2019	Dhaleshwari	Tangail	Bangladesh	0.0302	0.0067	–	–	–	0.1649	BDL	0.0464	[60]
2015	Meghna	Narayangonj	Bangladesh	0.003	–	1.0224	BDL	0.0088	BDL	0.0346	-	[68]
2019	Brahmaputra	Narsingdi	Bangladesh	0.001	–	-	0.44	1.44	0.11	0.01	0.12	[69]

References

1. Ali. H., Khan, E., ―Bioaccumulation of Cr, Ni, Cd and Pb in the Economically Important Freshwater Fish Schizothoraxplagiostomus from Three Rivers of MalakandDivision, Pakistan: Risk Assessment for Human Health*", Bulletin of Environmental Contamination and Toxicology,* Vol. 102(1), pp. 77-83. 2018.

2. Zhaoyong, Z., Xiaodong, Y., and Shengtian, Y., ―Heavy metal pollution assessment, source identification,and health risk evaluation in Aibi Lake of northwest China*", Environ. Monit. Assess*., Vol. 190(69), 2018.

3. Copaja S. V., Pérez C. A., Vega-Retter C., Véliz D., ―Heavy Metal Content in Chilean Fish Related to Habitat Use Tissue Type and River of Origin*", Bul.l Environ. Contam. Toxicol.*, Vol. 99(6), pp. 695-700, 2017.

4. Müller, A., Österlund, H., Marsalek, J., Viklander, M., ―The pollution conveyed by urban runoff: A review of sources*", Science of the Total Environment,* Vol. 709, pp. 136125, 2020.

5. Zhuang, H., Xu, S., Gao, M., Zhang, J., Hou, G., Liu, S., ―Heavy Metal Pollution Characteristics in the Modern Sedimentary Environment of Northern Jiaozhou Bay, China*",Bulletin of Environmental Contamination and Toxicology*, 2018.

6. Kumar, K., kumar, R. and Li, X., ―Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China*", Toxicol. Rep.,* Vol. 5, pp. 288 -295, 2018.

7. Nahar, K., Chowdhury, M., Chowdhury, M., Rahman, A., Mohiuddin, K. M., ―Heavy metals in handloom-dyeing effluents and their biosorption by agricultural byproducts*",*, *Environ. Sci. Pollut. Res. Int.,* Vol. 25(8), pp. 7954-7967. 2018.

8. Mahurpawar, M., ―Effect of Heavy Metals on Human Health*", International Journal of Research-Granthaalayah*, Vol. 31, pp. 1-7. 2015.

9. Pandey, V. C., Singh, V., ―Exploring the Potential and Opportunities of Current Tools for Removal of Hazardous Materials from Environments*", Phytomanagement of Polluted Sites,* pp. 501-516, 2019.

10. Gavrilescu, M., Demnerová, K., Aamand, J., Agathos, S., & Fava, F., ―Emerging pollutants in the environment: present and future challenges in biomonitoring, ecological risks and bioremediation", *New Biotechnology,* Vol. 32(1), 2015.

11. Salomons, W., Forstner, U., Mader, P. (1995) the book of heavy metals: problems and solutions, *Springers- Verlag.* Berlin, Germany.

12. El-Shahawi, M. S., Hamza, A., Bashammakhb, A. S., Saggaf Al- W. T., ―An overview on the accumulation, distribution, transformations, toxicity and analytical methods for the monitoring of persistent organic pollutants*",* Talanta, Vol. 80(5), pp. 1587-1597. 2010.

13. Elliott M., ―Biological pollutants and biological pollution- an increasing causes for concern", *Marine pollution Bulletin,* Vol. 46, pp. 275-280, 2003.

14. Tchounwou, B. P., Yedjou, G. Y., Patlolla, K. A., and Sutton, J. D., ―Heavy Metals Toxicity and the Environment*", NIH Public Access,* Vol. 101, pp. 133–164. 2012.

15. De Andrade, L. C., Tiecher, T., de Oliveira, J. S., Andreazza, R., Inda, A. V., & de Oliveira Camargo, F. A., ―Sediment pollution in margins of the Lake Guaíba, Southern Brazil*", Environ. Monit. Assess.,* Vol. 190(3), pp. 1-133, 2018.

16. Müller, A., Österlund, H., Marsalek, J., & Viklander, M., ―The pollution conveyed by urban runoff: A review of sources"*, Science of The Total Environment,* Vol. 709, pp. 136125, 2020.

17. Jan, A., Azam, M., Siddiqui, K., Ali, A., Choi, I., & Haq, Q., ―Heavy Metals and Human Health: Mechanistic Insight into Toxicity and Counter Defense System of Antioxidants", *International Journal of Molecular Sciences,* Vol. 16(12), pp. 29592–29630, 2015.

18. Sadiq, A. A. S., Halima I. M., Bataiya, A. G., Idris I. A., Shamsuddin I. M., Yahaya, A. S., Suleiman, M., ―A Review on Heavy Metals Contamination in Water and Soil: Effects, Sources and Phytoremediation Techniques*", International Journal of Mineral Processing and Extractive Metallurgy*. Vol. 2(2), pp. 21-27. 2017.

19. Wuana, R. A., & Okieimen, ―Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation*",* ISRN Ecology, Vol. 2011, 2011.

20. Janga, Y. –C., Somannaa, Y., and Kim, H., ―Source, Distribution, Toxicity and Remediation of Arsenic in the Environment – A review*", International Journal of Applied Environmental Sciences,* Vol. 11(2), pp. 559-581, 2016.

21. Chung, J.-Y., Yu, S.-D., & Hong, Y.-S., ―Environmental Source of Arsenic Exposure", *Journal of Preventive Medicine and Public Health,* Vol. 47(5), pp.253–257.2015.

22. Wani A. L., Ara, A., Usmani J. A., ―Lead toxicity: A review*", Interdisciplinary Toxicology,* Vol. 8(2), pp. 55-64, 2015.

23. Zhang, R., Wilson, V. L., Hou, A., Meng. G., ―Source of lead pollution, its influence on public health and the countermeasures*", Health, Animal science and Food safety,* Vol. 2(1), pp. 18 – 31, 2015.

24. Yuan, Z., Luo, T., Liu, X., Hua, H., Zhuang, Y., Zhang, X., Ren, J., Zhang, L., Zhang, Y., Xu, W., , Ren, J. ,―Tracing anthropogenic cadmium emissions: From sources to pollution*", Science of the Total Environment*, Vol. 676, pp. 87–96, 2019.

25. Ali, H., Khan, E., & Ilahi, I., ―Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation", *Journal of Chemistry,* Vol. 2019, pp. 1–14. 2019.

26. Chunhabundit, R., ―Cadmium Exposure and Potential Health Risk from Foods in Contaminated Area, Thailand", *Toxicol. Res.,* Vol. 32(1), pp. 65–72. 2016.

27. Saha, R., Nandi, R., & Saha, B., ―Sources and toxicity of hexavalent chromium. *Journal of Coordination Chemistry*", Vol. 64(10), pp. 1782–1806. 2011.

28. Bost, M., Houdart, S., Oberli, M., Kalonji, E., Huneau, J.-F., & Margaritis, I., ―Dietary copper and human health: Current evidence and unresolved issues", *Journal of Trace Elements in Medicine and Biology,* Vol. 35, pp. 107–115, 2016.

29. Röllin, H. B., & Nogueira, C. M. C. A., ―Manganese: Environmental Pollution and Health Effects", *Encyclopedia of Environmental Health,* pp.617-629, 2011.

30. Poznanović Spahić, M. M., Sakan, S. M., Glavaš-Trbić, B. M., Tančić, P. I., Škrivanj, S. B., Kovačević, J. R., & Manojlović, D. D., ―Natural and anthropogenic sources of chromium, nickel and cobalt in soils impacted by agricultural and industrial activity (Vojvodina, Serbia)", *Journal of Environmental Science and Health,* Vol.2018, pp. 1–12. 2018.

31. Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda., ―K. N. Toxicity, mechanism and health effects of some heavy metals", *Interdisciplinary Toxicology,* Vol.7(2), pp. 60–72. 2014.

32. Sall, M. L., Diaw, A. K. D., Gningue-Sall, D., Aaron S. E., Aaron, J. J., ―Toxic heavy metals: impact on the environment and human health, and treatment with conducting organic polymers, a review", *Environmental Science and Pollution Research*, Vol. 27, pp. 29927–29942, 2020.

33. Shekhawat, k., Chatterjee, s., and Joshi, B., ―Chromium Toxicity and its Health Hazards", *International Journal of Advanced Research,* Vol. 3(7), pp. 167-172, 2015.

34. Aslam, S., and Yousafzai, M. A., ―Chromium toxicity in fish: A review article", *Journal of Entomology and Zoology Studies,* Vol. 5(3) pp. 1483-1488, 2017.

35. Achmad, T. R., Budiawan and Auerkari I. E., ―Effects of Chromium on Human Body", *Annual Research & Review in Biology*, Vol. 13(2), PP. 1-8, 2017.

36. National Research Council (US) Committee on Medical and Biological Effects of Environmental Pollutants. Arsenic: Medical and Biologic Effects of Environmental Pollutants. Washington (DC): National Academies Press (US); 1977. 5, Biologic Effects of Arsenic on Plants and Animals.

37. Sanjrani, M. A., Zhou, B., Zhao, H., Bhutto, S. A., Muneer, A. S., Xia, S. B., ―Arsenic contaminated ground water in China and its treatment options, A review*", Applied ecology and environment research,* Vol. 17(2), pp.1655-1683, 2019.

38. Mazumder, G. D., Dasgupta U.B., ―Chronic arsenic toxicity: Studies in West Bengal, India", *Kaohsiung Journal of Medical Sciences,* Vol. 27, pp. 360-370. 2011.

39. Yunus F. M., Chowdhury K. S., Milton A. H., Hussain, S., and Rahman, M., ―A Review of Groundwater Arsenic Contamination in Bangladesh: The Millennium Development Goal Era and Beyond, Environ. Res", *Public Health,* Vol. 13, pp. 215. 2018.

40. Offem, B. O., & Ayotunde, E. O., ―Toxicity of Lead to Freshwater Invertebrates (Water fleas; Daphnia magna and Cyclop sp) in Fish Ponds in a Tropical Flood plain", *Water, Air, and Soil Pollution,*Vol.192(1-4), pp. 39–46. 2008.

41. Mudgal, V., Madaan, N., Mudgal, A., Singh, R. B., and Mishra, S., ―Effect of Toxic Metals on Human Health", *the Open Nutraceuticals Journal,* Vol. 3, pp. 94-99, 2010.

42. Genchi, G., Sinicropi, M. S., Lauria, G., Carocci, A., & Catalano, A., ―The Effects of Cadmium Toxicity", *International Journal of Environmental Research and Public Health,* Vol. 17(11), pp. 3782. 2020.

43. Bikash Debnath, B., Singh, S., W., Manna, K., ―Sources and Toxicological Effects of Lead on Human Health", *Indian J. Med. Spec.,* Vol. 10, pp. 66-71. 2019.

44. Genchi, G., Carocci, A., Lauria, G., Sinicropi, M. S., & Catalano, A., ―Nickel: Human Health and Environmental Toxicology", *International Journal of Environmental Research and Public Health,* Vol. 17(3), pp. 679. 2020.

45. Araya, M., Olivares, M., and Pizarro, F., ―Copper in human health", *Int. J. Environment and Health,* Vol. 1(4), pp. 608-620, 2007.

46. Gaetke, L. M., Chow-Johnson, H. S., & Chow, C. K., ―Copper: toxicological relevance and mechanisms", *Archives of Toxicology,* Vol. 88(11), pp.1929–1938.2014.

47. Avila, D. S., Puntel, L., & Aschner, M., ―Manganese in Health and Disease", *Interrelations between Essential Metal Ions and Human Diseases,* Vol.13, pp. 199–227. 2013.

48. Abbaspour, N., Hurrell, R., and Kelishadi R., ―Review on iron and its importance for human health", *J. Res. Med. Sci.,* Vol. 19(2), pp. 164–174. 2014.

49. Papanikolaoua, G., Pantopoulosb, K., ―Iron metabolism and toxicity", *Toxicology and Applied Pharmacology,* Vol. 202, pp.199 – 211, 2005.

50. Abarshi, M. M., Dantala, E. O., & Mada, S. B., ―Bioaccumulation of heavy metals in some tissues of croaker fish from oil spilled rivers of Niger Delta region, Nigeria", *Asian Pac. J. Trop. Biomed.,* Vol. 7(6), pp. 563–568, 2017.

51. Pal, D., & Maiti, S. K., ―Seasonal variation of heavy metals in water, sediment, and highly consumed cultured fish (Labeo rohita and Labeo bata) and potential health risk assessment in aquaculture pond of the coal city, Dhanbad (India) ", *Environmental Science and Pollution Research,* Vol. 25, PP. 12464–12480, 2018.

52. Jia, Y., Wang, L., Cao, J., Li, S., & Yang, Z., “Trace elements in four freshwater fish from a mine-impacted river: spatial distribution, species-specific accumulation, and risk assessment”, *Environ Sci. Pollut. Res.,* Vol. 25, pp. 8861–8870, 2018.
53. Bi, B., Liu, X., Guo, X., & Lu, S., “Occurrence and risk assessment of heavy metals in water, sediment, and fish from Dongting Lake, China”, *Environ Sci. Pollut. Res.,* Vol. 25, pp. 34076–34090, 2018.
54. Zhong, W., Zhang, Y., Wu, Z., Yang, R., Chen, X., Yang, J., & Zhu, L., “Health risk assessment of heavy metals in freshwater fish in the central and eastern North China”, *Ecotoxicology and Environmental Safety,* Vol. 157, pp. 343–349, 2018.
55. Huang, X., Qin, D., Gao, L., Hao, Q., Chen, Z., Wang, P., Tang, S., Wu, S., Jiang, H., Qiu, W., “Distribution, contents and health risk assessment of heavy metal(loid)s in fish from different water bodies in Northeast China”, *RSC Adv.,* Vol. 9(57), pp. 33130-33139, 2019.
56. Nisbet, C., Terzi, G., Pilgir, O., Sarac, N., “Determination of Heavy Metal Levels in Fish Samples Collected from the Middle Black Sea”, Kafkas Univ Vet Fak Derg, Vol. 16 (1), pp. 119-125, 2010.
57. Ahmed, A. S. S., Sultana, S., Habib, A., Ullah, H., Musa, N., Hossain, M. B., Sarker, M. S. I., “Bioaccumulation of heavy metals in some commercially important fishes from a tropical river estuary suggests higher potential health risk in children than adults”, *PLoS ONE*, Vol. Vol. 14(10), pp. 219336. 2019.
58. Rahman, M. M., & Hassan, M. M., “The Amount of Selected Heavy Metals in Water, Sediments and Fish Species from the Rupsha River, Khulna, Bangladesh”, *Asian Journal of Fisheries and Aquatic Research,* Vol. 6(2), pp. 1-9, 2020.
59. Ahmad, M. K., Islam, S., Rahman, S., Haque, M. R. and Islam, M. M., “Heavy Metals in Water, Sediment and Some Fishes of Buriganga River, Bangladesh”, *International Journal of Environmental Research,* Vol. 4(2), pp. 321-332, 2010.
60. Mohanta, M. C., Niloy, M. N. H., Chowdhury, G. W., Islam, D., and Lipy, E. P., “heavy metals in water, sediment and three fish species of Dhaleshwari river, Savar, Bangladesh”, *J. Zool.* Vol. 47(2), pp. 263-272, 2019.
61. Jothi, J. S., Anka, I. J., Hashem, S., Morshed, S., “Assessment of heavy metal concentration in edible fish muscle and water sample collected from different location in Chittagong: a public health concern”, *Ukrainian Food Journal*, Vol. 7(3), pp. 464-471. 2018.

62. Ahmed, A. S. S., Rahman, M., Sultana, S., Babu, S. M. O. F., & Sarker, M. S. I., ―Bioaccumulation and heavy metal concentration in tissues of some commercial fishes from the Meghna River Estuary in Bangladesh and human health implications", *Marine Pollution Bulletin.,* Vol. 145, pp. 436–447, 2019

63. Ahmed, M. K., Baki, M. A., Kundu, G. K., Islam, M. S., Islam, M. M., & Hossain, M. M., ―Human health risks from heavy metals in fish of Buriganga river, Bangladesh", *Springer Plus,* Vol. 5, pp. 1697, 2016.

64. Rastmanesh, F., Safaie, S., Zarasvandi, A. R., & Edraki, M., ―Heavy metal enrichment and ecological risk assessment of surface sediments in Khorramabad River, West Iran", *Environ. Monit. Assess.,* Vol. 190(5). 2018.

65. Jumbe, A. S., and Nandini, N., Heavy Metals Analysis and Sediment Quality Values in Urban Lakes", *American Journal of Environmental Sciences,* Vol. 5 (6), pp. 678-687. 2009.

66. Shanbehzadeh, S., Vahid Dastjerdi, M., Hassanzadeh, A., & Kiyanizadeh, T., ―Heavy Metals in Water and Sediment: A Case Study of Tembi River", *Journal of Environmental and Public Health,* Vol. 2014, pp. 1-5, 2014.

67. Kader, A., & Narayan Sinha, S., ―Heavy metal contamination in the sediment and plants of the Sundarbans, India", *Chemistry and Ecology,* Vol. *34(6), pp. 506–518*, 201.

68. Hassan, M., Mirza A.T.M., Rahman, T., Saha, B., and Kamal, A. K. I., ―Status of Heavy Metals in Water and Sediment of the Meghna River, Bangladesh", *American Journal of Environmental Sciences,* Vol. 11(6), pp. 427-439, 2015.

69. Bhuyan, M. S., Bakar, M. A., Rashed-Un-Nabi, M., Senapathi, V., Chung, S. Y., & Islam, M. S., ―Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh", *Applied Water Science,* Vol. 9(5), 2019.

70. Wei, J., Duan, M., Li, Y., Nwankwegu, A. S., Ji, Y., & Zhang, J., ―Concentration and pollution assessment of heavy metals within surface sediments of the Raohe Basin, China", *scientific reports,* Vol. 9(1), pp. 1-7, 2019.

71. Khan, M. I., Khisroon, M., Khan, A., Gulfam, N., Siraj, M., Zaidi, F., Ahmadullah, Abidullah, Fatima , S. H., Noreen, S., Hamidullah, Shah, Z, A., and Qadir, F., ―Bioaccumulation of Heavy Metals in Water, Sediments, and Tissues and Their

Histopathological Effects on Anodonta cygnea (Linea, 1876) in Kabul River, Khyber Pakhtunkhwa, Pakistan", *BioMed. Research International,* Vol. 2018, PP. 1-10, 2018.

72. Wang, X., Liu, B., & Zhang, W., ―Distribution and risk analysis of heavy metals in sediments from the Yangtze River Estuary, China", *Environmental Science and Pollution Research,* Vol. 27, pp. 10802–10810, 2020.
73. Khan, M. H. R., Liu, J., Liu, S., Li, J., Cao, L., & Rahman, A., ―Anthropogenic effect on heavy metal contents in surface sediments of the Bengal Basin river system, Bangladesh", *Environ Sci. Pollut. Res.,* Vol.27, pp.19688–19702, 2020.
74. Siddiqui, E., & Pandey, J., ―Assessment of heavy metal pollution in water and surface sediment and evaluation of ecological risks associated with sediment contamination in the Ganga River: a basin-scale study", *Environmental Science and Pollution Research,* Vol. 26, pp. 10926–10940, 2019.
75. Goher, M. E., Hassan, A. M., Abdel-Moniem, I. A., Fahmy, A. H., and El-sayed, S. M., ―Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt", *Egyptian Journal of Aquatic Research.* Vol. 40, pp. 225-233, 2014.
76. Mahato, M. K., Singh, G., Singh, P. K., Singh, A. K., & Tiwari, A. K., ―Assessment of Mine Water Quality Using Heavy Metal Pollution Index in a Coal Mining Area of Damodar River, India", *Bull Environ. Contam. Toxicol.,* Vol. 9(1), pp. 54-61, 2017.
77. Bhardwaj, R., Gupta, A., & Garg, J. K., ―Evaluation of heavy metal contamination using environmetrics and indexing approach for River Yamuna, Delhi stretch, India", *Water Science,* Vol. 31(1), pp. 52-66, 2017.
78. Okbah, M. A., Abdelhalim, A. M., Abu El-Regal, M. A., Soliman, N. F., & Nassar, M. E. M., ―Metals in a northern Nile Delta lake: water, suspended particulates, sediments, and biota", *Environmental Science and Pollution Research,* Vol. 25, pp. 33967–33977, 2018.
79. Abadi, M., Zamani, A., Parizanganeh, A., Khosravi, Y., & Badiee, H., ―Heavy metals and arsenic content in water along the southern Caspian coasts in Iran", *Environmental Science and Pollution Research,* Vol. 25, pp. 23725–23735, 2018.
80. Pavlidou, A., Anastasopoulou, E., Dassenakis, M., Hatzianestis, I., Paraskevopoulou, V., Simboura, N., Rousselaki, E.,Drakopoulou, P., ―Effects of olive oil wastes on river basins and an oligotrophic coastalmarine ecosystem", Science of the total environment, Vol. 38, pp. 497-498, 2014.

81. Islam, A. R. M. T., Islam, H. M. T., Mia, M. U., Khan, R., Habib, M. A., Bodrud-Doza, M., Siddique, M. B., and Chu, R., ―Co-distribution, possible origins, status and potential health risk of trace elements in surface water sources from six major river basins, Bangladesh", *Chemosphere,* Vol. 249, pp. 126180, 2020.

1.8. The aim and basic objectives:

The present study was being carried out with the following specific objectives:

1. To determine the eight different heavy metals concentrations (Fe, Ni, Pb, Cr, Cu, Mn, As, and Cd) in water, sediments and in various fish species grown in industrial contaminated area.
2. To compare the assessment data with national and international standards permissible or tolerable values.
3. To accurately predict the pollution level and environmental effects of contaminants in the fishes, sediments, and water in the contaminated areas.
4. To determine the comprehensive potential ecological risks for eight tested heavy metals in fishes and sediments due to different anthropogenic impacts.
5. To investigate the accumulation and mobilization of heavy and toxic metals in different fish species grown in polluted water bodies.
6. To accurately predict the pollution level and environmental effects of heavy and toxic metal contaminants in fishes, sediments, and water with sediment contamination factor and bioaccumulation factor, enrichment factor, pollution load index, potential ecological risk index, geo-accumulation index.
7. To estimate daily intake (mg/kg bw/day) of heavy metals from fishes for children and adult of highly contaminated areas and compare with the corresponding maximum tolerable daily intake (MTDI).
8. To determine the non-carcinogenic risk for children and adult people in highly contaminated area due to metal contaminated fish consumption by using Target hazard quotient.
9. To determine the carcinogenic risk for children and adult people in highly contaminated area due to metal contaminated fish consumption by using Target cancer risk.
10. To increase the awareness of the people against the impacts and remedies of the water, sediments and fishes‘ pollution due to anthropogenic activities.

CHAPTER-2

STUDY AREA

2.1. Geographical locations of the study area-1 (Highly contaminated area)

2.1.1. Geography

Savar is located at 23.8583°N 90.2667°E. It has 66,956 units of household and a total area of 280.13 square kilometers (108.16 sq. mi.). It is bounded by Kaliakair and Gazipur Sadar upazilas on the north, Keraniganj upazila on the south, Mirpur, Mohammadpur, Pallabi and Uttara thanas of Dhaka City on the east, and Dhamrai and Singair upazilas on the west. The study area links with Dhaka city with comparatively high traffic density and has significant industrial influences [1].

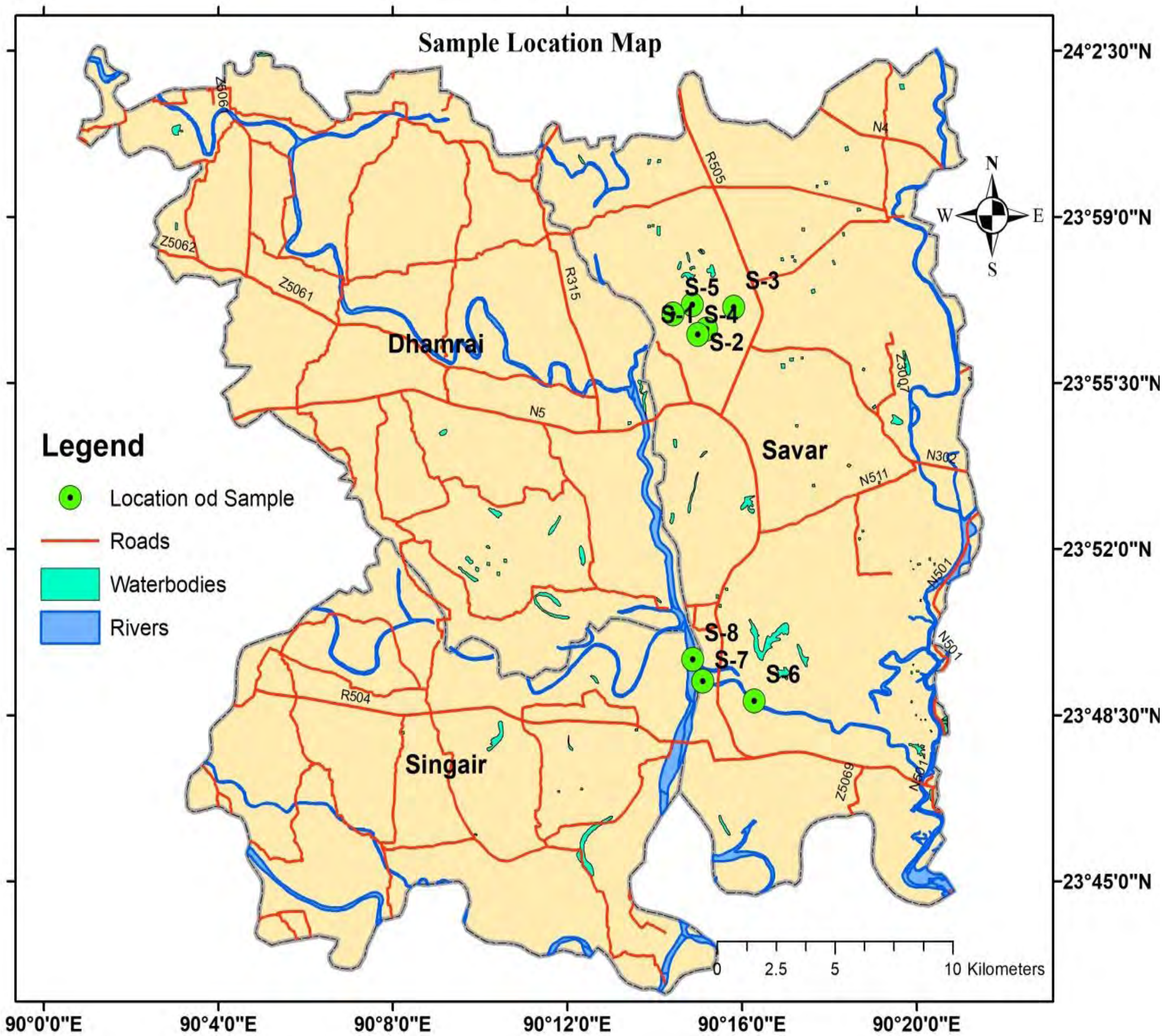


Figure 2.1: Location of the sampling sites at Savar, Dhaka, Bangladesh

The height of the land gradually increases from the east to the west. The southern part of the upazila is composed of the alluvium soil of the Bangshi and Dhalashwari rivers. Bangshi River is an important river in central Bangladesh and it is about 238 km long. It was originated in Jamalpur and passed through Ghazipur and Savar before flowing into Dhaleshwari River. In Savar the river flows through densely populated town and agricultural fields in which water from the river is being used for cultivation of vegetables and crops. At present the river is used as a convenient means for the continuous disposal of untreated liquid wastes from Dhaka Export Processing Zone (DEPZ) and other industrial establishments located in the Savar area [2].

Table 2.1: Details of surface water, sediments, and fishes sampling locations in the study area.

Sample ID	Sampling sites	Latitude	Longitude
S-1	Behind of DEPZ	23.943821°	90.253249°
S-2	DagortolyVill	23.941889°	90.249870°
S-3	Kaicha Bari	23.951456°	90.263544°
S-4	Jelepara	23.952277°	90.247786°
S-5	Maijhail	23.949115°	90.240370°
S-6	Khatrapara	23.81320°	90.27140°
S-7	Murad Jan Road	23.82010°	90.25180°
S-8	Bank Town	23.82780°	90.24790°

2.1.2. Industries and Economy of the study area

Agriculture and manufacturing are the two major economic sectors in Savar area. The major crops grown in this area are Paddy, Jute, peanut, onion, garlic, chili and other vegetables. The extinct or nearly extinct crops in the region are Aous paddy, Asha Kumari paddy, sesame, linseed, kali mator, randhuni saj, mitha saj, kaun and mas kalai (local names of the crops). There are 181 combined fisheries, dairies, and poultries dairy, 5 hatcheries, 209 poultries, and 1319 fisheries establishment are currently available in this area. The manufacturing facilities include ceramic industry, beverage industry, press and publications industry, garments industry, foot ware, jute mills, textile mills, printing and dying factory, transformer industry, automobile industry, biscuit and bread factory, pharmaceutical industry, soap factory, brick field, cold storage, welding, plant nursery, etc. [3-4]. The following chart shows the contributions of different sectors in the total economy of the study area.

Agriculture %	Industry %	Service %
23.6	59.6	16.8

Figure 2.2: Industrial pollution characteristics observed in the highly contaminated sites of the Bangshi river and DEPZ areas of Savar, Dhaka.

2.1.3. Temperature

In the study area, the hot season lasts for 3.5 months, from March 12 to June 26, with an average daily high temperature above 89°F in the study area. The hottest day of the year is April 15, with an average high temperature of 93°F and low temperature of 77°F. The cool season lasts for 1.5 months from December 13 to January 31, with an average daily high temperature below 78°F. The coldest day of the year is January 12, with an average low temperature of 57°F and high temperature of 75°F [5].

2.1.4. Rainfall

The long-term trend of annual rainfall in Dhaka shows no significant change, however, the trend in the seasonal rainfall appears to be erratic and variable. To show the variation within the months and not just the monthly totals, we show the rainfall accumulated over a sliding 31-day period centered on each day of the year. The capital city Dhaka and its surrounding areas such as Savar experiences extreme seasonal variation in monthly rainfall [6].The rainy season of a year lasts for 9.5 months from February 13 to November 29 with a sliding 31-day rainfall of at least 0.5 inches. The most rain falls observed during the 31 days periods on July 3, with an average total accumulation of 9.9 inches. The rainless period of a year lasts for 2.5 months, from November 29 to February 13. The least rain falls is being realized around January 8 with an average total accumulation of 0.2 inches.

2.2. Geographical locations of the study area-2 (Long range polluted area)

2.2.1. Geography

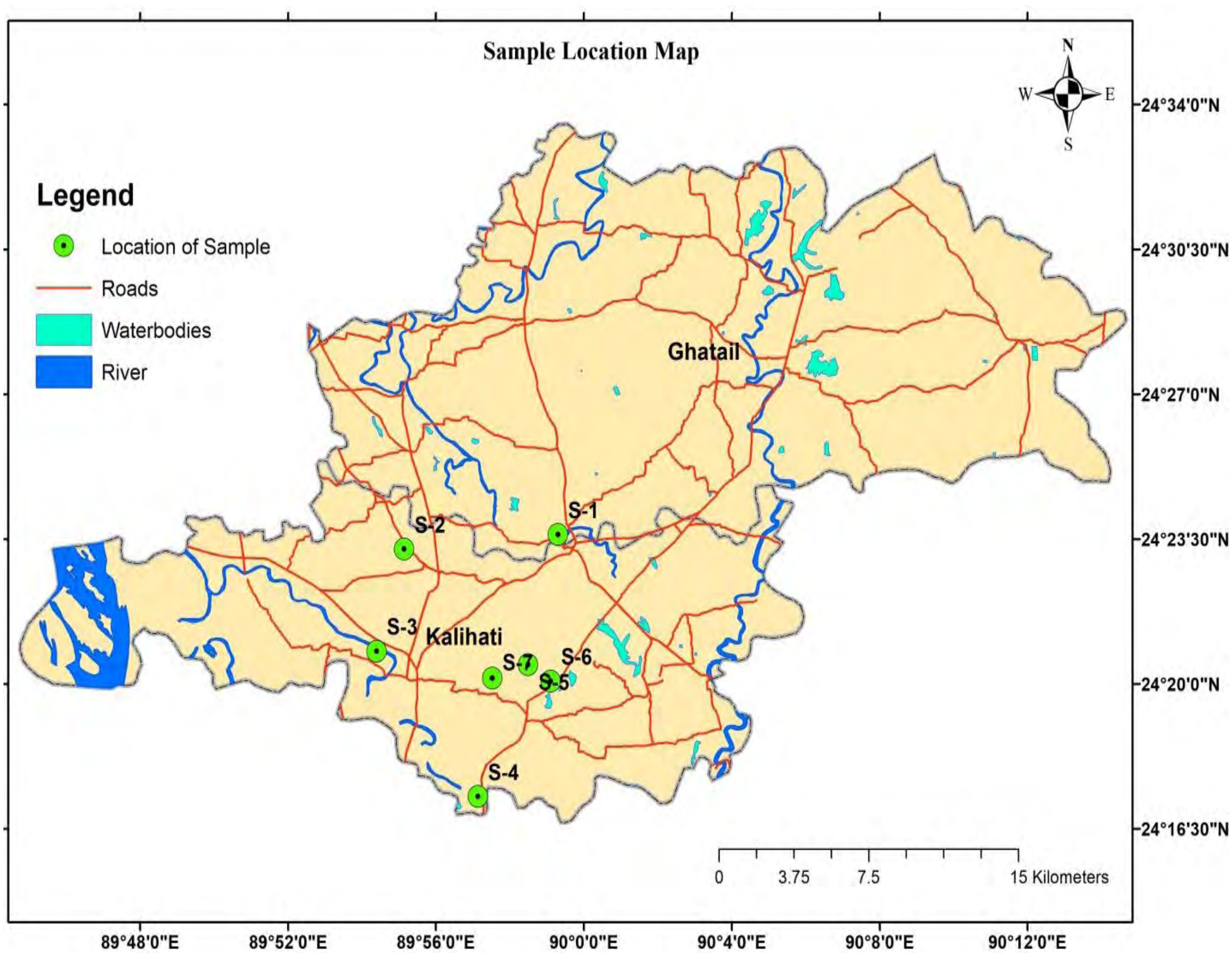


Figure 2.3: Location of the sampling sites at Kalihati, Tangail, Bangladesh

Khalihati upazilla in Tangail district, Bangladesh has been chosen as a long range contaminated study area. There is no industrial establishment available in this particular study area. Khalihati upazilla is highly rural area located at 24.3833°N 90.0083°E and far away from Tangail city. It has 65035 households and total area of 295.6 km^2 [7]. The upazila is surrounded by Bhuapur & Ghatail Upazila on the north, Basail Upazila on the south, Sakhipur Upazila on the east, and the Jamuna River on the west.

Table 2.2: Details of surface water, Sediments and Fishes sampling sites of Kalihati Upazila at Tangail district (Long range contaminated sites)

Sample ID	Sampling sites	Latitude	Longitude
S-1	Kalihati	24.393276°	89.988372°
S-2	Nagarbari	24.387413°	89.919110°
S-3	Elenga	24.346366°	89.906634°
S-4	Bhokta	24.287783°	89.952335°
S-5	Patitapara	24.340960°	89.974989°
S-6	Poshnabil	24.334232°	89.985204°
S-7	Dimukhabil	24.335511°	89.958790°

Kalihati Upazila is divided into 2 municipalities and 13 union parishads: Balla, Bangra, Bir Bashinda, Dashkia, Durgapur, Gohaliabari, Kok Dohora, Nagbari Union, Narandia, Paikara, Parkhi, Salla and Shahadebpur. There are about 1200 industries located in and around Tangail city area which include textile and garments industries, dyeing industries, battery manufacturing industries, packaging industry, glass industries, tanneries, metal workshops, pesticide and fertilizer industries, and food processing industries which collectively produce large volumes of effluents containing different toxic metals [8]. These industries discharge their untreated effluents randomly into the surrounding environment. Though the Khalihati upazilla is far away from the industrial establishments located in and around Tangail city area and free from direct contact of industrial activities with point source pollution, during the rainy season with heavy rainfall, frequent occurrence flood, and constant flow of the contaminated river water can carry out, transport, and mobilize heavy and toxic metals from industrial contaminated areas to rural non-contaminated regions and thus may contaminate the water bodies, soil, food chain, and aquatic organisms of the respective safe areas. However, it may take longer time to realize the real consequences of this long range pollution in different components of the corresponding environments and the respective impacts on the people who like to live in a clean and safe zone totally free from hazardous industrial pollution. The long range pollution is a potential threat in our country because Bangladesh is a land of river with considerable rainfall in most of the time in a year which causes the frequent occurrence of flood in various regions of the country that eventually poses potential risks of having long range contamination from highly industrial polluted areas. Long term effects of long range industrial pollution may result the distribution and spreading out of environmental contaminants can spread all over areas of Bangladesh.

Figure 2.4: Long range contamination sampling sites

2.2.2. Economy

Main sources of income of people in Khalihati Upazilla, Tangail is agriculture 46.75%, non-agricultural activity 3.73%, industry 2.21%, commerce 15.53%, transportation and communication 3.53%, service 6.20%, construction 1.24%, religious service 0.20%, rent and remittance 2.90% and others 17.71% [9]. In our present study we recognized the local area of Kalihati Upazila at Tangail District as a lower contamination site from where water, sediment, and fish samples were collected for analysis.

References

1. Ahmed, F., Fakhruddin, A. N. M., Imam, M. T., Khan, N., Abdullah, A. T. M., Khan, T. A., Rhaman, M. M., Uddin, M. N., ―Assessment of roadside surface water quality of Savar, Dhaka, Bangladesh using GIS and multivariate statistical techniques", *Applied Water Science,* Vol. 7(7), pp. 3511–3525. 2017

2. Rahman, M. S., Saha, N., & Molla, A. H., ―Potential ecological risk assessment of heavy metal contamination in sediment and water body around Dhaka export processing zone, Bangladesh", *Environmental Earth Sciences,* Vol.71(5), pp. 2293–2308. 2013.

3. Rahman, M. L., Isla, M. M., Mamun, M. L., ―Commuter‗s Modal Choice: A Case Study of Savar Pourashava", *Journal of Bangladesh Institute of Planners,* Vol. 2, pp. 78-97, 2009.

4. Aktaruzzaman M, Fakhruddin A. N, Chowdhury M. A, Fardous Z, Alam M. K., ―Accumulation of heavy metals in soil and their transfer to leafy vegetables in the region of Dhaka Aricha Highway, Savar, Bangladesh", *Pak. J Biol. Sci.,* Vol. 16(7), pp. 332-8. 2013.

5. https://weatherspark.com/y/111858/Average-Weather-in-Dhaka-Bangladesh-Year-Round#:~:text=In%20Dhaka%2C%20the%20wet%20season,or%20above%2098%C2%B0F.

6. Alam, M., & Rabbani, M. D. G., ―Vulnerabilities and responses to climate change for Dhaka. *Environment and Urbanization*", Vol. 19(1), pp. 81–97. 2007.

7. Shymal C. N. (2012), Banglapedia: National Encyclopedia of Bangladesh, *Asiatic Society of Bangladesh,* Bangladesh.
8. Kormoker, T., Proshad, R., Islam, M. S., Tusher, T. R., Uddin, M., Khadka, S., Sayeed, A., ―Presence of toxic metals in rice with human health hazards in Tangail district of Bangladesh", *International Journal of Environmental Health Research*, pp. 1–21. 2020.
9. "Population Census Wing, BBS". Archived from the original on 2005-03-27, 2006. https://en.wikipedia.org/wiki/Kalihati_Upazila

CHAPTER-3

SAMPLING, MATERIALS, AND METHODOLOGY

3.1. Survey Form

We provided some questionnaire to the people living around industrial zones of Savar area. We tried to know about the maximum number of young people that were playing a key role in earning money and managing the family in the study area. We wanted to know how much of fishes they buy from the market in each week, what kind of fish they take, how many times they get fishes and how much of them they eat in a day. Besides, we visited 20 houses where 15-16 year old children are used to live and learned from their mother about how much of fishes the children eat every day, what types of fishes they eat in every day. Food ingestion rate was also being addressed by providing questionnaire survey to local people of the study area. A total of 24 households, 3 from each sampling site, were surveyed and finally the data were used to calculate the average fish ingestion rate for adults and children. We also make sure that the fishes which were available to local people to buy and to eat collected from industrial contaminated sites of the study area.

3.2. Chemicals and reagents

The chemicals and reagents used in this research were analytical grade and used without further purification. Stock solutions of 1000 ppm were arranged from their corresponding salts for the selected heavy metals (Cu, Cr, Fe, Mn, Ni, Pb, AS and Cd). Distilled and deionized water was used in all solution preparation and dilution purposes throughout the experimental procedures. The chemicals and reagents which were used in this research are given below:

Chemicals	Sources	Purity (W/W basis)
Sulfuric Acid	Aldrich	69%
Nitric Acid	Aldrich	98%
Hydrogen peroxide	Aldrich	30%
Perchloric Acid	BDH	70%
Hydrochloric Acid	Merck Germany	37%
Ethyl alcohol	Merck, India	99.5%
Potassium Iodide	Merck, Germany	Pure
Sodium Borohydydride	BDH	Pure

3.2. Instruments

Analysis of the samples was performed using the following instruments:

1. Oven (Lab Tech, LDO-030E)
2. Digital Balance (AB 265/S/SACT METTLER, Toleto, Switzerland.
3. Hot plate (RC- 1887/166, Velp Scientific, Italy)
4. Atomic Absorption Spectroscopy(SHIMADZU AA-7000)

3.3. Surface water, sediments and fishes samples collection and preparation

A total of 24 samples of water, sediment, and fishes have been collected from eight different sites of Savar area including the Bangshi River, and DEPZ lake and a total of 21 samples of fishes, sediment, and surface water were collected from seven sites Kalihati Upazilla at Tangail district. The fish samples were being caught with the help of fisherman by cast net and wheel. All of the fishes samples were cleaned and washed with double distilled and deionized water and kept in ice box and transported to the labratory for further treatment [1]. Water samples were collected using polyethylene bottle to fetch water below the surface at designated points, mixed properly. Then filtered with Whatman filter paper and preserved in 5 mL of 55% HNO_3 per liter of water to prevent metal adsorption on the inner surface of the container. Fifty milliliters of mixed effluent-contaminated water sample was digested with 10 mL of concentrated HNO3 at 80°C until the solution became transparent. The solution was filtered through Whatman no. 42 filter paper and the filtrate was diluted to 50 mL with distilled and deionized water and stored in a plastic container rinsed with 0.01N nitric acid and kept in deep freezer prior to the time of analysis [2-3]. The sediments with the depth of 0–10 cm were taken by a Petersen's grab. After collection, the sediment samples (stored in clean polyethylene zip-bags) were transferred to the laboratory immediately. 2 mm sieve was used to remove stones, after air-dried Samples were crushed with a stainless-steel mill, subsequently sieved through a 60μm mesh and homogenized to ensure sample representativeness [4-5].

Figure 3.1: Water and sediment samples collection from the study areas.

3.4.Toxic metal analysis

The teflon vessel and polypropylene containers were cleaned, soaked in 5% HNO_3 for more than 24 h, then washed with distilled and deionized water and dehydrated. For metal analysis, 1 g of each of the sediment and fish samples was treated with a mixture of 10 mL HNO_3, 2 mL H_2SO_4, 2 mL $HClO_4$ (5:1:1:1 ratio) in a fume hood and was digested in a hot plate (RC- 1887/166, Velp Scientific, Italy) at 80°C until a transparent solution was obtained. After cooling, 2 mL of hydrogen peroxide was added into the resulting solution mixture and heated again at 80°C for about 4 hours. The digested solution was then filtered by using Whitman-41 for sediment samples and Whitman-42 for all fish samples. The digested samples were then transferred to a Pyrex volumetric flask, and the total volume was increased up to 50 mL with distilled and deionized water and then stored in 100 mL pre-sterilized Teflon bottle. After digestion, the Pyrex beaker was washed to perform blank digestion following the same procedure adopted for the samples [6-7]. The digested samples were analyzed for heavy and toxic metals concentrations using Atomic Absorption spectrophotometer (Shimadzu-7000). The analytical parameters, operating conditions and other experimental protocols of AAS for metal analysis are listed below in the Tables 3.1 & 3.2.

Figure 3.2: Sample digesting and preparing for analysis

Table 3.1: Analytical conditions for measurement of heavy metals in the digested samples solutions using AAS.

Elements	Wavelength (nm)	Slit (nm)	Lamp Current (mA)	Mode	Calibration Range (mg/ L)	Detection limit (mg/ L)
As	193.70	0.7	12.0	HG-AAS	0.001-0.010	0.001
Ni	232.00	0.2	12.0	Flame-AAS	0.50-10.00	0.080
Cd	228.80	0.7	8.0	Flame-AAS	0.05-1.00	0.004
Cr	357.90	0.7	10.0	Flame-AAS	0.50-10.00	0.030
Cu	324.80	0.7	6.0	Flame-AAS	0.50-4.00	0.026
Fe	248.30	0.2	10.0	Flame-AAS	0.50-6.00	0.060
Pb	217.00	0.7	10.0	Flame-AAS	0.50-10.00	0.035
Mn	279.50	0.5	8.0	Flame-AAS	0.00-2.00	0.020

Table 3.2: Concentrations of metals found in Certified Reference Materials by AAS

Elements	Certified value	Measured value	Deviation (%)	Recovery (%)
As(ppb)	10.00± 0.02	9.95±0.05	1.55	99.50
Ni(ppm)	2.00±0.05	1.96±0.04	0.53	98.00
Cd(ppm)	0.20±0.02	0.19±0.02	0.75	95.00
Cr(ppm)	4.00±0.06	3.90±0.06	1.00	99.75
Cu(ppm)	2.00±0.02	2.00±0.07	1.20	100.00
Fe(ppm)	1.00±0.10	0.93±0.06	0.96	93.00
Pb(ppm)	4.00±0.05	3.98±0.01	1.77	99.50
Mn(ppm)	1.00±0.01	0.98±0.02	1.23	97.00

3.5. Quality assurance and quality control

For performing the internal calibration, standard solutions having 1.0 mg/L of indium, yttrium, beryllium, tellurium, cobalt, and thallium were obtained from Spex CertiPrepVR (Metuchen, NJ, USA). During the analysis, 10 mg/L internal standard solution was ready from the primary standard stock solution. Quality assurance and quality control were confirmed and maintained by running blank solution periodically, drawing the calibration curves, using spiked samples, and with the midpoint standard checks. All the calibration procedures were assessed based on their corresponding correlation coefficients (R2) of the corresponding calibration curves. The calibration curves were guaranteed with the correlation coefficient (R2), where, Pb-0.9992, Cr-9999, Cu-9996, Fe-0.9988, Mn-0.9997, Ni-0.9994, As-0.9995 and Cd-0.9994. Mid-point checks for the metals lie in the range of 0.25 to 5.5%. Spike recoveries ranged from 96.54 to 98.85%.

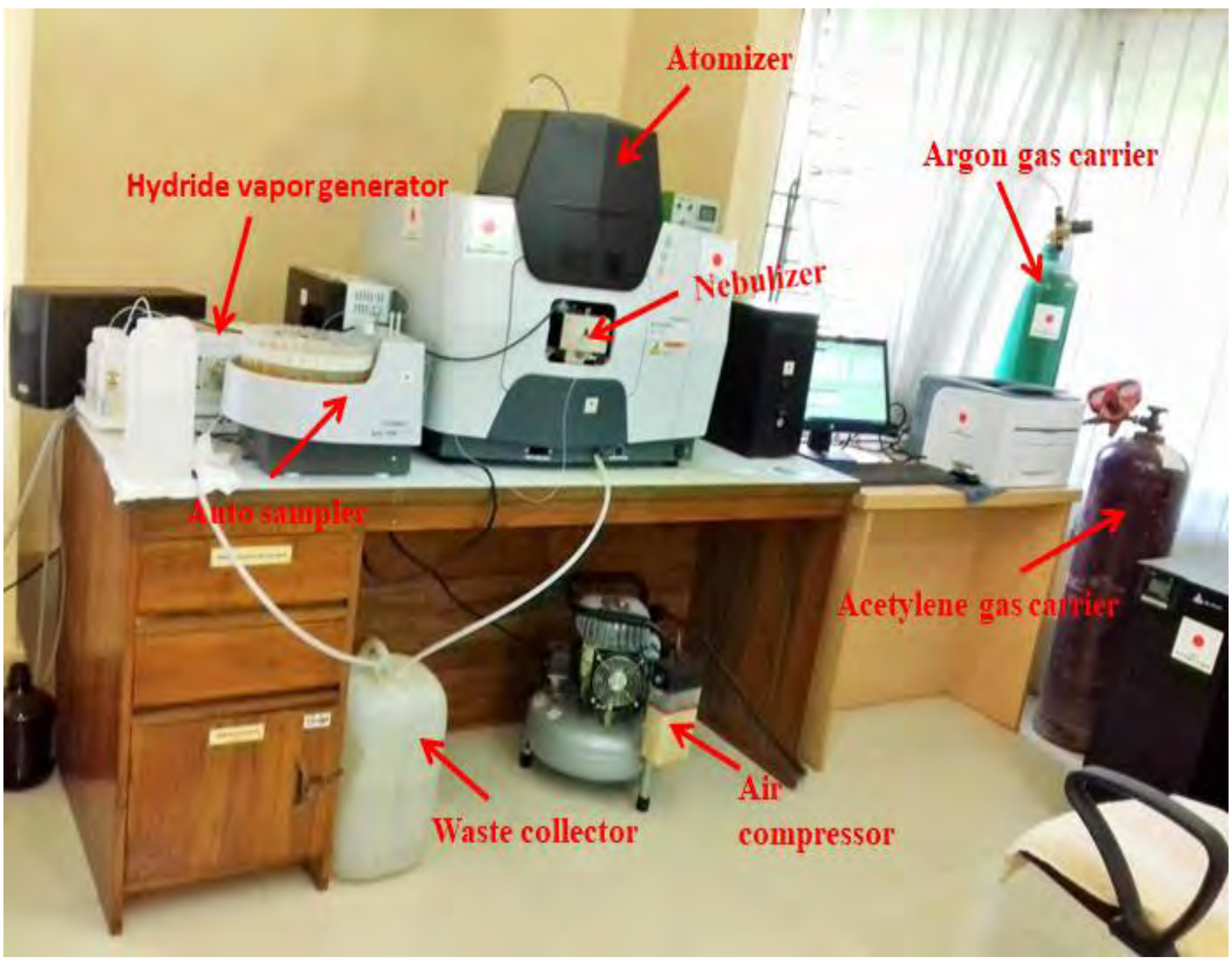
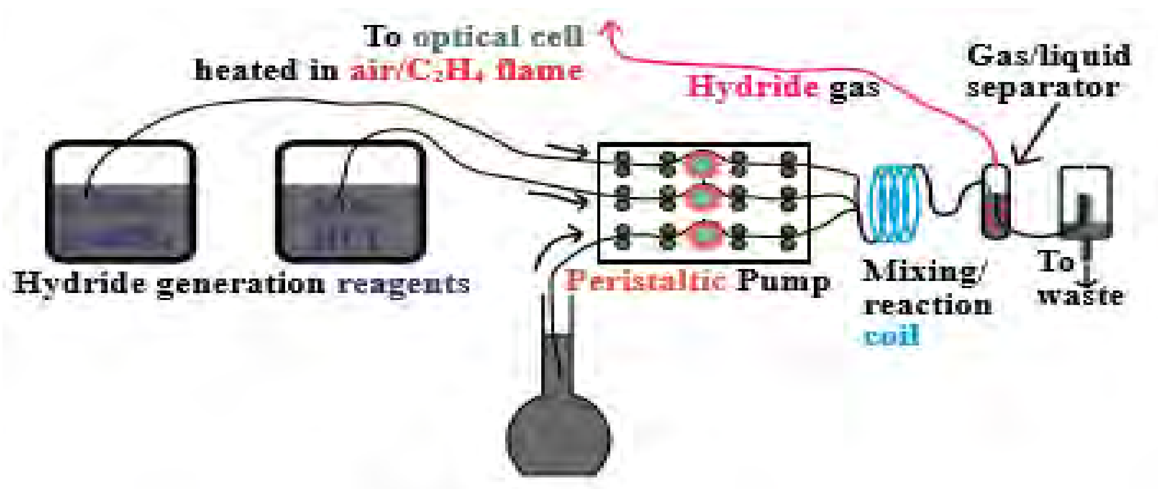


Figure 3.3: Atomic absorption spectrophotometer

Arsenic concentrations in the samples were analyzed by Hydride generation techniques using AAS. The technique provides a means of introducing samples containing arsenic into an atomizer in the gas phase. Hydride generation occurs by adding an acidified aqueous solution of the sample to a 0.35% aqueous solution of sodium borohydride, all of which is contained in a glass vessel. The volatile hydride generated by the reaction that occurs and is being swept into the atomization chamber by an inert gas, where it undergoes decomposition. This process forms an atomized form of the analyte, which can then be measured by absorption spectrometry.



$$AsCl_3 + HCl + NaBH_4 \longrightarrow AsH_3 + NaCl + BH_3$$

Figure 3.4: Working principle of Hydride Generator in AAS

3.6. Statistical analysis

The data were statistically investigated and analyzed using the statistical package SPSS (version 16.0). The mean ± standard deviations and other calculations of the metal concentrations in different fish species were determined by Microsoft excel-2013.

3.7. Water Quality Indices

3.7.1. Heavy Metal Pollution Index (HPI)

HPI is used to evaluate the level of trace heavy metals in the water bodies. HPI is calculated according to the following equations:

$$Qi = \frac{Ti}{Xi} \quad \text{.....1}$$

$$K = 1/\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Xi} \quad \text{.....2}$$

$$W = \frac{K}{Xi} \quad \text{.....3}$$

$$HPI = \sum_{i=1}^{n} QiWi / \sum_{i=1}^{n} Wi \quad \text{.....4}$$

Where k = proportionality constant; Xi =the limited concentration of trace metal number i according to the environmental standard; Wi = the mass ratio of trace heavy metal number i; Qi= the quality index of heavy metal number i; Ti=the concentration of heavy metal number i; n = total number of monitoring heavy metal [8].

The HPI value is categorized into following two groups:

I. Group 1: 0< HPI – none pollution

II. Group 2: HPI> 1 – pollution

3.7.2. Heavy Metal Evaluation Index (HEI).

HEI describes water quality condition in response to anthropogenic heavy metals and is calculated by the following equation:

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac} \quad \text{.....1}$$

Where, Hc is monitored/observed value and Hmac is maximum admissible concentration of the i^{th} parameter. The HEI values are being grouped into three categories such as low contamination (HEI< 10), Medium concentration (HEI = 10–20) and high contamination (HEI > 20) [9].

3.7.3. Contamination Index:

The contamination index (Cd) describes the quality of water which is being evaluated based on the degree of contamination. The Cd is computed separately for each sample of water analyzed, as a sum of the contamination factors of individual components exceeding the upper permissible value. Hence the Cd summarizes the combined effects of several quality parameters which are considered harmful to household water. The contamination index is calculated using the equation shown below :

$$DC = \sum_{i=1}^{n} Cfi \ldots\ldots 1$$

$$Cfi = \frac{CAi}{CNi} - 1 \ldots\ldots 2$$

Cfi = contamination factor for the i-th component, CAí = analytical value for the i-th component CNí = upper permissible concentration of the i-th component (N denotes the 'normative value'). The resultant Cd values are grouped into three categories which are as follows:
Cd < 1 (low), Cd = 1-3 (medium) and Cd > 3 (high) [10].

3.7.4. Comprehensive Pollution Index (CPI)

Single factor pollution index and comprehensive pollution index referred to the level III water quality categories cited in ―Environmental Quality Standards for Surface Water" (GB3838–2002, GHZB1–1999), published by the State Environment Protection Administration (SEPA) of China, which were adopted to justify the water quality of the study area [11]. It is the most trustworthy method of analysis used to assess the overall water quality status in a water body followed by classification of water based on a definite numerical range of values[12]. The calculation is done based on the physiochemical parameters data obtained during laboratory testing of the collected water samples and is mathematically expressed as:

$$PI = Ci/Si \ldots\ldots 1$$

$$CPI = \frac{1}{n}\sum_{i=1}^{n} PI \ldots\ldots 2$$

Where, PI is the pollution index of i[th] parameter; Ci is the measured concentration of the i[th] parameter; Si is the standard permissible concentration of the i[th] parameter in the water and n is the total number of parameters [13]. The standards permissible concentrations of water quality parameters have been prescribed by WHO and DoE. The results of the present investigation were compared with the permissible values of WHO and DoE to evaluate the water qualities.

3.8. Sediment Quality Index

3.8.1. Potential Ecological Risk Index (PERI)

The potential ecological risk index (PERI) has been introduced in order to assess the contamination level of tested heavy metals in the sediments studied. PERI is used to determine the comprehensive potential ecological risks of five heavy metals examined in sediments, combining with ecological and toxicological factors. PERI was first introduced and reported by Hakanson *et.al*., (1980) who proposed and constructed following three Eqs for calculating PERI-

$$E_f^i = T_{fr}^i \times C_f^i \quad \ldots\ldots 1$$

$$C_f^i = C_s^i / C_n^i \quad \ldots\ldots 2$$

$$RI = \sum\nolimits_f^i E_f^i \quad \ldots\ldots 3$$

Where by E_f^i is the potential ecological risk for a single element, C_f^i is the contamination factor for individual element, C_s^i is the concentration in the sediment samples for individual element, C_n^i is the background reference value for each element and RI is the sum of potential ecological risks for five heavy metals studied in each sampling location. This factor could be classified into the five categories:

Low risk: $E_f^i < 40$, PERI < 150; Moderate risk: $40 \leq E_f^i < 80$, $150 \leq$ PERI < 300; Considerable risk: $80 \leq E_f^i < 160$, $300 \leq$ PERI < 600; High risk: $160 \leq E_f^i < 320$, PERI $\geq$ 600; Very high risk: PERI > 320 [14]. T_{fr}^i= toxic response factor suggested by Hakanson (1980) for seven metals such as: Mn (1), Cr (2), Cu (5), Pb (5), Ni (5), As(10) and Cd(30). According to the CNEMC, 1990 the reference background values were Fe: 14355, Mn: 462, Ni: 18.8, Cr: 31.9, Pb: 10.9, Cu: 17mg/kg, As: 7.09 and Cd: 0.119 mg/kg [15-16].

3.8.2. Enrichment Factor (EF):

The EF of heavy metals has been commonly used to determine the status of anthropogenic contamination. Element Fe was chosen as the normalizing element in this study for identifying anomalous heavy metal contributions. (EF values can be calculated using the following equation:

$$\text{EF} = \frac{C/Fe(sample)}{C/Fe(Background)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where C/Fe (sample) and C/Fe (background) represent the heavy metal-to-Fe ratios in the present study and in the background, respectively. Iron was chosen as the element of normalization because natural sources (1.5%) extensively dominate with its input [17]. A crucial step in evaluating the impact of sediment pollution is to establish a reference background or baseline sample of known metal composition. Level of contaminant based on EF value are described as: Low Contamination Degree < 2; Deficiency to minimal enrichment 2–5; Moderate enrichment 5 – 20; significant enrichment 20 – 40; Very high enrichment > 40; Extremely high enrichment [18].

3.8.3. Geo-accumulation Index (Igeo)

Pollution characteristics due to the heavy metal contamination in sediments can be evaluated using the geo-accumulation index. Geo-accumulation index, proposed by Muller (1979), is used to determine metals contamination in sediments, by comparing the present concentrations with that of pre-industrial period using the following formula:

$$I_{geo} = \log_2 [\ C_n/1.5B_n\ ] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where Cn is the measured concentration of the element ‗n‘ and Bn is the geochemical background value. The factor 1.5 was introduced to minimize the effect of possible variations in the background values which might be attributed to lithologic variations in the sediments. The factor 1.5 was introduced to minimize the effects of possible variations in the background values which might be attributed to lithologic variations in the sediments [19]. Seven categories are defined according to the Igeo values: Igeo<0 indicates unpolluted; 0<Igeo<1, unpolluted to moderate contamination; 1<Igeo<2, moderately polluted; 2<Igeo< moderate to heavily polluted; 3<Igeo<4, heavily polluted; 4<Igeo<5, heavily polluted to extreme pollution; and 5 < Igeo, extreme pollution [20].

3.8.4. Contamination Factor (CF):

The contamination factor (CF) evaluates the enrichment of metals in sediments in comparison to the natural background concentrations of each metal in sediments. CF is the ratio obtained by dividing the concentration of each metal in the sediments by the respective background value [21]:

$$\mathrm{CF} = \frac{Cs}{Cref} \quad \ldots 3$$

where Cs and C_{ref} are concentrations of the element in the sediment samples and the background or pristine value of the element, respectively. The method of the CF calculation is identical to the EF calculation, except the fact that the CFs do not normalize concentrations against the normalizing element [22]. In order to evaluate and explain the degree of contamination in sediments, the following characteristics classification are proposed:
CF < 1, no/low contamination; 1 < CF < 3, moderate; 3 < CF < 6, considerable;
6 < CF — very high contamination [23].

3.8.5. Pollution Load Index (PLI)

Pollution load index (PLI) is a parameter used to evaluate the contamination status of sediment samples to heavy metals. PLI is defined as with the following equation [24]:

$$PLI = \sqrt[n]{CF1 \times CF2 \times CF3 \times \ldots\ldots CFn} \quad \ldots 1$$

Where, CF is the contamination factor and n is the number of metals. PLI = 0 indicates a perfect state of pollution; PLI = 1 suggests only baseline levels of pollutants present and PLI >1 would indicate progressive deterioration of sites [23].

3.9.Health risk assessment factor

3.9.1. Bio-accumulation Factor (BAF)

Bio accumulation factor (BAF) of metals from sediment to fish was defined as the ratio of the metal concentration in the fish's tissues to the metal concentration in sediment or surface water [25]. The transfer factor was considered for each fish sample individually. The transfer factor was calculated using the equation shown below:

$$BAF = C_{Fish}/C_{Sediment} \dots\dots\dots 1$$

$$BAF = C_{Fish}/C_{Surface\ water} \dots\dots\dots 2$$

Where, C_{fish}, $C_{sediment}$, and $C_{surface\ water}$ represent the total metal concentration in the fish (mg/kg), total metal concentration in sediment (mg/kg) on a dry weight basis and the total metal concentration in the surface water (mg/L) respectively [26].

3.9.2. Estimated Daily Intake of Metals (EDI)

The estimated daily intake of metals (mg/kg body-weight/day) depends on the metal concentration, food consumption, and body weight. To evaluate the risk of heavy metals from fish consumption at the extreme level, the following factors were actively considered in the present study: the ingested dose was equal to the amount fish absorbed or consumed [27]. The rate was found to be 44.91 g per adult and 21.35g for children. Therefore, the EDI of heavy metals for adults was calculated as with the following equation [28]:

$$\text{EDI} = \frac{C \times FIR}{Bw} \dots\dots\dots 1$$

Where C is the concentration of heavy metals in fishes (mg/kg wet weight), FIR is the average daily consumption of fish in the local area 44.91 g/day bw for adults and 21.35 g/day bw for children, and bw represents the body weight, 60 kg for adults and 16kg for children.

3.9.3. Target Hazard Quotient (THQ)

The target hazard quotient (THQ) values actively provide an indication of the risk level due to pollutant exposure (United States Environmental Protection Agency, 2011). THQ ratio values less than unity indicate no significant chronic-toxic risks [29]. The equation used for estimating THQ values is given below:

$$\text{THQ} = \frac{EF \times ED \times FIR \times CM}{Bw \times ATn \times RfD} \times 10^{-3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where THQ is the target hazard quotient, EF is the exposure frequency (365 days/year), ED is the exposure duration (70 years for non-cancer risk as used by the. FIR is the fish ingestion rate (44.91 g/person/day; from the survey in the study areas , CM is fish heavy metal concentration (mg/kg d.w.) , Bw is the average body weight (60 kg), ATn is the average exposure time for non-carcinogens (EF×ED) as used in characterizing non-cancer risks, and RfD is the reference dose of the metal (1.4×10^{-1} mg/kg/day for Mn, 7.0×10^{-1}mg/kg/day for Fe, 4×10^{-3}mg/kg/day for Pb, 2.0×10^{-2}mg/kg/day for Ni, 4.0×10^{-2}mg/kg/day for Cu, 3×10^{-3}mg/kg/day for Cr , 0.0003 for arsenic and 0.001 for cadmium [30].

The risks induced by the seven trace metals together could be estimated based on the total target hazard quotient (TTHQ), which is the sum of the individual metal THQ values. Total THQ (TTHQ) is calculated to estimate the additive effects of due to high exposure of all the metals and their corresponding accumulation in fishes [31]. If TTHQ ≤ 1, there is no obvious negative effect; if TTHQ > 1, it may have negative impact on human health [32].

$$TTHQ = THQ_{Fe} + THQ_{Ni} + THQ_{Mn} + THQ_{Pb} + THQ_{Cr} + THQ_{Cu} + THQ_{As} + THQ_{Cd}$$

3.9.4. Target Cancer Risk

For carcinogens effects, the potential risks are estimated based on the incremental probability of an individual to develop cancer over a lifetime as a result of higher exposure of metals (i.e., incremental or excess individual lifetime cancer risk) [30]. The target cancer risk model (TR) is calculated by multiplying the oral carcinogenic potency slope of carcinogenic substance with its exposure level used to estimate the carcinogenic risk of inorganic Ni, Pb, Cr, As and Cd for a lifetime. The model developed for calculation was based on following equation:

$$\mathrm{TR} = \frac{EF \times ED \times FIR \times CM \times CPSo \times 10^{-3}}{Bw \times ATn} \qquad \ldots\ldots 1$$

Where CPSo represents the carcinogenic potency slope, oral (1.7 $(mg/kg/day)^{-1}$ for Ni, Pb -0.0085$(mg/kg/day)^{-1}$, Cr- 0.41$(mg/kg/day)^{-1}$, 1.5 for arsenic and cadmium 6.1[33].

References

1. Mehmood, M. A., Qadri, H., Bhat, R. A., Rashid, A., Ganie, S. A., Dar, G. H., & Shafiq-ur-Rehman., ―Heavy metal contamination in two commercial fish species of a trans-Himalayan freshwater ecosystem", *Environmental Monitoring and Assessment,* Vol. 191(2). 2019.
2. Siraj, M., Khisroon, M., Khan, A., Zaidi, F., Ullah, A., & Rahman, G., ―Bio-monitoring of Tissue Accumulation and Genotoxic Effect of Heavy Metals in Cyprinus carpio from River Kabul Khyber Pakhtunkhwa Pakistan", *Bulletin of Environmental Contamination and Toxicology,* Vol. 100(3), pp. 344–349.2017.
3. Mamun, M. A. -A., Islam, M. S., Mohanta, S. C., Siddique, M. A. B., Hossain N. and Bithi, U. H., ―Physico-Chemical Assessment of Water Quality Parameters in Rupsha River of Khulna Region, Bangladesh", *International journal of Engineering and Science*, Vol. 7(1), pp. 73-78 (2018).
4. Zhang, Z., Lu, Y., Li, H., Tu, Y., Liu, B., & Yang, Z., ―Assessment of heavy metal contamination, distribution and source identification in the sediments from the Zijiang River, China", *Science of The Total Environment,* Vol. 645, pp. 235–243. 2018.
5. Torregroza-Espinosa, A. C., Martínez-Mera, E., Castañeda-Valbuena, D., González-Márquez, L. C., & Torres-Bejarano, F., ―Contamination Level and Spatial Distribution of Heavy Metals in Water and Sediments of El Guájaro Reservoir, Colombia", *Bulletin of Environmental Contamination and Toxicology,* Vol.101(1), pp. 61–67. 2018.
6. Goni, M. A., Ahmad, J. U., Halim, M. A., Mottalib, M. A., & Chowdhury, D. A., ―Uptake and Translocation of Metals in Different Parts of Crop Plants Irrigated with Contaminated Water from DEPZ Area of Bangladesh", *Bulletin of Environmental Contamination and Toxicology,* Vol. 92(6), pp. 726–732. 2014.
7. Turner, A., ―Trace elements in fragments of fishing net and other filamentousplastic litter from two beaches in SW England*", Environmental Pollution,* Vol. 224, pp. 722-728, 2017.

8. Son, C. T., Giang, N. T. H., Thao, T. P., Nui, N. H., Lam, N. T., & Cong, V. H., ―Assessment of Cau river water quality assessment using a combination of water quality and pollution indices”, *Journal of Water Supply: Research and Technology,* Vol. 69 (2), pp. 160–172, 2020

9. Kabir, M. H., Islam, M. S., Tusher, T. R., Hoq, M. E., Muliadi and Mamun, S. A., ―Changes of heavy metal concentrations in Shitalakhya river water of Bangladesh with seasons”, *Indonesian Journal of Science & Technology,* Vol. 5 (3), pp. 395-409, 2020.
10. El- Hamid, H. T. A., Hegazy, T. A., ―Evaluation of Water Quality Pollution Indices for Groundwater Resources of New Damietta, Egypt”, *MOJ Eco Environ Sci.,* Vol. 2(6), 2017.
11. Yan, C.-A., Zhang, W., Zhang, Z., Liu, Y., Deng, C., & Nie, N., ―Assessment of Water Quality and Identification of Polluted Risky Regions Based on Field Observations & GIS in the Honghe River Watershed, China”, *PLOS ONE,* Vol. 10(3), pp.1-13, 2015.
12. Karim, M., Das, S. K., Paul, S. C., Mohammad Farhan Islam and Md. Shahadat Hossain.,―Water Quality Assessment of Karrnaphuli River, Bangladesh Using Multivariate Analysis and Pollution Indices”, *Asian Journal of Environment & Ecology,* Vol. **7**(3), pp.1-11, 2018.
13. Mishra, S., Sharma, P. M., and Amit K., ―Assessment of Surface Water Quality in Surha Lake using Pollution Index India”, *J. Mater. Environ. Sci.,* Vol. **7** (Y), pp. 713-719, 2016.
14. Bahloul, M., Baati, H., Amdouni, R., & Azri, C., ―Assessment of heavy metals contamination and their potential toxicity in the surface sediments of Sfax Solar Saltern, Tunisia”, *Environmental Earth Sciences,* Vol. 77(1), 2018.
15. Xie, Q., Qian, L., Liu, S., Wang, Y., Zhang, Y., & Wang, D., ―Assessment of long-term effects from cage culture practices on heavy metal accumulation in sediment and fish”, *Ecotoxicology and Environmental Safety,* Vol.194, pp.110433. 2020.
16. China National Environment Monitoring Center(CNEMC), 1990, The background values of Chinese Soils, Environment Science Press of China, Beijing(in Chinese).

17. Abdullah, M. Z., Louis, V. C., Abas, M, T., ―Metal Pollution and Ecological Risk Assessment of Balok River Sediment, Pahang Malaysia", *American Journal of Environmental Engineering,* Vol. 5(3A), pp. 1-7, 2015.
18. Malsiu, A., Shehu, I., Stafilov, T., & Faiku, F., ―Assessment of Heavy Metal Concentrations with Fractionation Method in Sediments and Waters of the Badovci Lake (Kosovo)", *Journal of Environmental and Public Health,* Vol. 2020, pp, 1–14. 2020.
19. Yu, G. B., Yu, S., Liu, Y., Wu, S. C., Leung, A. O. W., Luo, X. S., Xu, B., Li, H. B., Wong, M. H., ―Inconsistency and comprehensiveness of risk assessments for heavy metals in urban surface sediments", *Chemosphere,* Vol. 85, pp. 1080–1087, 2011.
20. Hasan, A. B., Kabir, S., Selim, R., A. H. M., Nazim Z., M., Ahsan, A., & Rashid, M., ―Enrichment factor and geo-accumulation index of trace metals in sediments of the ship breaking area of Sitakund Upazilla (Bhatiary–Kumira), Chittagong, Bangladesh", *Journal of Geochemical Exploration,* Vol. 125, pp. 130–137. 2013.
21. Remeikaitė-Nikienė, N., Garnaga-Budrė, G., Lujanienė, G., Jokšas, K., Stankevičius, A., Malejevas, V., & Barisevičiūtė, R., ―Distribution of metals and extent of contamination in sediments from the south-eastern Baltic Sea (Lithuanian zone)", *Oceanologia,* Vol. 60(2), pp. 193–206. 2018.
22. Ustaoğlu, F., & Tepe, Y., ―Water quality and sediment contamination assessment of Pazarsuyu Stream, Turkey using multivariate statistical methods and pollution indicators, ", *International Soil and Water Conservation Research,* Vol. 7(1), pp. 47-56, 2019.
23. Singh, H., Pandey, R., Singh, S. K., & Shukla, D. N., ―Assessment of heavy metal contamination in the sediment of the River Ghaghara, a major tributary of the River Ganga in Northern India", *Applied Water Science,* Vol. 7(7), pp. 4133–4149. 2017.
24. Shirani, M., Afzali, K. N., Jahan, S., Strezov, V., & Soleimani-Sardo, M., ―Pollution and contamination assessment of heavy metals in the sediments of Jazmurian playa in southeast Iran", *Scientific Reports,* Vol. 10(1). pp. 4775, 2020.
25. Kormoker, T., Proshad, R., Islam, M. S., Tusher, T. R., Uddin, M., Khadka, S., Chandra, K., Sayeed, A., ―Presence of toxic metals in rice with human health hazards in Tangail district of Bangladesh", *International Journal of Environmental Health Research,* PP. 1–21, 2020.

26. Ahmed, A. S. S., Sultana, S., Habib, A., Ullah, H., Musa, N., Hossain, M. B., Rahman, M. M., Sarker, M. S. I., —Bioaccumulation of heavy metals in some commercially important fishes from a tropical river estuary suggests higher potential health risk in children than adults", *PLOS ONE,* Vol.14(10), pp. 219336, 2019.
27. Sadeghi, P., Loghmani, M., & Frokhzad, S., —Human health risk assessment of heavy metals via consumption of commercial marine fish (Thunnus albacares, Euthynnus affinis, and Katsuwonus pelamis) in Oman Sea", *Environmental Science and Pollution Research,* Vol. 27, pp. 14944-14952. 2020.
28. FAO/WHO. 2011.WHOfood standards programme codex committee on contaminants in foods. Fifth Sess [accessed 2014 Feb 10]
29. Jiang, Z., Xu, N., Liu, B., Zhou, L., Wang, J., Wang, C., Dai, B., Xiong, W., —Metal concentrations and risk assessment in water, sediment and economic fish species with various habitat preferences and trophic guilds from Lake Caizi, Southeast China", *Ecotoxicology and Environmental Safety,* Vol.157, pp.1–8. 2018.
30. Xie, Q., Qian, L., Liu, S., Wang, Y., Zhang, Y., & Wang, D., —Assessment of long-term effects from cage culture practices on heavy metal accumulation in sediment and fish", *Ecotoxicology and Environmental Safety,* Vol. 194, pp. 110433. 2020.
31. Qian, Y., Cheng, C., Feng, H., Hong, Z., Zhu, Q., Kolenčík, M., & Chang, X., —Assessment of metal mobility in sediment, commercial fish accumulation and impact on human health risk in a large shallow plateau lake in southwest of China", *Ecotoxicology and Environmental Safety,* Vol.194, pp. 110346, 2020.
32. Gong, Y., Chai, M., Ding, H., Shi, C., Wang, Y., & Li, R., —Bioaccumulation and human health risk of shellfish contamination to heavy metals and As in most rapid urbanized Shenzhen, China", *Environmental Science and Pollution Research.* Vol. 27, pp. 2096-2106, 2019.
33. Rahman, M., & Islam, M. A., —Concentrations and Health Risk Assessment of Trace Elements in Cereals, Fruits, and Vegetables of Bangladesh", *Biological Trace Element Research,* Vol. 191(1), 2019.

CHAPTER-4

RESULTS AND DISCUSSIONS

4. Results and Discussions

4.1. General Information

In the present study water, sediments, and different fishes samples were collected around industrial zones of Savar upazila, Dhaka district. Savar area has been highly recognized for agricultural activities for a long time. Various types of vegetables and crops have been grown in and around of Savar Upazila, for years. However, rapid industrialization and growing urbanization in the Savar region have greatly affected the agricultural activities in this area in recent years. A large variety of industries have been established in Savar area which are continuously discharging untreated toxic industrial effluents into surrounding environment and thus constantly contaminating water, agricultural lands, sediments, lakes, canals, and rivers in the respective areas with different types toxic metallic, non-metallic, and organic substances. The present research works have concentrated on the determination and evaluation of heavy and toxic metals pollution in water bodies and aquatic living species particularly in different types of fishes which have been grown in various lakes and rivers in the Savar area. The study has also determined potential ecological impacts and subsequent health risks of people who are highly exposed to industrial contaminated fishes and water bodies. The present investigation has also included Kalihati Upazila at Tangail districts as a long range contaminated site and collected similar environmental samples such as water, sediment, and fishes and thus evaluated heavy metal pollution status in the respective area as well.

4.2. Distribution of heavy and toxic metals in water body of highly contaminated sites as well as long range pollution sites and the respective pollution assessments

The heavy metal concentrations (mg/L) in surface water were ranged from 0.04 to 0.12 for Cr, 0.09 to 0.77 for Cu, 0.04 to 0.18 for Pb, 0.12 to 1.82 for Mn, 0.08 to 0.66 for Ni, 1.33 to 3.87 for Fe, 0.0257 to 0.0463 for As and 0.0067 to 0.0286 for Cd (Table 4-1 & The highest concentrations (mg/L) of Fe (3.87), Mn (1.82), Ni (0.66), Cu(0.77), As(0.0463) and Cd (0.0286) were recorded behind the water in DEPZ lake area, whereas the highest Cr (0.12), and Pb (0.18) concentrations were found in water bodies near Murad Jahn road indicating that these sites are

Table 4-1: Heavy and toxic metals concentration (Mean ± S.D.) in Water (mg/L) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh

Sample ID	Conc. of iron		Conc. of nickel		Conc. of manganese		Conc. of lead	
	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS
S-1(W)	3.37±0.07	1.60±0.15	0.12±0.02	BDL	1.82±0.09	0.189±0.01	0.13±0.02	0.06±0.01
	3.29-3.39	1.47-1.77	0.11-0.12		1.72-1.93	0.18-0.18	0.134-0.15	0.063-0.064
S-2(W)	1.63±0.04	1.85±0.05	0.13±0.01	BDL	0.56±0.04	0.23±0.02	0.04±0.00	0.03±0.00
	1.59-1.67	1.79-1.89	0.14-0.12		0.52-0.59	0.23-0.24	0.042-0.043	0.028-0.033
S-3(W)	2.41±0.06	1.72±0.01	0.66±0.03	BDL	0.36±0.03	0.245±0.01	0.17±0.01	0.02±0.00
	2.34-2.45	1.71-1.73	0.68-0.64		0.32-0.39	0.24-0.26	0.167-0.182	0.019-0.024
S-4(W)	2.36±0.02	–	0.09±0.00	–	0.12±0.02	–	0.14±0.01	–
	2.35-2.38	–	0.09-0.09	–	0.10-0.13	–	0.142-0.143	–
S-5(W)	3.87±0.01	1.60±0.16	0.09±0.00	BDL	0.87±0.03	0.18±0.02	0.16±0.01	0.04±0.01
	3.82-3.85	1.46-1.77	0.08-0.08		0.86-0.87	0.17-0.18	0.162-0.168	0.038-0.046
S-6(W)	1.33±0.03	0.69±0.04	0.08±0.00	BDL	0.33±0.01	0.23±0.03	0.14±0.02	0.08±0.01
	1.29-1.34	0.68-0.73	0.07-0.07		0.33-0.34	0.19-0.25	0.142-0.143	0.073-0.081
S-7(W)	2.33±0.0.06	0.78±0.05	0.56±0.00	BDL	0.38±0.00	0.24±0.01	0.18±0.00	0.04±0.03
	2.24-2.33	0.75-0.83	0.56-0.56		0.38-0.38	0.23-0.24	0.181-0.185	0.042-0.045
S-8(W)	2.14±0.01	1.81±0.23	0.63±0.01	BDL	1.38±0.01	0.22±0.03	0.07±0.00	0.09±0.01
	2.13-2.15	1.55-1.95	0.62-0.64		1.37-1.38	0.21-0.22	0.073- 0.076	0.082-0.094
DoE (1997) standard[1]	0.3-1.0		0.1		0.1		0.05	
WHO (2011) guideline[2]	0.3		0.07		0.1		0.01	
CCME(2007) Aquatic life standards[3]	0.3		0.0025		0.05		0.007	

Table 4-2: Heavy and toxic metals concentration (Mean ± S.D.) in Water (mg/L) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh

Sample ID	Conc. of Chromium		Conc. of Copper		Conc. of Arsenic		Conc. of Cadmium	
	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS
S-1(W)	0.06±0.01	BDL	0.34±0.01	0.11±0.01	0.0407±0.005	0.0053±0.0005	0.0286±0.0015	BDL
	0.062-0.072		0.331-0.353	0.110-0.122	0.0368-0.0464	0.0046-0.0054	0.0296-0.0268	
S-2(W)	0.09±0.01	0.03±0.01	0.45±0.01	0.08±0.01	0.0463±0.0028	0.0046±0.0004	0.0260±0.0010	0.0014±0.0002
	0.081-0.092	0.022-0.033	0.441-0.454	0.084-0.092	0.0460-0.0481	0.0041-0.0049	0.025-0.027	0.0012-0.0016
S-3(W)	0.05±0.00	BDL	0.77±0.02	0.14±0.02	0.0417±0.009	0.0084±0.0200	0.0119±0.0005	BDL
	0.041-0.053		0.761-0.780	0.142-0.151	0.0408-0.0426	0.0084-0.0083	0.0116-0.0125	
S-4(W)	0.05±0.01	–	0.09±0.01	–	0.0369±0.0013	–	0.0093±0.0007	–
	0.040-0.051	–	0.082-0.091	–	0.0354-0.0377	–	0.0092-0.0083	–
S-5(W)	0.06±0.01	BDL	0.16±0.01	0.09±0.01	0.0260±0.00416	BDL	0.0081±0.0007	BDL
	0.062-0.071		0.151-0.167	0.083-0.092	0.02130-0.02873		0.0087-0.0073	
S-6(W)	0.07±0.02	BDL	0.12±0.00	0.07±0.01	0.0314±0.00029	0.0084±0.0009	0.0067±0.0002	0.0013±0.0003
	0.071-0.072		0.110-0.117	0.063-0.072	0.03132-0.0376	0.0073-0.0093	0.0065-0.0069	0.0011-0.0016
S-7(W)	0.12±0.01	BDL	0.11±0.01	0.10±0.03	0.0313±0.0012	0.01910±0.0007	0.0078±0.0004	BDL
	0.113-0.120		0.101-0.126	0.113-0.121	0.03119-0.0374	0.01132-0.0126	0.0078-0.0084	
S-8(W)	0.04±0.01	0.04±0.01	0.33±0.01	0.10±0.02	0.0257±0.0070	0.0091±0.0094	0.0286±0.0015	BDL
	0.032-0.042	0.042-0.050	0.330-0.340	0.101-0.113	0.0245-0.0345	0.0094-0.0096	0.0267-0.0297	
DoE (1997) standard[1]	0.05		1		0.05		0.005	
WHO (2011) guideline[2]	0.05		2		0.01		0.003	
CCME(2007) Aquatic life standards[3]	0.05		0.004		–		0.001	

highly polluted and this metal contaminated water bodies find their ultimate way directly to Bangshi River and thus are polluting the river. Metals concentrations were observed to be decreased from sampling locations 1 to 5. These water samples were collected from DEPZ lake in which surface water samples Fe, Ni, Mn, Pb, Cr, Cu, As and Cd concentrations were varied considerably and showed a decreasing trend of Fe>Mn>Ni>Cu>Pb>Cr>As>Cd. Metal concentrations in the water samples were compared with the permissible values reported and published by DoE, WHO & CCME. All metal concentrations were higher than tolerable levels except copper and arsenic. We also collected similar water samples from different sources such as lake, Bil, river, and pond in the long range contamination sites. The metal concentration observed in the water samples of LCS are also compared with standard permissible limits which showed the Fe, Mn, and Pb concentrations were higher than standard values. In the surface water samples of LCS site Fe, Ni, Mn, Pb, Cr, Cu, As, and Cd concentrations were varied considerably and followed the order of Fe>Mn>Cu>Pb>Cr>As>Cd>Ni. The present study also compared the results of metal concentrations in water samples of highly contaminated site to the extent of metal contents observed in water bodies of low contaminated site. The comparison results showed a significant differences in metal concentration in the water bodies of two sampling locations (HCS and LCS). The findings of the present investigation revealed that Fe, Ni, Mn, Pb, Cr, Cu, As and Cd metal contents in water bodies of highly contaminated area are 1.69, 100, 3.31, 2.50, 3.01, 6.75, 4.46 and 41.15 times higher than the corresponding metal concentrations found in the water samples obtained from the long range contaminated area.

4.3.Water Pollution Indices

Water pollution level has been measured by using water quality indices at the highly contaminated sites. The results of water pollution indices calculated in the water samples of the highly contaminated sites are summarized in the Table 4-4.

Table 4.3: Categories of Pollution Indices for characterizing water pollution status

Index method	Category	Degree of pollution
HPI	<1	non pollution
	>1	Pollution
HEI	<10	Low
	10 to 20	medium
	>20	High
Cd	<1	low
	1 to 3	medium
	>3	High
CPI	<2	Cleanness
	0.2-0.4	Sub cleanness
	0.4-0.7	slight polluted
	0.7-1	Medium polluted
	>1	Severely polluted

Table 4.4: Water pollution level at highly contaminated sites of the study area

Sample ID	HPI		HEI		Cd		CPI	
	WHO	DoE	WHO	DoE	WHO	DoE	WHO	DoE
S-1(W)	8.86	5.09	59.12	35.26	51.12	27.26	7.39	4.41
S-2(W)	4.98	1.91	32.21	18.58	24.21	10.58	4.03	2.32
S-3(W)	6.29	2.44	47.58	22.29	39.58	14.29	5.95	2.79
S-4(W)	4.95	1.73	32.19	12.22	24.19	4.22	4.02	1.53
S-5(W)	5.04	1.87	45.47	22.25	37.47	14.25	5.68	2.78
S-6(W)	4.39	1.45	29.74	12.44	21.74	4.44	3.72	1.56
S-7(W)	5.51	1.93	45.75	21.28	37.75	13.28	5.72	2.66
S-8(W)	7.64	4.97	50.00	32.16	42.00	24.16	6.25	4.02
Mean	6.17	2.96	42.76	22.06	34.76	14.06	5.34	2.76
Degree of Pollution	Pollution	Pollution	High	High	High	High	Severely polluted	Severely polluted

4.3.1. Heavy Metal Pollution Index (HPI)

The HPI of water bodies in the DEPZ Lake and Bangshi River were observed to be higher which indicated that this river and lake have been severely polluted by heavy and toxic metals according to the HPI classification mentioned in the Table 4-4. DEPZ Lake water also had higher HPI values in comparison to the Bangshi river water. The HPI values could be slightly differed based on the geographical locations of samples. It was found to be the highest at the upstream but get reduced in the down part of the river water. The results of water pollution indices showed that the level of metal pollution increased from the upper part to lower part of the river and lake water, specifically when CPI, Cd and HEI and HPI values were actively considered to define the contamination status. This observation could be rationalized by the presence lower concentration of the contaminants in the downstream water bodies. The upstream water bodies of DEPZ lake and Bangshi river received more industrial effluents due to agricultural and industrial activities in the study area. In addition, the accumulation and mobilization of pollutants with the flow of water to the downstream might result the higher concentrations of metals in water body of that part of Bangshi river.

4.3.2. Contamination Index (Cd)

Table4-4 presents the results of the water quality indices in the study area. According to WHO and DoE guidelines, the contamination index was observed to be higher in all water samples collected from different sampling sites. Based on the DoE standard guidelines some data are being observed within the permissible limits, however in comparison to the tolerable limits set up by WHO, relatively higher contamination index values were noticed in all water samples examined in the present study. In addition, a slight variations were realized among the contamination index values obtained from different water samples which might be due to the differences in contaminant concentrations in the water bodies of various locations in the study area.

4.3.3. Heavy Metal Evaluation Index (HEI)

The heavy metal evaluation index (HEI) was determined in each of the samples similarly like contamination index and similar results were observed. These results showed that water bodies at all sampling points were at a risk of high pollution according to the DoE and WHO standard (Table 4-4).

4.3.4. Comprehensive Pollution Index (CPI)

In the water bodies of DEPZ lake and Bangshi river, the CPI values ranged from 1.53 to 4.41 with an average value of 2.76. The data were compared with permissible values of DoE. According to the CPI‘s classification based on WHO and DoE, the water bodies in the lake and river of the study area are highly polluted with heavy and toxic metal contaminants. According to WHO standard, the CPI value sof DEPZ lake and Bangshi River water varied from 3.72 to 7.39 and the CPI's classification method has demonstrated that the DEPZ lake and Bangshi river water are highly polluted.

4.4. Metals in sediment and their pollution assessments

Heavy metal concentrations in sediments of different locations at DEPZ lake and Bangshi River are presented in Table 4.5 & 4.6. The concentrations of different metals, Fe, Ni, Mn, Pb, Cr , Cu, As, and Cd in the river sediments were in the range of 1024.89 to 20163.34, 21.85 to 101.52, 389.06 to 464.19, 10.35 to 19.42, 53.55 to 155.17, 24.04 to 409.12, 6.32 to 10.57 and 0.88 to 1.87 mg/kg dry weight, respectively. The average concentrations of the eight heavy metals in the river and lake sediments followed the order: Fe>Mn>Cu>Cr>Ni>Pb>As>Cd. Heavy metal concentrations in sediments are affected by different factors including contaminated wastewater influx from different natural and anthropogenic sources as well as different physicochemical parameters exist in the aquatic environment. Elevated concentrations of heavy metals were found in sediment samples at the most upstream site (DEPZ area) which could be attributed due to presence of the anthropogenic sources in the study area. Weathering of metal-containing rocks, i.e., lithogenic sources, domestic sewage, agricultural activity, and industrial effluents may also result the higher concentrations of different metals in sediments of the respective areas [4]. The ultimate fate of heavy metals in an aquatic environment is greatly affected by various processes such as precipitation, sorption, and dissolution [5].

Table 4.5: Heavy and toxic metals concentrations (Mean ± S.D.) in sediment (mg/kg) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh

Sample ID & Types	Conc. of Iron		Conc. of Nickel		Conc. of Manganese		Conc. of Lead	
	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS
S-1(S)	4344.60±141.51	1272.34±111.71	101.52±8.62	38.05±3.52	459.27±20.33	245.35±41.44	15.72±3.09	9.56±0.63
	4197.50-4479.77	1143.35-1337.43	95.23-111.35	34.76-41.76	443.35-482.17	197.70-273.01	13.34-19.06	8.98-10.23
S-2(S)	5341.31±99.12	1062.30±81.69	79.27±7.01	33.77±2.05	423.19±9.15	324.78±28.11	18.18±1.02	12.42±0.81
	5231.42-5423.96	1008.71-1156.32	71.24-84.41	31.77-35.87	413.53-424.31	298.09-354.12	17.25-19.27	11.53-13.19
S-3(S)	3581.53±169.60	1425.64±58.19	72.31±7.06	30.38±3.15	416.67±16.23	368.31±16.62	11.43±0.74	5.42±1.00
	3385.86-3686.37	1370.69-1486.60	65.11-79.12	26.75-32.51	397.94-426.43	349.28-379.98	11.65-12.11	4.37-6.35
S-4(S)	20163.34±403.95	–	40.12±4.22	–	413.96±25.97	–	10.35±0.86	–
	19699.31-20436.36	–	35.71-44.12	–	394.76-443.51	–	9.36-10.94	–
S-5(S)	2514.99±87.53	1526.50±35.46	52.18±3.99	41.06±1.70	393.45±17.45	283.41±34.88	14.67±0.58	13.53±2.46
	2413.92-2566.49	1487.57-1556.50	47.60-54.87	39.51-42.87	378.37-412.57	246.65-316.04	14.10-15.25	11.64-16.31
S-6(S)	4386.04±115.93	1236.47±200.42	40.61±3.03	46.24±2.16	410.32±14.68	286.42±19.12	11.41±1.02	13.38±0.66
	4275.85-4506.97	1073.57-1175.56	37.63-43.67	43.75-47.64	397.42-426.30	265.98-303.88	10.64-12.57	12.65-13.95
S-7(S)	2753.45±92.71	2835.18±79.33	21.85±4.11	47.70±3.93	464.19±8.06	305.37±40.60	19.42±1.15	12.65±1.84
	2687.77-2859.58	2743.67-2884.58	21.25-25.98	43.64-51.47	454.89-469.12	277.59-351.96	18.54-20.72	10.87-14.54
S-8(S)	1024.89±95.16	1535.47±46.66	26.40±5.99	15.21±0.70	389.06±9.32	240.36±13.11	16.67±1.65	7.48±0.96
	934.23-1123.99	1486.90-1579.95	21.55-33.09	14.95-15.93	378.35-395.30	226.64-254.45	15.62-18.57	6.54-8.46
LEL and TRV[6]	–		16		–		31	
WHO[7]	–		20		30		10	
Background[8-9]	14355		18.8		462		10.9	

Table 4.6: Heavy and toxic metals concentrations (Mean ± S.D.) in sediment (mg/kg) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh

Sample ID	Conc. of Chromium		Conc. of Copper		Conc. of Arsenic		Conc. of Cadmium	
	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS
S-1(S)	155.17±8.05	53.81±6.59	409.12±11.07	30.10±2.03	9.88±1.49	2.60±0.38	1.84±0.11	BDL
	146.25-161.89	46.98-60.11	397.45-419.46	28.76-32.43	8.74-11.57	2.19-2.96	1.91-1.71	
S-2(S)	59.28±4.24	55.56±5.64	56.13±8.46	26.31±2.00	10.57±1.02	1.65±0.21	1.87±0.11	0.14±0.01
	56.35-64.14	49.87-61.15	47.59-64.50	24.66-28.53	9.43-10.90	1.53-1.89	1.74-1.94	0.13-0.15
S-3(S)	61.87±4.09	66.61±11.32	63.47±5.04	33.06±2.49	8.57±0.79	2.83±0.59	1.21±0.07	0.11±0.02
	58.35-66.37	54.76-77.31	58.46-68.55	31.61-35.94	7.96-9.44	2.15-3.20	1.28-1.15	0.10-0.12
S-4(S)	68.88±3.38	–	52.21±7.53	–	7.39±1.12	–	1.68±0.14	–
	65.65-72.40	–	43.56-57.34	–	6.26-8.50	–	1.82-1.57	–
S-5(S)	69.99±5.55	71.79±5.32	97.70±11.06	35.66±1.08	7.85±0.68	2.49±0.27	1.15±0.01	BDL
	63.62-73.75	65.65-74.99	86.34-108.40	34.65-36.76	7.18-8.54	2.25-2.78	1.15-1.16	
S-6(S)	81.13±2.23	72.19±7.38	32.72±2.20	36.64±1.76	7.48±0.88	3.42±0.12	0.87±0.04	BDL
	78.49-82.90	63.67-76.62	30.55-35.88	34.61-37.69	6.71-8.43	3.29-3.53	0.84-0.93	
S-7(S)	97.20±3.90	74.46±5.10	36.50±4.50	39.84±2.58	6.33±0.78	3.28±0.29	1.59±0.05	0.17±0.02
	94.50-101.67	69.27-79.46	32.55-41.40	37.98-42.78	5.54-8.85	3.06-3.61	1.55-1.64	0.16-0.19
S-8(S)	53.55±2.09	49.71±6.47	24.04±2.41	16.36±1.54	7.55±1.21	2.65±0.40	1.73±0.05	BDL
	45.61-49.71	42.45-54.86	21.91-26.66	14.62-17.53	6.46-8.85	2.19-2.94	1.69-1.79	
LEL and TRV[6]	26		16		6		0.6	
WHO[7]	25		25		3		6	
Background[8-9]	31.9		17		7.09		0.119	

The results of metal analysis in sediments collected from highly contaminated area have been compared to the data obtained from sediments samples of long range contaminated sites, Kalihati upazila at Tangail district. All of the metal concentrations in sediments of HCS were found to be relatively very much higher than those observed in the sediments of LCS. The average concentrations of the eight heavy metals in the sediments samples obtained from different sources such as river and lake of LCS followed the order: Fe>Mn> Cr > Ni >Cu >Pb>As>Cd. The concentrations of Fe, Ni, Mn, Pb, Cr, and Cu in sediments of LCS were in the range of 1062.30 to 2835.18, 15.21 to 47.70, 240.36 to 368.31, 5.42 to 13.53, 49.71 to 74.46, 16.36 to 39.84, 1.65 to 3.42 and 0.00 to 0.17 mg/kg dry weight, respectively. The metal data determined in sediments of LCS were also compared with standard tolerable values provided by USEPA, WHO and other sources which suggested the Cr, Cu and Pb concentrations in sediments to be considerably higher than those permissible levels. Comparison of the results of the metal study in the sediments samples of two study areas (HCS and LCS) showed the presence of higher influx of the heavy metal concentrations in the highly contaminated area than that of the long range contaminated area. The data also explained that Fe, Ni, Mn, Pb, Cr, Cu, As, and Cd contents in sediments of HCS are 3.54, 1.51, 1.44, 1.39, 1.27, 3.10, 3.04 and 24.78 times more than those found in the sediments of LCS.

4.4.1. Potential Ecological Risk Index

The data for potential ecological risk index (E_f^i and RI) of eight heavy metals have been illustrated in the Table 4-7. The potential ecological risk indices of Cr, Cu, Mn, Pb, Ni, and As in sediment samples were lower than 40 which indicated low potential ecological risk of these metals. However, the exception was found in the case of Cu determined in sediment sample collected from Bank Town industrial area of Savar which suggested that sediments of this area is highly contaminated with Cu. There three several metal processing, painting, textiles industries are located at the Bank Town area which might contribute to the appearance of higher level of Cu in the sediments of the respective area. Low ecological risk index values were observed for some metals and the trend PERI were found to be in the order of Mn> Pd > Cr > As> Ni>Cu. However Cd concentration was higher in all sediment samples which increase the potential ecological risk to surrounding environment as well as to human health due to chronic Cd pollution in the study area. PERI classification method also explained the pollution characteristics in surrounding environmental components due to toxic exposure of Cd. The maximum PERI was 643.99 found in the samples collected near DEPZ area. The average PERI calculated in different sediments samples in the HCS was realized as 444.81 (Table 4.7). Most of the sediments in HCS were considered at a considerable risk level based on the PERI values determined in those samples. According to the classification of PERI, the average PERI values for all heavy metals examined in the sediment of Bangshi river and DEPZ lake, the metal pollution level can be described as highly considerable. Comparison of heavy metal contents in sediments of different sampling sites demonstrated the variation of pollutants concentrations in different locations of the study area. The order of sediment metal pollution different sampling locations based on the PERI values was observed to be DEPZ >Dagotoly Vill > Jelepara > Bank Town > Murad Jan Road >Khaicha bari >Maijhail > Khatrapara. It should be noted that different fishes grown in DEPZ lake has now become the vital source of protein to local residents as well as the resident of capital city Dhaka through the consumption of metal contaminated fishes. Ni, Cu, Pb, Cr, As, and Cd concentrations determined in the sediments samples collected from around the DEPZ area were much higher the permissible values reported by WHO, USEPA and others which could be due to the large emission of industrial effluents from various industries of DEPZ area. Mn and Fe contents in sediments were relatively lower than standard tolerable safety limits.

Table 4.7: Potential ecological risk factor (Ei) and ecological risk index (RI) values for sediments collected from Savar area, Dhaka.

Station	Potential Ecological Risk Factor (E_f^i)							RI	Risk grade
	Ni	Mn	Pb	Cr	Cu	As	Cd		
S-1(S)	27.00	0.9941	7.2110	9.7285	120.3294	13.9382	464.7983	643.9996	High
S-2(S)	21.0824	0.9160	8.3394	3.7166	16.5088	14.9168	472.4874	537.9675	Considerable
S-3(S)	19.2314	0.9019	5.2431	3.8790	18.6676	12.0660	306.9832	366.9722	Considerable
S-4(S)	10.6702	0.8960	4.7477	4.3185	15.3559	10.4286	424.5630	470.9800	Considerable
S-5(S)	13.8777	0.8516	6.7294	4.3881	28.7353	11.0810	291.8067	357.4697	Considerable
S-6(S)	10.8005	0.8881	5.2339	5.0865	9.6235	10.5554	221.4202	263.6083	Moderate
S-7(S)	5.8112	1.0047	8.9083	6.0940	10.7353	8.9268	401.2185	442.6988	Considerable
S-8(S)	7.02128	0.8421	7.6468	3.3574	7.0706	10.6512	438.2269	474.8167	Considerable

4.4.2. Metal Enrichment Factor (EF)

A common approach to estimate the anthropogenic impacts on sediments is to calculate a normalized enrichment factor (EF) using the metal concentrations observed in the contaminated samples and respective metal concentration in the uncontaminated sample (background value). The EF method normalizes the measured heavy metal contents with respect to a sample reference metal such as Fe or Al. In this approach the Fe or Al is considered to act as a ―proxy" for the clay content. Fe as an acceptable normalization element to be used in the calculation of the enrichment factor since it has been considered that the Fe distribution is not related to other heavy metals. Fe is usually found in various environmental components as a relatively higher natural concentration. Therefore Fe is not expected to be substantially enriched from anthropogenic sources in estuarine sediments. Figure 4.1 shows the enrichment factors of eight different metals determined in sediments sample of the study area.

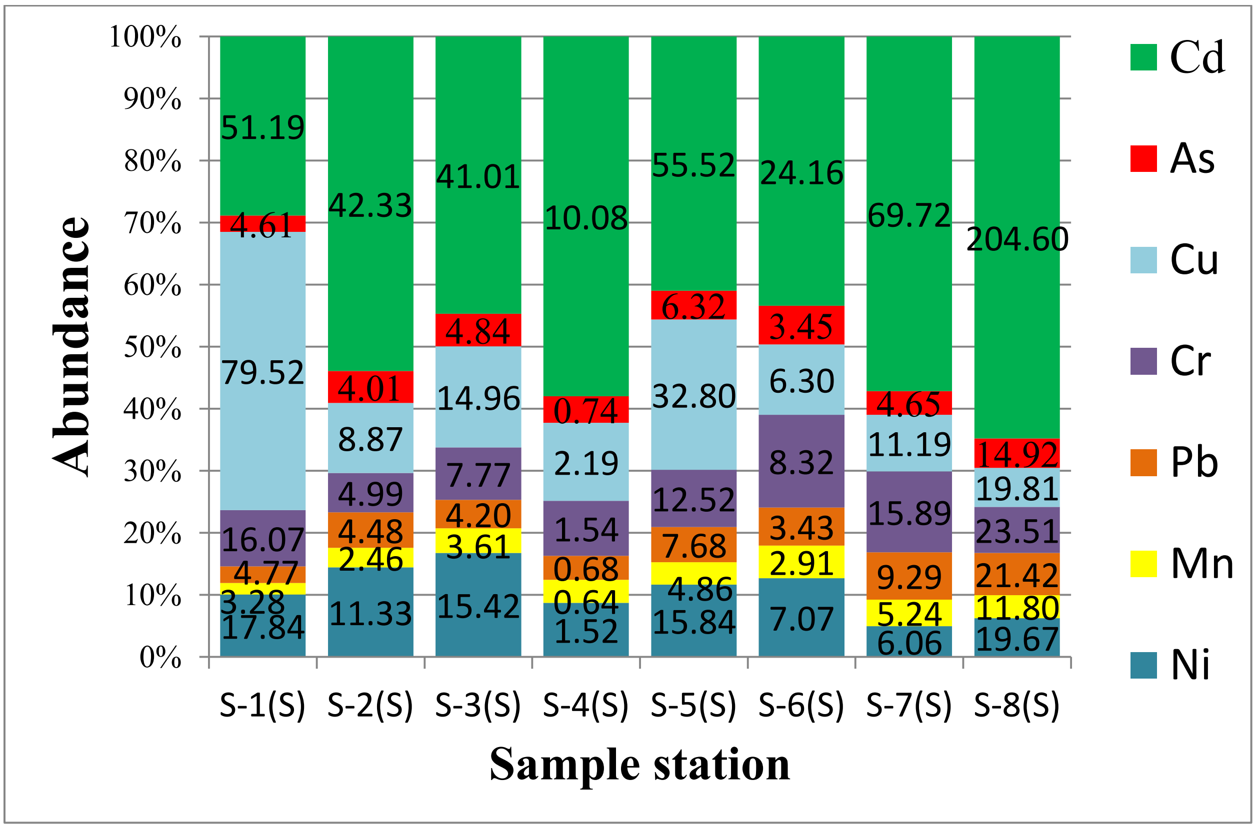


Figure 4.1: The enrichment factors (EF) for each metal in the eight zones of highly contaminated area

Classification of enrichment factors and corresponding metal enrichment level are given below:

Enrichment Factor (EF) Values:

< 2 represent deficiency to minimal metal enrichment, $2 - 5$ represent moderate metal enrichment, $5 - 20$ describe significant metal enrichment, $20 - 40$ explain very high metal enrichment, > 40 means extremely high metal enrichment.

Metal enrichment factors values provide the real evidence of metal contamination and pollution in different environmental components such as water, soil, sediments, aquatic species, food chain etc. of a study area. Based on the mean enrichment factors values (Fig. 4.1) determined for Ni, Mn, Pb, Cr, Cu, As and Cd in all sediments samples, these metallic elements have been divided into the following four groups to describe the pollution status in the study area:

(1) Moderate enrichment (EF≤2-5): Mn

(2) Significant enrichment (EF≤5-20): Ni, Pb, Cr, and As

(3) Very high enrichment (EF=20-40): Cu

(4) Extremely high enrichment (EF> 40): Cd

The first group corresponding to the deficiency of metal enrichment which is being associated with a natural origin. The last two groups of elements (Cu, Cd) are highly related to the anthropogenic activities mostly due to the continuous exposure of urban wastes (discharging without treatment) and industrial effluents and their availability in the respective areas. Most of the heavy metals were accumulated in very excessive level in the sediments of DEPZ lake and Bangshi river which was supported with the observation of higher metals enrichments factors in the sediments of the respective areas. Relatively lower enrichments of metals were realized in the sediments samples collected from other locations of the study area (Fig. 4.1).

4.4.3. Geo-accumulation Index (Igeo)

Geo-accumulation index (Igeo) were estimated in all sediments samples for eight metals studied. Positive Igeo values demonstrated the pollution status of an environmental sample as well as the respective study areas. However, the negative Igeo values certify that the environmental components are non-contaminated or safe. In the present investigation the Igeo values of Fe, Ni and Mn in sediments were found to be negative (Fig. 4.2) which revealed that sediments within the water bodies at different locations of Savar area ate relative safe and not highly contaminated the above metals. However long time deposition of toxic industrial effluents into the nearby water bodies may lead to excess accumulation of these heavy metals in sediments in the respective areas in near future. On the other hand As, Cd, Cu, Cr, and Pb showed positive Igeo in the similar sediments samples which indicated that sediments of lake, river and other water bodies of Savar area are highly polluted with the above heavy and toxic metals particularly with Cd and As (Fig.4.2). Highest metal accumulation was observed for Cd and the minimum metal accumulation was realized with Fe in all sediments samples examined in the present investigation which are also being reflected with the respective Igeo values of the two metals (Fig. 4.2).

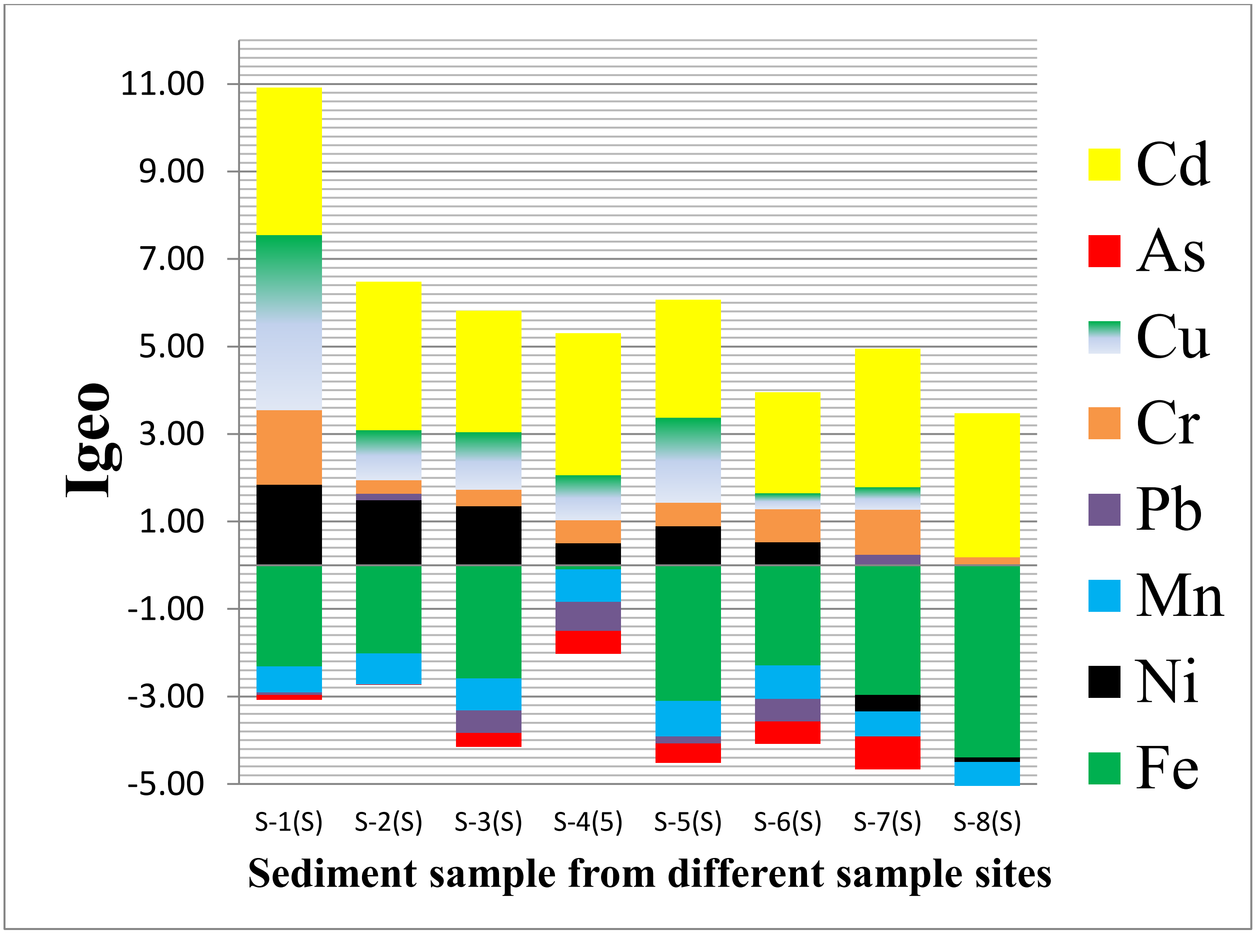


Figure 4.2: Geo-accumulation Index (Igeo) for heavy metals in the surface sediment of highly contaminated area

4.4.4. Metal Contamination Factor (CF)

Assessment of the anthropogenic effects on sediment quality can be ascertained by standardized contamination factor (CF) for metal concentration. CF is a mathematically computed record, contingent upon a direct extent between the concentration of the metals in the samples taken from the study area as well as from the earth crust. CF for Cd was seen to be considerably higher in all sediments samples collected different sample station (Table 4.8). Contamination factor for Cr was found to be the highest in the sediments of DEPZ lake and Banshi river areas. The class 1 of CF grade was followed in the present study. Metals such as Fe, Mn and As, Pb, Ni also followed the CF class 2 and Cr, Cu was considered within the class of 3 and Cd was in the range of the class 4. Metal contamination factor values in sediments and the corresponding pollution classification information indicated that most of the CF values followed class 3 categorization and river and thus demonstrated that lake sediments and river sediments in the Savar area have retained a considerable level of metal contamination.

4.4.5. Pollution Load Index (PLI)

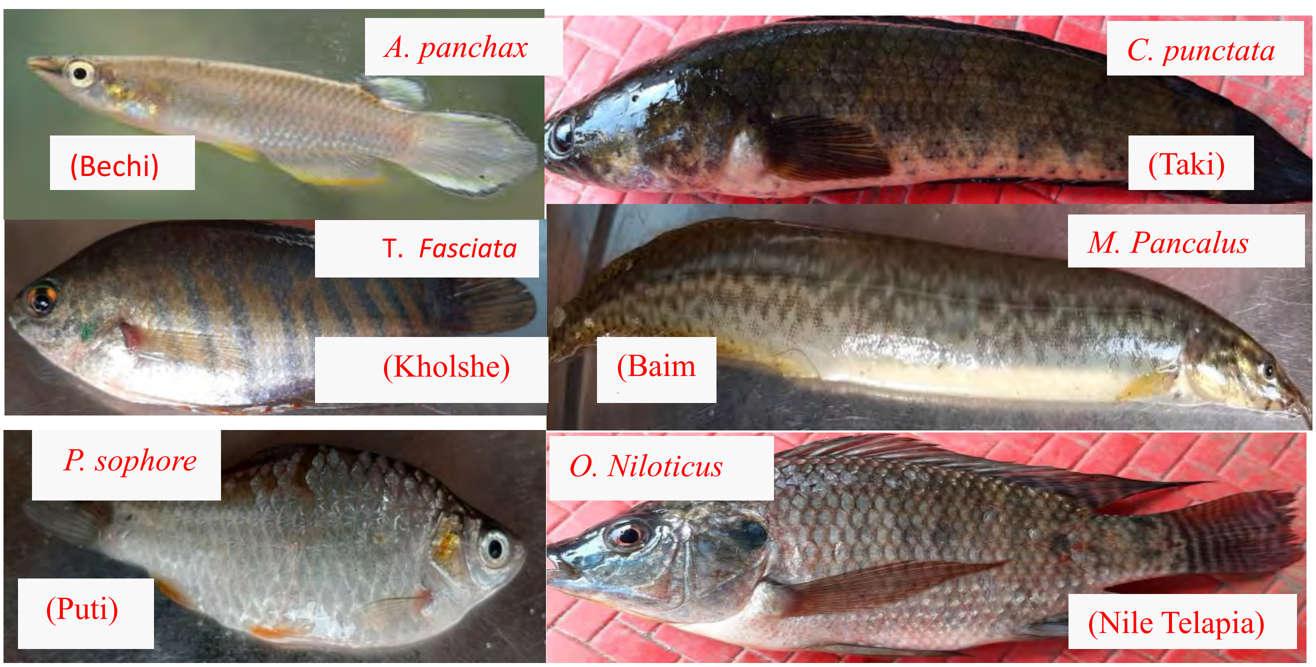
The pollution load index (PLI) parameter is used to assess the overall metal toxicity in environmental samples. This parameter also describes the ultimate consequences metal pollution in various environmental components. The PLI values calculated for eight metals in sediments of the study area are presented in the Table 4.8. PLI values of sediments collected from various sampling sites ranged between 1.29 and 3.16. The lowest PLI value was recorded in sediments of Bank Town area whereas the highest PLI was observed in the sediments of DEPZ lake areas of Savar. Higher industrial activities in the DEPZ are might result the elevated level of PLI in the sediments of the respective area. The overall pollution load index was observed to be maximum at DEPZ lake area and the lowest PLI was realized in sediments of Bangshi River area in Savar, Dhaka.

Table 4.8: Contamination factor (Cf) and pollution load index values of heavy metals for sediments in highly contaminated area

Sample type	CF									PLI
	Fe	Ni	Mn	Pb	Cr	Cu	As	Cd	PLI	Contamination source
S-1(S)	0.3027	5.4000	0.9941	1.4422	8.2537	24.0659	1.3938	15.4933	3.1647	progressive deterioration
S-2(S)	0.3721	4.2165	0.9160	1.6679	3.1532	3.3018	1.4917	15.7496	2.2182	progressive deterioration
S-3(S)	0.2495	3.8463	0.9019	1.0486	3.2910	3.7335	1.2066	10.2328	1.8507	progressive deterioration
S-4(5)	1.4046	2.1340	0.8960	0.9495	3.6638	3.0712	1.0429	14.1521	2.1299	progressive deterioration
S-5(S)	0.1752	2.7755	0.8516	1.3459	3.7229	5.7471	1.1081	9.7269	1.8349	progressive deterioration
S-6(S)	0.3055	2.1601	0.8881	1.0468	4.3154	1.9247	1.0555	7.3807	1.5844	progressive deterioration
S-7(S)	0.1918	1.1622	1.0047	1.7817	5.1702	2.1471	0.8927	13.3739	1.6422	progressive deterioration
S-8(S)	0.0714	1.4043	0.8421	1.5294	2.8484	1.4141	1.0652	14.6076	1.2987	progressive deterioration
Mean	0.3841	2.8874	0.9118	1.3515	4.3023	5.6757	1.1571	12.5896	1.9655	progressive deterioration
Contamination level	Low	Moderate	Low	Moderate	Considerable	Considerable	Moderate	Very high		

4.5. Heavy and toxic metals accumulations in fishes

A total of eight different fishes were collected from various industrial contaminated lakes and rivers located at Savar area, Dhaka. The concentrations of the eight selected heavy metals in muscles of those different fish species were determined and the results of the metal analysis in the contaminated fishes have been displayed in the Tables 4.9 & 4.10. Concentrations of Fe, Ni, Mn, Pb, Cr, Cu, As and Cd in various fish species of highly contaminated site were found to be varied from 24.42 to 209.57, 1.15 to 8.46, 2.13 to 47.86, 1.37 to 13.76, 0.28 to 2.11, 8.49 to 24.93, 0.61 to 1.39 and 0.07 to 1.31 mg/kg dry weight respectively. Average metal concentrations in the fishes samples generally followed the order: Fe >Mn> Cu >Pb> Ni> Cr> As > Cd. The average concentrations of the heavy metals in the corresponding sediments and water samples were also observed in elevated level which might result the excessive accumulation of heavy and toxic metals in different fishes grown in the contaminated water bodies. Different metal concentrations estimated in the various fish species under the present investigation were compared with the standard permissible values reported by WHO, MHPRC and other countries such as China, India. Iron concentrations determined in all fish samples were higher than the prescribed tolerable levels (Tables 4.9 & 4.10). Some chemical forms of Iron compounds are highly toxic. At certain pH levels, ferric hydroxide can greatly affect the populations of benthic organisms and so of fish species grown in in various streams [13]. Excess iron uptake by humans with different food items such as fishes is a serious health concern in the developing countries particularly for the people who like eat fishes as a source protein. Elevated concentrations of iron in human body cause the potential risk of developing cancer. Workers who are highly exposed to asbestos that contains almost 30% of iron are at high risk of asbestosis, which is the second most important cause for having lung cancer. Iron would initiate cancer mainly by the oxidation process in DNA molecules [14]. Fish toxicity of manganese compounds has only been recognized for Mn(II) salts. The deleterious effects of either chronic or acute exposure to manganese depend on the species and, within a species it depends on the tissues. A common noticeable target is the antioxidant system of the organism, which seems particularly prone to the disruptive effects of manganese [15]. Manganese contents in all fish species were considerably higher that the respective permissible levels of WHO and USEPA. Manganese neurotoxicity describes the role of excessive manganese in the oxidation of dopamine, resulting in free radicals and cytotoxicity. Manganese toxicity also greatly affects the mitochondrial energy metabolism processes which has been illustrated by different studies. Some research findings suggested that the mitochondrial dysfunctional effects of manganese could result in various oxidative stresses to cellular defense mechanisms (e.g. glutathione) as well as free radical damage to mitochondrial DNA [14]. Lead concentration determined in the fishes samples were found to be higher than standard permissible values provided by WHO, USEPA and others. Lead can severely affect many cellular processes and enzyme systems all over the human body through different possible mechanisms. Most of the previous research works on lead poisoning provided more focus on its toxic effects on the hematology, cardiovascular, renal, and neurotoxicity's issues [16-17]. In a previous study, it was reported that heavy metals including Pb is highly nephrotoxic especially in the renal cortex. In that study relatively higher concentrations of toxic heavy metals such as Cr, Pb, and comparatively lower concentrations of the antioxidant element Se have been found in patients with cancer and diabetes [18].



Italic letter: Scientific name, In parenthesis: Local name

Figure 4.3: Different fish species studied for heavy and toxic metal contamination in the present investigation

Table 4.9: Heavy and toxic metals concentration (Mean ± S.D.) in fishes (mg/kg) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh

Common Name of Fish	Length	Conc. of iron		Conc. of nickel		Conc. of manganese		Conc. of lead		Habitat	Feeding habits
	Cm	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS		
Puti (a)	5.1	105.96±4.08	46.08±0.74	2.62±0.43	0.35±0.01	30.68±7.91	7.71±0.23	2.89±0.10	0.44±0.13	Upper	omnivorous
		101.34-109.09	45.24-46.65	2.35-3.12	0.34-0.37	24.65-39.52	7.45-7.85	2.80-2.99	0.30-0.54		
Telapia	16.3	39.47±2.69	32.02±0.50	1.15±0.12	0.03±0.01	45.59±3.23	7.33±0.39	13.76±0.49	0.48±0.10	Middle	omnivorous
		37.54-42.54	32.17-33.12	1.01-1.23	0.02-0.03	41.76-47.55	7.22-7.93	13.23-14.18	0.71-0.93		
Taki (a)	10.4	24.42±0.91	9.85±0.71	5.33±0.20	BDL	2.13±3.22	10.05±0.11	1.86±0.31	1.45±0.40	Bottom	Carnivorous
		23.44-25.23	9.03-10.28	5.19-5.56	BDL	1.91-2.34	9.98-10.17	1.57-2.19	1.20-1.91		
Bechi	6.5	58.64±2.35	–	4.49±0.45	–	36.82±3.36	–	1.37±0.36	–	Upper	omnivorous
		57.01-61.34	–	4.12-4.99	–	32.94-38.76	–	1.14-1.78	–		
Puti (b)	5.7	209.57±11.27	112.33±0.17	3.50±0.29	0.03±0.01	32.50±2.62	6.89±0.25	2.46±0.25	0.31±0.23	Upper	omnivorous
		187.87-221.34	112.23-112.53	3.19-3.77	0.02-0.03	30.20-35.44	6.67-7.15	2.23-2.72	0.15-0.57		
Kholshe	6.3	194.38±11.39	150.31±0.0.5	4.63±0.34	0.04±0.01	33.60±1.09	18.32±0.11	2.16±0.33	2.19±0.05	Upper	omnivorous
		183.85-206.26	150.25-150.35	4.24-4.97	0.03-0.05	32.43-34.60	18.20-18.39	1.88-2.53	2.13-2.23		
Baim	13.8	130.45±3.65	98.46±0.20	8.46±0.37	BDL	22.38±1.79	10.59±0.32	5.58±0.39	2.58±0.07	Bottom	Carnivorous
		126.35-133.36	98.33-98.73	8.20-8.89	BDL	21.44-24.76	10.23-10.84	5.17-5.95	2.55-2.66		
Taki (b)	14.2	126.41±10.51	92.11±0.21	2.55±0.28	0.01±0.00	47.86±3.36	8.24±0.08	1.79±0.38	2.21±0.05	Bottom	Carnivorous
		119.71-138.38	91.87-92.26	2.30-2.86	0.01-0.01	44.95-51.54	8.15-8.29	1.39-2.14	2.17-2.27		
Indian std[10]		–		1.5		–		2.5			
WHO (1989)[11]		100		0.5-0.6		1		2			
MHPRC[12]		–		–		–		0.5			

Table 4.10: Heavy and toxic metals concentration (Mean ± S.D.) in fishes (mg/kg) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh

Common Name of Fish	Length	Conc. of Chromium		Conc. of Copper		Conc. of Arsenic		Conc. of Cadmium		Habitat	Feeding habits
	Cm	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS		
Puti (a)	5.1	0.55±0.10	BDL	12.52±1.26	3.00±0.14	0.94±0.16	0.05±0.01	0.10±0.01	BDL	Upper	omnivorous
		0.46-0.65		11.43-13.90	2.83-3.09	0.83-0.96	0.04-0.05	0.09-0.10			
Telapia	16.3	1.27±0.05	BDL	11.59±0.68	3.25±0.07	1.08±0.11	0.07±0.01	0.81±0.04	0.02±0.00	Middle	omnivorous
		1.23-1.32		11.01-12.34	3.19-3.33	0.94-1.14	0.06-0.07	0.77-0.84	0.02-0.02		
Taki (a)	10.4	2.11±0.01	BDL	17.41±0.51	5.45±0.29	1.11±0.05	0.03±0.00	1.31±0.02	BDL	Bottom	Carnivorous
		2.10-2.12		16.98-18.02	5.16-5.75	1.07-1.16	0.02-0.03	1.23-1.33			
Bechi	6.5	1.55±0.10	–	21.23±1.49	–	0.66±0.03	–	0.07±0.00	–	Upper	omnivorous
Range		1.46-1.65	–	19.95-22.86	–	0.69-0.70	–	0.07-0.07	–		
Puti (b)	5.7	0.28±0.05	BDL	16.07±0.87	4.55±0.21	0.61±0.03	BDL	0.09±0.00	BDL	Upper	omnivorous
		0.24-0.34		15.25-16.98	4.32-4.75	0.58-0.63		0.08-0.09			
Kholshe	6.3	0.78±0.03	BDL	8.49±0.69	3.05±0.02	1.39±0.12	0.09±0.00	0.09±0.01	BDL	Upper	omnivorous
		0.76-0.81		7.99-9.28	3.04-3.07	1.17-1.39	0.09-0.09	0.08-0.09			
Baim	13.8	1.28±0.07	BDL	24.93±0.77	2.52±0.38	0.61±0.11	0.07±0.01	0.72±0.01	0.01±0.00	Bottom	Carnivorous
		1.21-1.55		24.26-25.77	2.17-2.92	0.54-0.78	0.07-0.73	0.71-0.75	0.01-0.01		
Taki (b)	14.2	1.49±0.05	BDL	21.23±0.62	3.36±0.11	1.32±0.03	0.10±0.01	0.73±0.081	BDL	Bottom	Carnivorous
		1.45-1.55		18.87-20.09	3.24-3.49	1.23-1.39	0.09-0.11	0.68-0.82			
Indian std[10]		20		30		1.1		1.5			
WHO (1989)[11]		–		30		–		0.5			
MHPRC[12]		2		–		0.1		0.1			

Nickel concentrations in all the fish samples were found to be comparatively higher than standard tolerable values. Moreover, chromium, arsenic, cadmium concentrations in fishes were higher than Chinese and WHO standard values. However, copper concentration in all fishes was lower than the corresponding permissible levels of WHO and others. All metal concentrations were found to be varied in different fish species (Tables 4.9 & 4.10). Puti Kholshe fish contained much higher concentration of Fe than the permissible values of WHO and USEPA. Manganese concentrations found in all fishes samples were much higher than safety limits of WHO and others. Lead concentration was observed higher in demersal fishes such as Taki, Baim and one upper fish (Kholshe). The average concentrations of the eight heavy metals in the different fishes obtained from river, Vil and lake of long range contaminated site followed the order: Fe>Mn>Cu>Pb>Ni>As>Cd>Cr (Tables 4.9 & 4.10). The concentrations of Fe, Ni, Mn, Pb, Cr, Cu, As and Cd in different fish samples of LCS were in the range of 9.85 to 150.31, 0.00 to 0.35, 6.89 to 18.32, 0.31 to 2.58, 0.00, 2.52 to 5.45, 0.00 to 0.10 and 0.00 to 0.018 mg/kg dry weight, respectively. Metal concentrations observed in fishes of two study areas (HCS and LCS) were compared and the results of metal analysis showed as significant variations among them. Concentration level of Fe, Ni, Mn, Pb, Cu, As, and Cd in different fish species of highly contaminated area were 1.44, 62.25, 3.18, 2.89, 4.58, 16.88 and 109.32 times more than those observed in the various fishes samples of the long range contaminated area.

4.5.1. Source analysis of toxic metals in fishes

Inter-relationships among the measured metal concentrations in different fish samples were investigated in terms of Pearson‘s correlation coefficient matrixes which are shown in the Table 4.11. Inter-metal interactions may illustrate the sources and pathways of the metals present in various fish muscles. A clear pattern of strong association was found among metal pairs found in fish muscles.

Table 4.11: Correlation between heavy metals in the fishes samples obtained from the DEPZ and Bangshi river areas.

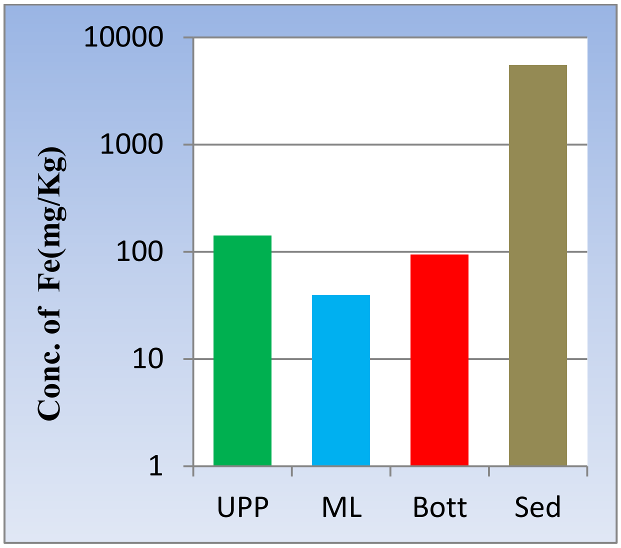
Correlations								
	Fe	Ni	Mn	Pb	Cr	Cu	As	Cd
Fe	1							
Ni	0.129	1						
Mn	0.234	-0.62	1					
Pb	-0.34	-0.32	0.314	1				
Cr	-0.77*	0.241	-0.35	0.012	1			
Cu	-0.18	0.614	-0.21	-0.22	0.44	1		
As	-0.04	-0.39	0.175	0.007	0.211	-0.59	1	
Cd	-0.6	0.161	-0.44	0.3	0.77	0.271	0.261	1

*. Correlation is significant at the 0.05 level

The positive correlation of Mn and Cr with As indicates that an increase of those metals in fish muscles could enhances the amount of As in different fish species. Cd was found to be positively correlative with Cr (r=0.77), Cu (r=0.271), As (r=0.261) which suggested that if cadmium level increase in fishes, Cr, Cu, and As contents will also be observed to be higher. Cu has found to have a positive correlation with Ni (r=0.614) and Cr(r=0.44). Pd has a positive correlation with Mn(r=0.314) and Fe was positively correlative with Ni(r=0.129) and Mn (r=0.234). Higher correlation coefficients between the metals indicated common sources, mutual dependence, and similar or nearly identical metal accumulation properties in fishes [19]. Cr showed negatives relationship with Fe (r = -0.768*) and inverse relationship was found between Fe and Cr.

4.5.2. Relationship between heavy metals in fishes and the environment

Aquatic living species such as fishes accumulate heavy metals from water, sediments, and their food chain. Uptake of metals by fishes through various routes depends on the environmental concentrations of heavy metals in the habitat of the fish species [20]. In the present study the lowest metal concentration was found in water whereas the maximum concentrations metals was observed in sediments. The results of the heavy metals contamination in sediments and fishes of different water layers have been showed in table. 4.5; 4.6; 4.9; and 4.10. Fe, Cu, Mn and Ni concentrations in water, sediments, and fishes were relatively higher in comparison to other metals studied in the present investigation (Fig. 4.4). These four metals are recognized as essential elements to living species like fishes which might cause the accumulation of these metals in fishes in very excessive levels compared to other heavy metals such as Pb, Cr, As and Cd [21-22]. Fishes that are used to be inhabited in the lower water layer near to sediments accumulated metals much higher than the fishes that are inhabited in the middle water layer. In DEPZ area different types of fishes are grown into the lake and this lake water finally flows toward the Bangshi river and ultimately mixed into the river water bodies. All fishes including upper level, middle and lower level in DEPZ lake are more contaminated with toxic metals than the fishes grown in Bangshi river water. This might be due to the presence of much higher metal concentrations in the sediments of DEPZ lake area. In most cases fishes with larger size accumulated relatively higher amount of metals than the fishes with smaller size irrespective of the metals studied in the present research work [23]. Accumulation of eight heavy metals in fishes and sediments samples were varied significantly [24]. The bottom layer fishes like Taki, baim which are being fed with animals are known as carnivore and they are usually inhabited adjacent to sediment layer [25], whereas upper and middle layered fishes such as Puti, Bechi, Khoilsh are being fed with insects, animal, plant and are known as omnivore[26-27]. The findings of the present study revealed that lower layer fishes generally accumulate higher amount of metals than the upper and middle layer fish species.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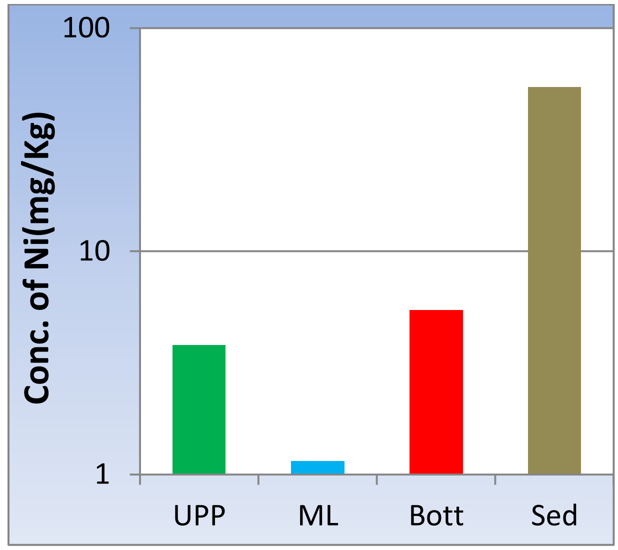
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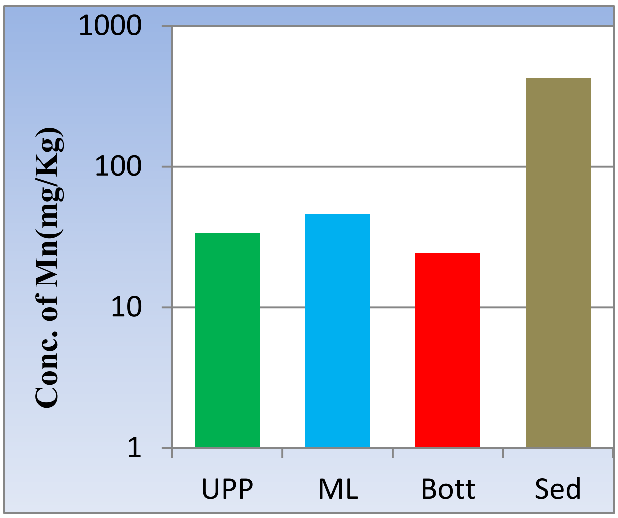
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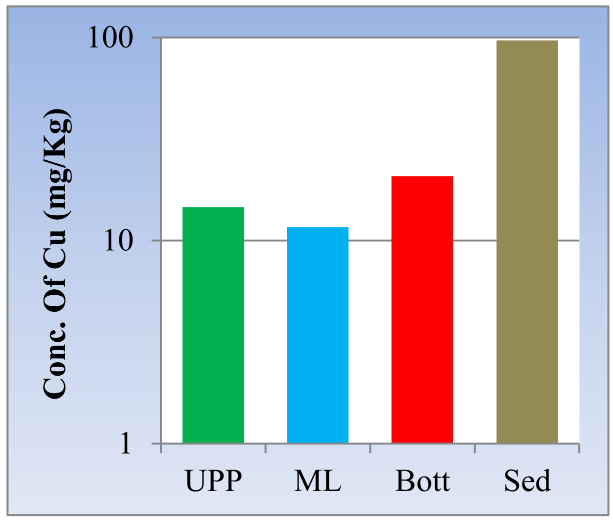
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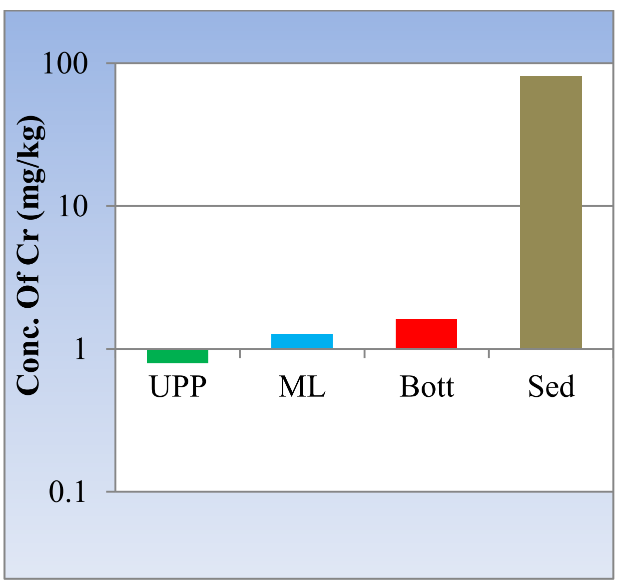
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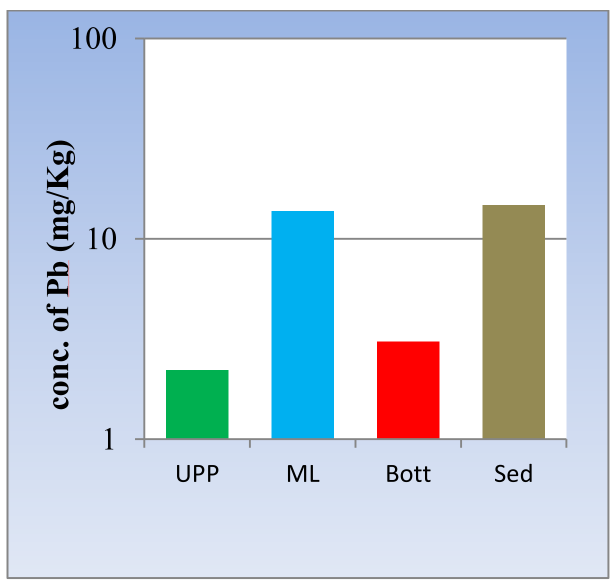
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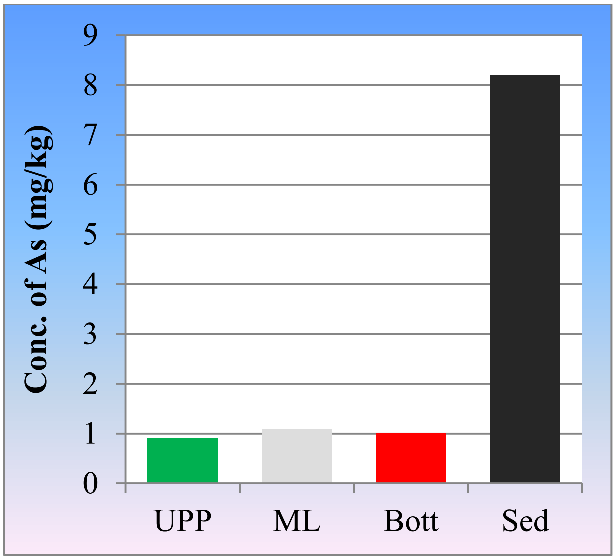

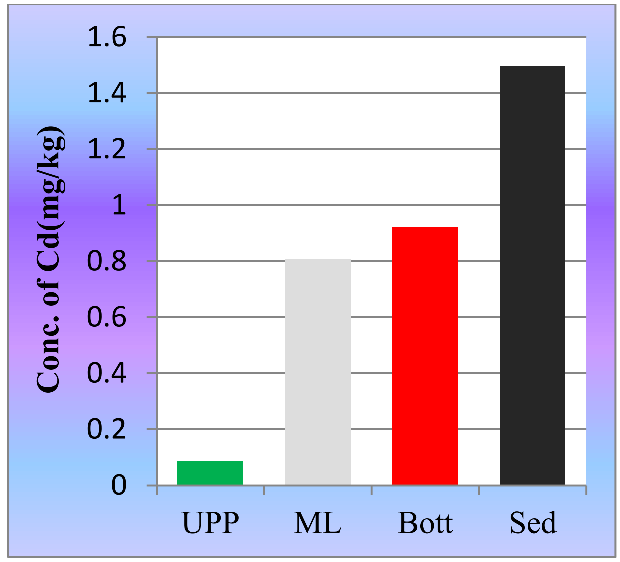

Figure 4.4: Distribution of heavy metals in sediments and fishes inhabiting in different water layers (mg/Kg dry weight) (UPP:Fish living in Upper layer, ML: Fish living in middle layer, Dem: Fish living in lower layer and Sed: means Sediment)

4.6.Heavy Metal Concentrations in Fishes, Water, and Sediment

Concentration of eight heavy metals, Fe, Ni, Mn, Pb, Cr, Cu, As, and Cd in different fishes, sediment and surface water from Bangshi river & DEPZ lake area (highly contaminated sites-HCS) and Kalihati Upazila (long range contaminated sites-LCS) were listed in the Tables 4.12 and 4.13. Relatively higher level of iron usually exists in the natural environment. Out of eight metals studied in the present study, iron concentrations were much higher in all sediment, fishes and surface water samples. The highest Fe concentration was found in sediments of HCS sites and lowest concentration was found in water bodies of LCS. Considerable quantity of Ni was observed in water, sediments and fishes samples of HCS. Since nickel is a cumulative body poison and thus its concentration should remain as low as possible. The industrial effluents of DEPZ area were the main sources of nickel contamination in the aquatic system of various lakes and Bangshi River in the study area. However, most of metal concentration in water, sediments, and fishes of LCS were found to be below the detection limits. Although manganese is an element of low toxicity, but it has considerable biological significances. Appreciable amount of manganese was appeared in all environmental samples of both HCS and LCS study areas which were within the safety limits except in the sediments where Mn concentration was relatively higher. Lead is a non-essential element. Average level of Pb observed in fish species of the contaminated area was much more compared to that of long range contaminated sites. Comparison of different metal concentrations in water, sediments, and fish samples are presented in the Tables 4.12 & 4.13. Chromium does not normally accumulate in fish and hence low concentrations were reported even from various industrial areas in the world. The observed concentrations of Cr in the fish samples of Bangshi River was found to be higher which might be due to the presence of wastewater coming from various industries in the area. However, in the Cr concentrations all fish sample and surface water of LCS were below the detection limits. Copper is an essential part of several enzymes and is necessary for the synthesis of hemoglobin. Copper contents were found in all fish, sediment, and water samples of both study area. In most of the cases, sediments metal concentrations were exceeded the standard tolerable limits. Arsenic is a widespread contaminant in the environment. Arsenic exposure arises from both anthropogenic and natural activity. Arsenic concentration in six species of fishes was found higher in both study areas. But in the long range contaminated site As concentrations in the samples were much lower than those of highly contaminated sites. As concentrations in the sediments samples were significantly more than the permissible by WHO and USEPA. It was vividly observed that Cd in the selected fishes from Bangshi River were below the standard tolerable values. But long time accumulation of Cd in different fish species may pose potential hazards to human health. Like other metals cadmium concentration was found significantly higher than standard safety limits.

Table 4.12: Comparison of the concentration of different metals in fishes (mg/kg), surface water (mg/L) and sediments (mg/kg) of highly contaminated sites (HCS) and long range contaminated sites (LCS) in Bangladesh.

Sample ID and Types	Conc. of iron		Conc. of nickel		Conc. of manganese		Conc. of lead	
	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS
Puti (a)	105.96±4.08	46.08±0.74	2.62±0.43	0.35±0.01	30.68±7.91	7.71±0.23	2.89±0.10	0.44±0.13
Water	3.37±0.07	1.60±0.15	0.12±0.02	BDL	1.82±0.09	0.189±0.01	0.13±0.02	0.06±0.01
Sediment	4344.60±141.51	1272.34±111.71	101.52±8.62	38.05±3.52	459.27±20.33	245.35±41.44	15.72±3.09	9.56±0.63
Telapia	39.47±2.69	32.02±0.50	1.15±0.12	0.03±0.01	45.59±3.23	7.33±0.39	13.76±0.49	0.48±0.10
Water	1.63±0.04	1.85±0.05	0.13±0.01	BDL	0.56±0.04	0.23±0.02	0.04±0.00	0.03±0.00
Sediment	5341.31±99.12	1062.30±81.69	79.27±7.01	33.77±2.05	423.19±9.15	324.78±28.11	18.18±1.02	12.42±0.81
Taki (a)	24.42±0.91	9.85±0.71	5.33±0.20	BDL	2.13±3.22	10.05±0.11	1.86±0.31	1.45±0.40
Water	2.41±0.06	1.72±0.01	0.66±0.03	BDL	0.36±0.03	0.245±0.01	0.17±0.01	0.02±0.00
Sediment	3581.53±169.60	1425.64±58.19	72.31±7.06	30.38±3.15	416.67±16.23	368.31±16.62	11.43±0.74	5.42±1.00
Bechi	58.64±2.35	–	4.49±0.45	–	36.82±3.36	–	1.37±0.36	–
Water	2.36±0.02	–	0.09±0.00	–	0.12±0.02	–	0.14±0.01	–
Sediment	20163.34±403.95	–	40.12±4.22	–	413.96±25.97	–	10.35±0.86	–
Puti (b)	209.57±11.27	112.33±0.17	3.50±0.29	0.03±0.01	32.50±2.62	6.89±0.25	2.46±0.25	0.31±0.23
Water	3.87±0.01	1.60±0.16	0.09±0.00	BDL	0.87±0.03	0.18±0.02	0.16±0.01	0.04±0.01
Sediment	2514.99±87.53	1526.50±35.46	52.18±3.99	41.06±1.70	393.45±17.45	283.41±34.88	14.67±0.58	13.53±2.46
Kholshe	194.38±11.39	150.31±0.0.5	4.63±0.34	0.04±0.01	33.60±1.09	18.32±0.11	2.16±0.33	2.19±0.05
Water	1.33±0.03	0.69±0.04	0.08±0.00	BDL	0.33±0.01	0.23±0.03	0.14±0.02	0.08±0.01
Sediment	4386.04±115.93	1236.47±200.42	40.61±3.03	46.24±2.16	410.32±14.68	286.42±19.12	11.41±1.02	13.38±0.66
Baim	130.45±3.65	98.46±0.20	8.46±0.37	BDL	22.38±1.79	10.59±0.32	5.58±0.39	2.58±0.07
Water	2.33±0.0.06	0.78±0.05	0.56±0.00	BDL	0.38±0.00	0.24±0.01	0.18±0.00	0.04±0.03
Sediment	2753.45±92.71	2835.18±79.33	21.85±4.11	47.70±3.93	464.19±8.06	305.37±40.60	19.42±1.15	12.65±1.84
Taki (b)	126.41±10.51	92.11±0.21	2.55±0.28	0.01±0.00	47.86±3.36	8.24±0.08	1.79±0.38	2.21±0.05
Water	2.14±0.01	1.81±0.23	0.63±0.01	BDL	1.38±0.01	0.22±0.03	0.07±0.00	0.09±0.01
Sediment	1024.89±95.16	1535.47±46.66	26.40±5.99	15.21±0.70	389.06±9.32	240.36±13.11	16.67±1.65	7.48±0.96

Table 4.13: Comparison of different metal concentrations in fish (mg/kg), surface water (mg/L) and sediments (mg/kg) of highly contaminated Sites (HCS) and long range contaminated sites (LCS) in Bangladesh.

Sample ID and Types	Conc. of Chromium		Conc. of Cupper		Conc. of Arsenic		Conc. of Cadmium	
	HCS	LCS	HCS	LCS	HCS	LCS	HCS	LCS
Puti (a)	0.55±0.10	BDL	12.52±1.26	3.00±0.14	0.94±0.16	0.05±0.01	0.10±0.01	BDL
S-1(W)	0.06±0.01	BDL	0.34±0.01	0.11±0.01	0.0407±0.005	0.0053±0.0005	0.0286±0.0015	BDL
S-1(S)	155.17±8.05	53.81±6.59	409.12±11.07	30.10±2.03	9.88±1.49	2.60±0.38	1.84±0.11	BDL
Telapia	1.27±0.05	BDL	11.59±0.68	3.25±0.07	1.08±0.11	0.07±0.01	0.81±0.04	0.02±0.00
S-2(W)	0.09±0.01	0.03±0.01	0.45±0.01	0.08±0.01	0.0463±0.0028	0.0046±0.0004	0.0260±0.0010	0.0014±0.0002
S-2(S)	59.28±4.24	55.56±5.64	56.13±8.46	26.31±2.00	10.57±1.02	1.65±0.21	1.87±0.11	0.14±0.01
Taki (a)	2.11±0.01	BDL	17.41±0.51	5.45±0.29	1.11±0.05	0.03±0.00	1.31±0.02	BDL
S-3(W)	0.05±0.00	BDL	0.77±0.02	0.14±0.02	0.0417±0.009	0.0084±0.0200	0.0119±0.0005	BDL
S-3(S)	61.87±4.09	66.61±11.32	63.47±5.04	33.06±2.49	8.57±0.79	2.83±0.59	1.21±0.07	0.11±0.02
Bechi	1.55±0.10	–	21.23±1.49	–	0.66±0.03	–	0.07±0.00	–
S-4(W)	0.05±0.01	–	0.09±0.01	–	0.0369±0.0013	–	0.0093±0.0007	–
S-4(S)	68.88±3.38	–	52.21±7.53	–	7.39±1.12	–	1.68±0.14	–
Puti (b)	0.28±0.05	BDL	16.07±0.87	4.55±0.21	0.61±0.03	BDL	0.09±0.00	BDL
S-5(W)	0.06±0.01	BDL	0.16±0.01	0.09±0.01	0.0260±0.00416	BDL	0.0081±0.0007	BDL
S-5(S)	69.99±5.55	71.79±5.32	97.70±11.06	35.66±1.08	7.85±0.68	2.49±0.27	1.15±0.01	BDL
Kholshe	0.78±0.03	BDL	8.49±0.69	3.05±0.02	1.39±0.12	0.09±0.00	0.09±0.01	BDL
S-6(W)	0.07±0.02	BDL	0.12±0.00	0.07±0.01	0.0314±0.00029	0.0084±0.0009	0.0067±0.0002	0.0013±0.0003
S-6(S)	81.13±2.23	72.19±7.38	32.72±2.20	36.64±1.76	7.48±0.88	3.42±0.12	0.87±0.04	BDL
Baim	1.28±0.07	BDL	24.93±0.77	2.52±0.38	0.61±0.11	0.07±0.01	0.72±0.01	0.01±0.00
S-7(W)	0.12±0.01	BDL	0.11±0.01	0.10±0.03	0.0313±0.0012	0.01910±0.0007	0.0078±0.0004	BDL
S-7(S)	97.20±3.90	74.46±5.10	36.50±4.50	39.84±2.58	6.33±0.78	3.28±0.29	1.59±0.05	0.17±0.02
Taki (b)	1.49±0.05	BDL	21.23±0.62	3.36±0.11	1.32±0.03	0.10±0.01	0.73±0.081	BDL
S-8(W)	0.04±0.01	0.04±0.01	0.33±0.01	0.10±0.02	0.0257±0.0070	0.0091±0.0094	0.0286±0.0015	BDL
S-8(S)	53.55±2.09	49.71±6.47	24.04±2.41	16.36±1.54	7.55±1.21	2.65±0.40	1.73±0.05	BDL

4.7.The BCFs of eight heavy metals

In aquatic ecological risk assessment, BAF are used to measure the accumulation of chemical species in tissues relative to the metals concentrations in water or sediment. The BAF values of eight heavy metals for fish collected from Bangshi River and DEPZ Lake at different sampling points are given in the Figures 4.5 & 4.6. BAF is a ratio of heavy metal concentration in the aquatic organism to that in the sediments. This factor specifies the enrichment of the heavy metals in the analyzed muscle relative to that in the sediments. The trends of average BAF for different metals in eight fish species were in the descending order: Cu> Cd >As> Ni> Mn>Fe>Pb>Cr. In addition, the average BAF values from surface water to various fish species were found in the order of: Cu >Mn> Pb> Fe>Cd>As> Ni> Cr (Fig.6). BAF values of heavy metals may be indicative of the mobility and bioavailability of these elements in the aquatic environment. Chromium concentration was found considerably lower in all fish samples which demonstrates the lower mobility of Cr from water and sediments to fish species.

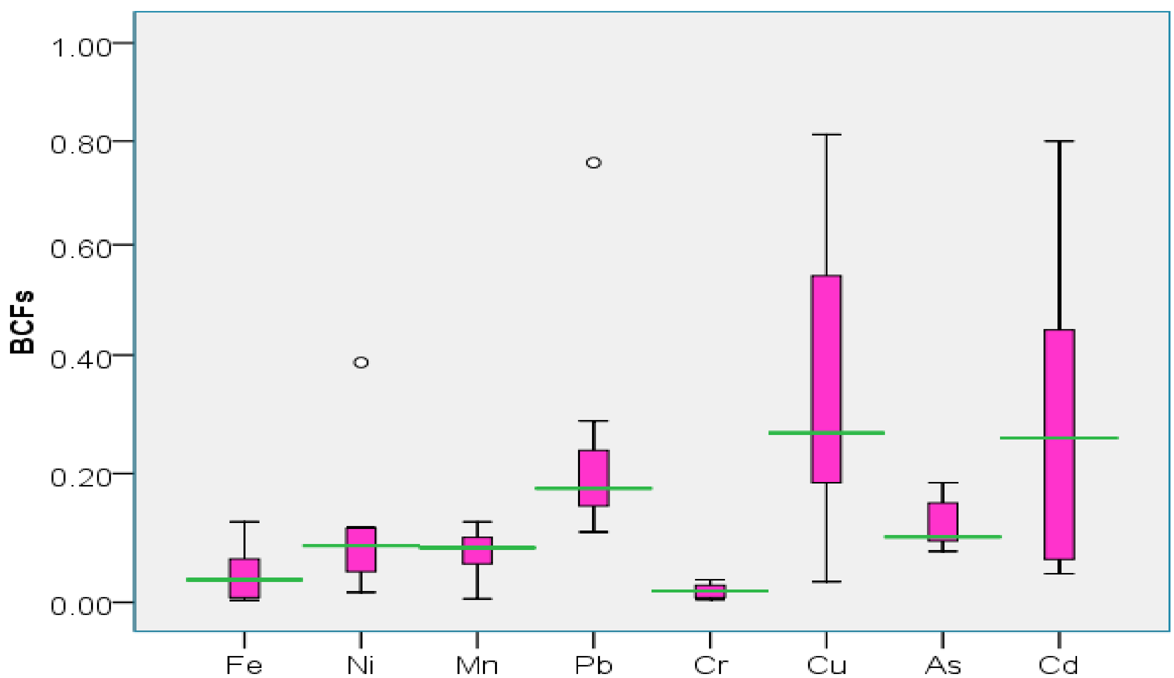

Figure 4.5: BCFs value boxes of eight heavy metals from water to fish represent a range of 25th to 75 percentile, solid green lines in a median values, lower bar mean minimum, higher bar mean maximum value and circle symbols represents outliers.

Although heavy metal accumulation in fish depends on many factors other than the metal concentration in sediments, BAF values for the heavy metals examined in the present study is observed to be increased in the downstream. Since BAF values inversely depend on metal concentrations in sediments, therefore BAF values cannot be used for the determination of absolute accumulation of heavy metals in biota, they only show metal accumulation in the fish relative to the metal level in the sediment.

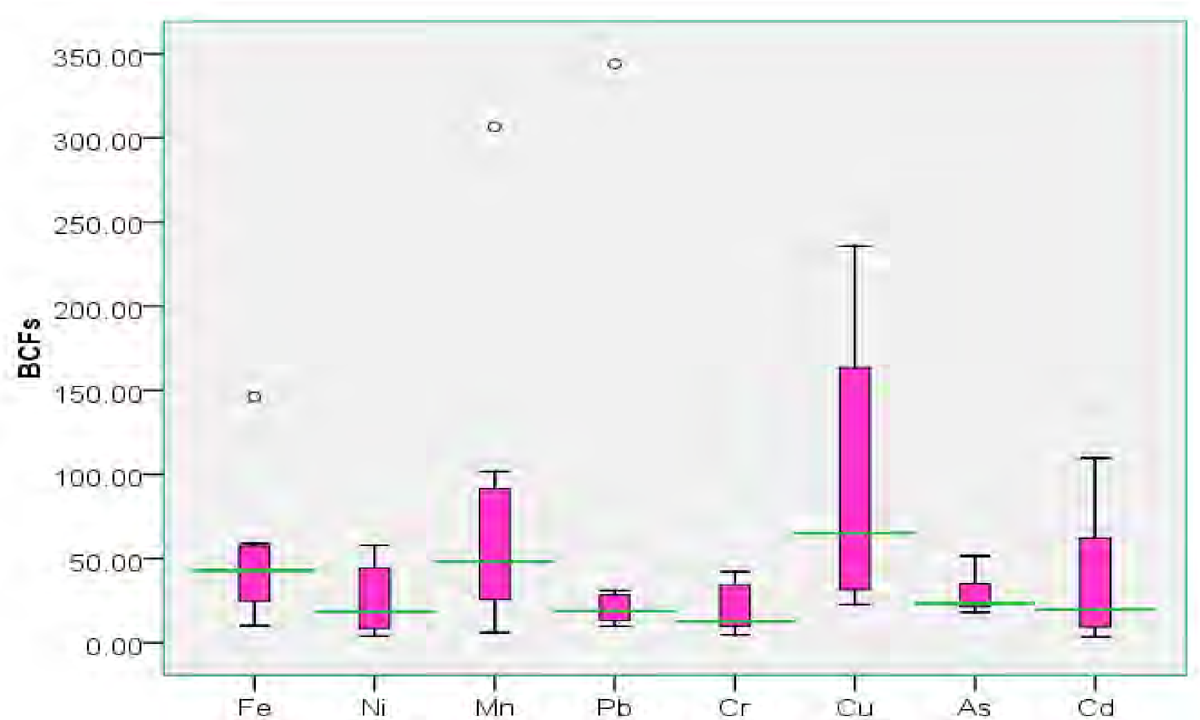

Figure 4.6: BCFs value boxes of eight heavy metals from sediment to fish represent a range of 25th to 75 percentile, Solid green lines in a median values, lower bar mean minimum, higher mean Maximum value and circle symbols represents outliers.

The reduction of Cr (VI) to Cr (III) (which usually occurs in moist soil) might be attributed to the low bioavailability of Cr, as the transformation of Cr (VI) to low-solubility cationic forms occurs through the reduction [26]. There are no similarities observed in the bioaccumulation pattern of individual metal in sediments and fish samples and they were found to be varied among the sampling sites.

4.8.Human exposure and health risk assessment through contaminated fish consumption

4.8.1. Estimated daily intakes (EDI) of toxic metals from fishes

The dietary intake approach of foods is a reliable tool for investigating population's diet in terms of intake levels of nutrients, bioactive compounds, and contaminants. It provides important information about the potential nutritional deficiencies or exposure to food contaminants [28].

Table 4.14: Estimated daily intake (mg/kg bw/day) of Fe, Ni, Mn and Pb from fishes for adult and children of Savar, Dhaka, and comparison with the corresponding maximum tolerable daily intake (MTDI)

General Name of fish sample	EDI							
	Fe		Ni		Mn		Pb	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Puti	79.3111	141.3904	1.9611	3.4961	22.964	40.9386	2.1632	3.8563
Telapia	29.5433	52.6678	0.8608	1.5345	34.1241	60.8342	10.2994	18.361
Taki	18.2784	32.5854	3.9895	7.1122	1.5943	2.8422	1.3922	2.4819
Bechi	43.892	78.2478	3.3608	5.9913	27.5598	49.1317	1.0254	1.8281
Puti	156.8631	279.645	2.6198	4.6703	24.3263	43.3672	1.8413	3.2826
Kholshe	145.4934	259.3758	3.4656	6.1782	25.1496	44.835	1.6168	2.8823
Baim	97.6418	174.0692	6.3323	11.2888	16.7514	29.8633	4.1766	7.4458
Taki	94.6179	168.6783	1.9087	3.4027	35.8232	63.8632	1.3398	2.3885
MTDI[29-30]	15		0.90		5		0.21	

The EDI of eight heavy metals (Fe, Ni, Mn, Pb, Cr, Cu, As and Cd) were estimated following the mean concentrations of each metal found in fish samples and the respective consumption rates of adults and children. The EDI data are presented in Table 4.14. Averagely estimated daily intakes of Fe, Ni, Mn, Pb, Cr, and Cu for human were 83.60, 3.04, 23.36, 2.96, 0.86, 12.24, 0.73 and 0.37 mg/day for adults and 148.33, 5.46, 41.96, 5.32, 1.55, 21.98, 1.29 and 0.65 mg/day respectively for children.

Table 4.15: Estimated daily intake (mg/kg bw/day) of Cr, Cu, As and Cd from fishes for adult and children of Savar, Dhaka and compare with the corresponding maximum tolerable daily intake (MTDI).

General Name of fish sample	EDI							
	Cr		Cu		As		Cd	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Puti	0.4117	0.7339	9.3712	16.7064	0.7064	1.2594	0.0719	0.1282
Telapia	0.9506	1.6947	8.6751	15.4654	0.8088	1.4419	0.6048	1.0782
Taki	1.5793	2.8155	13.0314	23.2315	0.8284	1.4769	0.977	1.7418
Bechi	1.1602	2.0683	15.8907	28.3288	0.4968	0.8856	0.0538	0.0959
Puti	0.2096	0.3736	12.0284	21.4434	0.4536	0.8086	0.0666	0.1188
Kholshe	0.5838	1.0408	6.3548	11.3288	1.0374	1.8494	0.0685	0.1221
Baim	0.9581	1.708	18.6601	33.266	0.4592	0.8186	0.5447	0.971
Taki	1.1153	1.9882	14.6257	26.0737	0.9922	1.7688	0.5492	0.9792
MTDI[29-30]	1.00		4.50		0.126		0.046	

Metal specific EDIs data revealed that EDI of Fe, Mn, Cu, Cr, Ni, As, Cd and Pb from consumption of contaminated fish were much higher. The maximum tolerable daily intake (MTDI) (Tables 4.14 & 4.15) indicated that these metals had the major contribution to the potential health risk via food consumption such as fish for both adults and children in the study area. But for the children relative health risks are higher than adults. Calculated of EDI data following the EDI Eq. showed that the EDI for all eight heavy metals were higher than the RfDo. These results indicated that local fish consumption might have an adverse effect on human health. In the present study, the EDI data was determined and evaluated only for fish, which accounted for only a fraction of contamination through daily dietary consumption.

4.8.2. Target Hazard Quotient (THQ)

The THQ-max based on the maximum concentration in fish was larger than the corresponding THQ-average. The THQ-average was found to be in the order of As >1> Pb > Cd >Cr > Cu > Mn > Fe > Ni for both adult and children for all type of fishes but Pb was observed to be more than 1 for children. The THQ-values demonstrated certain degree of adverse health effects through contaminated fish consumption. Although the values of THQ-average and THQ-max were quite distinct, the comparison of THQ values with 1, revealed that As and Pb have larger potential health risk comparing with other six metals. The relative contributions of As and Pb to the total metal THQ from contaminated fish consumption showed that As and Pb were the two major risk contributors and accounted for 52.83% and 16.34% of the total THQ, respectively. The risk contribution of Cd, Fe, Cu, Ni, Mn, and Cr were less than 10%. These results revealed. the relatively minor risk of Fe and the major contributions of As and Pb to the inhabitants of the study area. The total THQ values (4.56 and 8.13 for adults and children) exceeded 1. However, according to the series of assumptions for health risk assessment, the THQ value was highly conservative and was a relative index. Although individual THQ average was lower than 1(except As and Pb), the THQ-max exceeded 1 for As, Pd for all fishes and Cd in only tilapia fish. This result implies that the potential noncarcinogenic risk of metals for consumers through the fish consumption from the contaminated sites. However, for multiple metals, the THQs of the six fish species were observed to be decreased in the following order: O. niloticus > C. punctata > T. fasciata > A. panchax. > P. sophore > M. pancalus. The TTHQ of all fishes studied showed the risk level (TTHQ > 1) with highest (6.7385) in Telapia fish (O. niloticus) for adults and 12.012 for children. Lowest value was found in Puti Fish (P. sophore) 2.9383 for adults and 5.2382 for children.

4.8.3. Target Cancer Risk

The target carcinogenic risk (TR) values of eight heavy metals in different fish samples are presented in Table 4.17. The TR values for Ni in the fish samples studied were 1.46E-03 to 1.08E-02 for adults and 2.61E-03 to 1.92E-02 for children. The TR values for Pb in the fish samples were 1.00E-05 to 1.00E-05 for adults and 2.00E-05 to 1.60E-04 for children. The TR values for Cr in different fish samples were 9.00E-05 to 1.15E-03 for adults and 1.50E-04 to 1.15E-03 for children. The TR values for As in the fish sample studied were 6.80E-04 to 1.56E-03 for adults and 1.21E-03 to 2.77E-03 for children. Similarly the TR values for Cd in the fish sample were 3.30E-04 to 5.96E-03 for adults and 5.90E-04 to 1.06E-02 for children (Table: 4.16). The target carcinogenic risk of Ni, As, and Cd for different samples in the present study was more than 10^{-4} and Generally, TR above 10^{-4} are regarded as unacceptable. On the other hand, Pd and Cr ranging from 10^{-4} to 10^{-6} are regarded as an acceptable (based on USEPA 2000) [31]. The present study clearly showed that consumption of contaminated fishes definitely poses high cancer risks to the people for As, Ni and Cd.

Table 4.16: Target hazard quotient (THQ) and Total Target Hazard index (TTHQ) values of metals via consumption of eight different fishes for children and adult people in highly contaminated sites.

General Name of fish sample	THQ																TTHQ	
	Fe		Ni		Mn		Pb		Cr		Cu		As		Cd			
	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Puti	0.1133	0.2020	0.0981	0.1748	0.1640	0.2924	0.5408	0.9641	0.1372	0.2446	0.2343	0.4177	2.3548	4.1979	0.0719	0.1282	3.7144	6.6218
Telapia	0.0422	0.0752	0.0430	0.0767	0.2437	0.4345	2.5748	4.5903	0.3169	0.5649	0.2169	0.3866	2.6961	4.8064	0.6048	1.0782	6.7385	12.0129
Taki	0.0261	0.0466	0.1995	0.3556	0.0114	0.0203	0.3481	0.6205	0.5264	0.9385	0.3258	0.5808	2.7615	4.9230	0.9770	1.7418	5.1757	9.2270
Bechi	0.0627	0.1118	0.1680	0.2996	0.1969	0.3509	0.2564	0.4570	0.3867	0.6894	0.3973	0.7082	1.6559	2.9521	0.0538	0.0959	3.1777	5.6650
Puti	0.2241	0.3995	0.1310	0.2335	0.1738	0.3098	0.4603	0.8206	0.0699	0.1245	0.3007	0.5361	1.5120	2.6954	0.0666	0.1188	2.9383	5.2382
Kholshe	0.2078	0.3705	0.1733	0.3089	0.1796	0.3203	0.4042	0.7206	0.1946	0.3469	0.1589	0.2832	3.4581	6.1648	0.0685	0.1221	4.8450	8.6373
Baim	0.1395	0.2487	0.3166	0.5644	0.1197	0.2133	1.0442	1.8615	0.3194	0.5693	0.4665	0.8316	1.5307	2.7288	0.5447	0.9710	4.4811	7.9887
Taki	0.1352	0.2410	0.0954	0.1701	0.2559	0.4562	0.3350	0.5971	0.3718	0.6627	0.3656	0.6518	3.3074	5.8962	0.5492	0.9792	5.4155	9.6543

Table 4.17; Target cancer risk (TR) values of different metals via consumption of 8 different fishes for children and adult people in highly contaminated sites

General Name of fish sample	TR									
	Ni		Pb		Cr		As		Cd	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Puti	3.33E-03	5.94E-03	2.00E-05	3.00E-05	1.70E-04	3.00E-04	1.06E-03	1.89E-03	4.40E-04	7.80E-04
Telapia	1.46E-03	2.61E-03	9.00E-05	1.60E-04	3.90E-04	6.90E-04	1.21E-03	2.16E-03	3.69E-03	6.58E-03
Taki	6.78E-03	1.21E-02	1.00E-05	2.00E-05	6.50E-04	1.15E-03	1.24E-03	2.22E-03	5.96E-03	1.06E-02
Bechi	5.71E-03	1.02E-02	1.00E-05	2.00E-05	4.80E-04	8.50E-04	7.50E-04	1.33E-03	3.30E-04	5.90E-04
Puti	4.45E-03	7.94E-03	2.00E-05	3.00E-05	9.00E-05	1.50E-04	6.80E-04	1.21E-03	4.10E-04	7.20E-04
Kholshe	5.89E-03	1.05E-02	1.00E-05	2.00E-05	2.40E-04	4.30E-04	1.56E-03	2.77E-03	4.20E-04	7.40E-04
Baim	1.08E-02	1.92E-02	4.00E-05	6.00E-05	3.90E-04	7.00E-04	6.90E-04	1.23E-03	3.32E-03	5.92E-03
Taki	3.24E-03	5.78E-03	1.00E-05	2.00E-05	4.60E-04	8.20E-04	1.49E-03	2.65E-03	3.35E-03	5.97E-03

References

1. Hoque, M., and Deb, P., ―Assessment of Physicochemical Water Quality Parameters and Heavy Metals Concentration in Water Samples from Buriganga River Adjacent to Dhaka City", *J. Environ. Sci. & Natural Resources,* Vol. 9(2) pp. 97-104. 2016.
2. Goher, M. E., Hassan, A. M., Abdel-Moniem, I. A., Fahmy, A. H., and El-sayed, S. M., ―Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt", *Egyptian Journal of Aquatic Research.* Vol. 40, pp. 225-233, 2014.
3. CCME (Canadian Council of Ministers of the Environment), 2007. For the protection of aquatic life 2007. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, 1999, Winnipeg.
4. Mahato, M. K., Singh, G., Singh, P. K., Singh, A. K., & Tiwari, A. K., ―Assessment of Mine Water Quality Using Heavy Metal Pollution Index in a Coal Mining Area of Damodar River, India", *Bull Environ. Contam. Toxicol,* Vol. 9(1), pp. 54-61, 2017.
5. Bhuyan, M. S., Bakar, M., Senapathi, V., Chung, S. Y., & Islam, M. S., ―Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh", *Applied Water Science,* Vol. 9(5), 2019.
6. Raknuzzaman, M., Ahmed, M. K., Islam, M. S., Habibullah-Al-Mamun, M., Tokumura, M., Sekine, M., & Masunaga, S., ―Assessment of Trace Metals in Surface Water and Sediment Collected from Polluted Coastal Areas of Bangladesh", *Journal of Water and Environment Technology,* Vol. 4(4), pp. 247–259, 2016.
7. Mortuza M. G., Al-Misned F. A., ―Environmental Contamination and Assessment of Heavy Metals in Water, Sediments and Shrimp of Red Sea Coast of Jizan, Saudi Arabia", *J. Aquat. Pollut. Toxicol.,* Vol. 1(1), 2017.
8. Xie, Q., Qian, L., Liu, S., Wang, Y., Zhang, Y., & Wang, D., ―Assessment of long-term effects from cage culture practices on heavy metal accumulation in sediment and fish", *Ecotoxicology and Environmental Safety,* Vol. 194, pp. 110433, 2020.
9. China National Environment Monitoring Center(CNEMC), 1990, The background values of Chinese Soils, Environment Science Press of China, Beijing(in Chinese)

10. Rahman, M. M., Shehzad, M. T., Nayak, A. K., Sharma, S., Yeasmin, M., Samanta, S., Yeasmin, M., Samanta , S., Correll , R., Naidu, R., ―Health risks from trace elements in muscles of some commonly available fish in Australia and India", *Environmental Science and Pollution Research,* Vol. 27, pp. 21000–21012, 2020.
11. Abarshi, M. M., Dantala, E. O., & Mada, S. B., ―Bioaccumulation of heavy metals in some tissues of croaker fish from oil spilled rivers of Niger Delta region, Nigeria", *Asian Pac. J. Trop. Biomed.,* Vol. 7(6), pp. 563–568, 2017.
12. MHPRC (Ministry of Health of the People's Republic of China) (2013) National Food Safety Standard, maximum levels of contaminants in foods (GB2762-2012)
13. Rastmanesh, F., Safaie, S., Zarasvandi, A. R., & Edraki, M., ―Heavy metal enrichment and ecological risk assessment of surface sediments in Khorramabad River, West Iran", *Environ. Monit. Assess.,* Vol. 190(5). 2018.
14. Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N., ―Toxicity, mechanism and health effects of some heavy metals", *Interdisciplinary Toxicology,* Vol. 7(2), pp. 60–72. 2014.
15. Jumbe, A. S., and Nandini, N., Heavy Metals Analysis and Sediment Quality Values in Urban Lakes", *American Journal of Environmental Sciences,* Vol. 5 (6), pp. 678-687. 2009.
16. Slaninova, A., Machova, J., & Svobodova, Z., ―Fish kill caused by aluminium and iron contamination in a natural pond used for fish rearing: a case report", *Veterinarni Medicina,* Vol. 59(11), pp. 573–581, 2014.
17. Arndt, A., Borella, M. I., & Espósito, B. P., ―Toxicity of manganese metallodrugs toward *Daniorerio*", *Chemosphere,* Vol. 96, Pp. 46-50. 2014.
18. Manganese, WHO Regional Office for Europe, Copenhagen, Denmark, 2001, Air Quality Guidelines - Second Edition.
19. Kormoker, T., Proshad, R., Islam, M. S., Shamsuzzoha, M., Akter, A., & Tusher, T. R., ―Concentrations, source apportionment and potential health risk of toxic metals in foodstuffs of Bangladesh", *Toxin Reviews,* pp. 1-14, 2020.
20. Yi, Y., Tang, C., Yi, T., Yang, Z., & Zhang, S., ―Health risk assessment of heavy metals in fish and accumulation patterns in food web in the upper Yangtze River, China", *Ecotoxicology and Environmental Safety,* Vol. 145, pp. 295–302.2017.

21. Foster, I., Charlesworth, S., ―Heavy metals in the hydrological cycle: trends and explanation", *Hydrol. Process,* Vol. 10, pp. 227–261.2015.

22. Anan, Y., Kunito, T., Tanabe, S., Mitrofanov, I., & Aubrey, D. G., ―Trace element accumulation in fishes collected from coastal waters of the Caspian Sea", M*ar. Pollut. Bull.,* Vol. 51, pp. 882–888. 2005.

23. Yi, Y. J., and Zhang, S. H., ―The relationships between fish heavy metal concentrations and fish size in the upper and middle reach of Yangtze River", *Procedia Environmental Sciences,* Vol. 13, pp. 1699 – 1707. 2012.

24. Khan, M. N., Sultana, S., Sabbir, W., Das, M., and Saikat, KM, S, A., ―Biological aspects of Guchi Baim (*Mastacembelus pancalus*) in Khulna region of Bangladesh", *Int. J. Bus. Soc. Sci. Res*., Vol. 5(1), pp. 54-59. 2016.

25. Tesfahun, A., and Temesgen, M., ―Food and feeding habits of Nile tilapia *Oreochromis niloticus* (L.) in Ethiopian water bodies: A review", *International Journal of Fisheries and Aquatic Studies,* Vol. 6(1), pp. 43-47**.** 2018.

26. Das, s., Nandi, N., Majumder, M.,Saikia, S. K., ―New characterization of feeding habits of *Puntius Sophore* (hamilton, 1822) through morphometry", *Journal of Fisheries Sciences.com,* Vol. 7(3), pp. 225-231, 2013.

27. IUCN Bangladesh. 2015. *Red List of Bangladesh Volume 5: Freshwater Fishes.* IUCN, International Union for Conservation of Nature, Bangladesh Country Office, Dhaka, Bangladesh, pp xvi+360.

28. WHO, 1985.GuidelinesfortheStudyofDietaryIntakesofChemicalContaminants. WHO, Geneva, Switzerland,pp.1–100,OffsetPublicationNo.87.

29. Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Ali, M. M., & Eaton, D. W, Health risk assessment due to heavy metal exposure from commonly consumed fish and vegetables", *Environ. Syst. Decis.,* Vol. 36(3), 2016.

30. Gebeyehu, H. R., & Bayissa, L. D., ―Levels of heavy metals in soil and vegetables and associated health risks in Mojo area, Ethiopia", *PLoS One.,* Vol. 15(1), 2020.

31. Ahmed, M. K., Baki, A., Sarkar, K., & Hossain, M. M., ―Human health risk assessment of heavy metals in tropical fish and shellfish collected from the river Buriganga, Bangladesh", *Environ Sci. Pollut. Res.,* Vol. 22(20) pp.15880-15890, 2015.

CHAPTER-5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The rampant discharge of untreated industrial effluents into nearby land and natural water bodies is a growing problem in Bangladesh. Heavy and toxic metals contamination is a serious potential threat for their toxicity and bioaccumulation in the food chain. Aquatic environmental contamination has become a global concern in recent years because they have toxic effects on fishes and other organisms in water bodies. The present research work was designed to assess the concentrations of eight potential heavy and toxic metals in the water, sediments, and different fish species of Bangshi River and DEPZ area at Savar which is recognized as a highly contaminated sites (HCS) and different Vil, lake, and river in Kalihati upazila at Tangail district as a long range contaminated sites (LCS). Comparison of eight different metal concentrations data found in fishes, sediments, and water bodies with the permissible levels of WHO, USPA, China and India showed that the respective environmental components including aquatic fishes, sediments and other are adversely polluted with heavy and toxic metal contamination. In the long range contaminated area Mn in fishes, Fe, Mn, and Pb in water and Cu, Ni and Cr metals concentration in sediments have been found considerably higher than the permissible levels of WHO, EPA, India and other sources. From Water pollution indices values revealed that all water bodies in different locations of the study area are highly contaminated and its followed the order: S1>S8>S3>S7>S5>S2>S4>S6. In contrast, heavy metal accumulation was much higher in the lakes compared to the river sediment, most likely due to the high metal enrichment in the respective areas for different anthropogenic activities. Sediment pollution indices indicated that most of the sediments samples at different sampling sites are at a considerable risk of metal pollution. Among the eight heavy and toxic metals studied in the present investigation, Cd and Cu are posing more risks whereas others metal concentrations were followed the order of Ni>As>Pb>Cr>Mn>Fe. The results of the present research works demonstrated that Fe, Ni, Mn, Pb, Cr, Cu, As and Cd contents determined in sediments of the highly contaminated areas are 3.54, 1.51, 1.44, 1.39, 1.27, 3.10, 3.04 and 24.78 times higher than those observed in the long range contaminated area. Metal concentrations in different fishes and invertebrate tissues were observed to be intermediate between the sediments and the water samples. Bioaccumulation of metals from surface sediments to different fish species were much higher than those observed for from the surface water to fishes. Fishes that inhebitate near the river or lake bed and being fed on demersal have higher concentrations of heavy metals in comparison to fish living in the upper or middle zones of the water bodies.

Most of the heavy and toxic metals are transferred through the food chain via the following route: surface water- sediment – human. Metal concentrations in different fish samples have generally been found in the order of: Fe>Mn> Cu> Ni>Pb> Cr>Cd>As. The estimated daily intake values of heavy metals in all fishes were found higher than the maximum tolerable daily intake (MTDI) and followed the order of: Fe>Mn> Cu> Ni>Pb> Cr>Cd>As which suggesting a considerable potential health risks to both children and adult. The total target hazard quotients values of all fish samples were found to be higher which result the non carcinogenic risks from the consumption of these contaminated fishes. However, considering the multiple metals contaminations in the study areas, the THQs of the six different fish species were found to be decreased in the following order: O. niloticus > C. punctata > T. fasciata > A. panchax. > P. sophore > M. pancalus. Carcinogenic risks data calculated in various fish species in the present study have been remained within the safety range for Pb and Cr. However As, Cd, and Ni values in all fishes were found much higher than the safety limits and thus imposed great threat of causing potential risks of developing cancer in children and adult.

5.2. Recommendations

1. Industrial effluents should be treated prior to discharge into the surrounding environment.

2. We need to reduce the excessive use of insecticides and fertilizers in the fields in the close vicinity of river and lake.

3. People need to be aware of contaminated foods and subsequent health risk of eating them.

4. Awareness of people about the effects and remedies of pollution should be increased so that they can play important role in the abatement of pollution

5. Government of Bangladesh should take proper action for making new national and regional policies and appropriate preventive measures on the basis of assessment data prior further deterioration of water quality, sediment quality, and food chain contamination in this region.

6. Regular monitoring of heavy metals in aquatic environment as well as fish is necessary.

7. Efficient methodologies for removing toxic heavy metals from sewage waste and industrial effluents are urgently needed before releasing the effluent into the environment to avoid and mitigate environmental pollution.