Chapter

Environmental Pollution with Heavy Metals: A Public Health Concern

Mir Mohammad Ali, Delower Hossain, Al-Imran, Md. Suzan Khan, Maksuda Begum and Mahadi Hasan Osman

Abstract

Heavy metals (HMs) are natural environmental constituents, but their geochemical processes and biochemical equilibrium have been altered by indiscriminate use for human purposes. Due to their toxicity, persistence in the environment and bioaccumulative nature; HMs are well-known environmental contaminants. As result, there is excess release into natural resources such as soil and marine habitats of heavy metals such as cadmium, chromium, arsenic, mercury, lead, nickel, copper, zinc, etc. Their natural sources include the weathering of metal-bearing rocks and volcanic eruptions, while mining and other industrial and agricultural practices include anthropogenic sources. Prolonged exposure and increased accumulation of such heavy metals may have detrimental effects on human life and aquatic biota in terms of health. Finally, the environmental issue of public health concern is the pollution of marine and terrestrial environments with toxic heavy metals. Therefore, because of the rising degree of waste disposal from factories day by day, it is a great concern. Pollution of HMs is therefore a problem and the danger of this environment needs to be recognized.

Keywords: Bioaccumulation, Contamination, Heavy metal, Health hazard, Soil, Toxicity, Water

1. Introduction

Heavy metals (HMs) are an environmental threat and are of grave concern worldwide [1]. Rapid industrialization and urbanization have caused heavy metals to contaminate the atmosphere and it is a problem for human health [2–4]. HMs poses a major environmental threat to living organisms and habitats due to their non-biodegradability, bioaccumulation, environmental stability, persistence and biotoxicity characteristics [5–7]. In order to prevent microbial activities, they can directly influence the physical and chemical properties of sediment, soils and water [8]. They can also disrupt the natural ecosystem and impact the human body acutely and permanently through the food chain [9–11]. The non-degradable HMs can also accumulate in the surface sediment for a

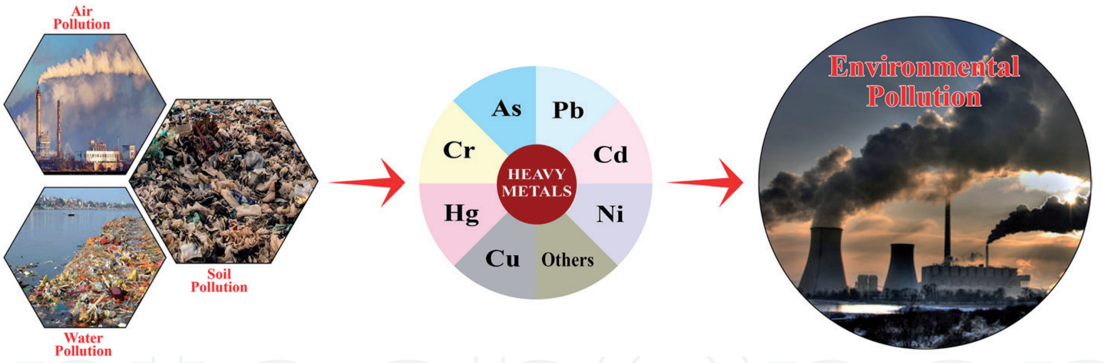

Figure 1.
Sources, metals and the environmental degradation.

long time via the food chain's amplification effect, causing various diseases and complications in the human body [1, 12, 13].

Natural activities (e.g. geological weathering, atmospheric precipitation, wave erosion, wind and bioturbation) and anthropogenic activities (e.g. rapid industrialization, urbanization, agricultural runoff and transport) play a key role in the spread of HMs to the marine habitats of aquatic ecosystems such as rivers and estuaries [2, 4, 14]. In addition, human activities that can produce industrial pollution, the deposition of urban waste and the offensive use of chemical fertilizers and pesticides result in the accumulation and sinking of HMs in aquatic habitat surface sediments [15–17]. The HMs released into the water column have a negative effect on water quality [11, 18] and on surface sediments that alter environmental parameters such as pH, temperature, bioturbation etc. [19, 20]. Sediment quality can therefore play a critical role in identifying the effects of natural and anthropogenic activities [21–23]; sediment quality can also provide information on the anthropogenic impact on the ecosystem and guide environmental policy and management [24].

Farm waste, agricultural runoff, pesticides, solid waste, waste management, effluents from fish processing plants, jute processing, cement manufacturing, oil refining, fertilizer manufacturing, building materials, soup and detergent factories and brickyard waste are the major sources of pollution (**Figure 1**). Due to the potential risk of HMs in water, soil and sediment through the disposal of the effluents mentioned, this riverine water, sediment and environment may be important.

2. Heavy metals

2.1 Definition

Any metal or metalloid of environmental significance is a heavy metal [25]; the term originated in reference to the adverse effects, all denser than iron, cadmium, mercury and lead (**Figure 2**). It has since been extended to some other similarly toxic metal or metalloid, irrespective of density, such as arsenic, chromium, cobalt, nickel, copper, zinc, arsenic, selenium, silver, cadmium, antimony, mercury, thallium and lead are commonly found to be heavy metals [26, 27].

In a general, collective term that refers to a group of metals and metalloids with an atomic density greater than 4 g/cm^3 or 5 times or more than water, the term heavy metal is often referred to as trace elements as they exist in minute concentrations in biological systems [28].

Heavy metals are classified as "metals that occur naturally and have an atomic number greater than 20" [29, 30]. They are a significant class of contaminants that

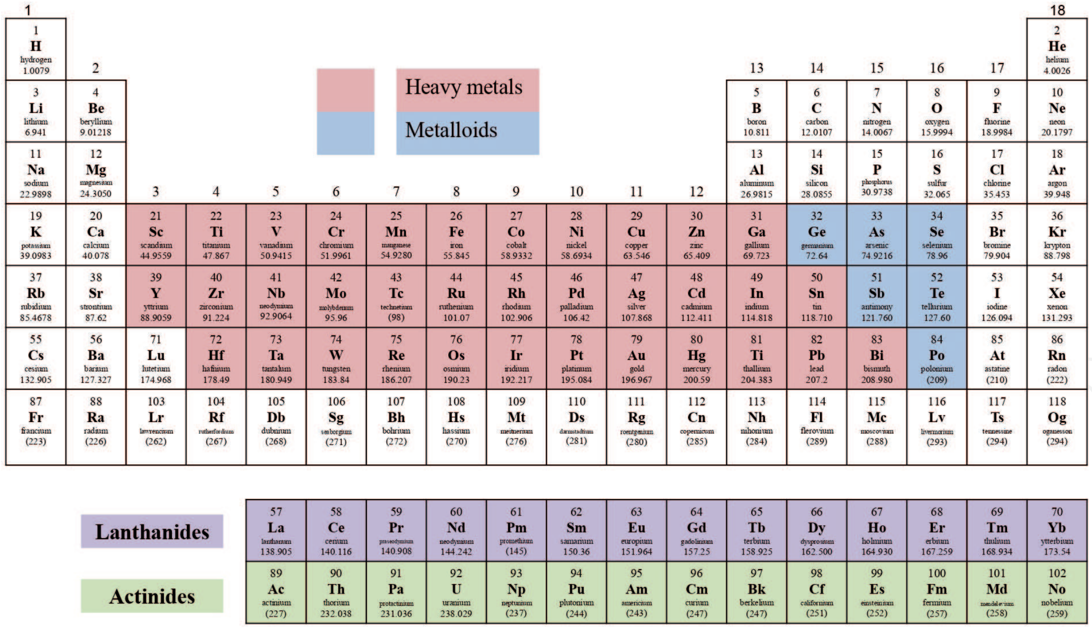

Figure 2.
Position of heavy metals in periodic table.

affect the environment. A serious problem with cultural, ecological and economic consequences is heavy metal contamination in the environment. Because of the toxicity, persistence, and bioaccumulative nature of these materials, research on heavy metals in the atmosphere is an important part of environmental research.

2.2 Sources of heavy metals

Heavy metals may come from natural and anthropogenic processes and end up in various environmental compartments (soil, water, air and their interface). **Figure 3** gives information on natural and anthropogenic sources of heavy metals.

2.2.1 Natural sources

Various natural sources of HMs have been recorded in several studies. Natural emissions of HMs occur under numerous and certain environmental conditions. Volcanic eruptions, sea-salt sprays, forest fires, rock weathering, biogenic sources and particles of wind-borne soil are included in these pollutants. The release of metals from their endemic spheres to different environmental compartments will lead to natural weathering processes. In the form of hydroxides, oxides, sulfides, sulfates, phosphates, silicates and organic compounds, heavy metals can be found.

Lead (Pb), nickel (Ni), chromium (Cr), cadmium (Cd), arsenic (As), mercury (Hg), selenium (Se), zinc (Zn) and copper (Cu) are the most popular heavy metals. While the above-mentioned heavy metals can be present in traces, humans and other mammals still cause significant health problems.

2.2.2 Anthropogenic sources

Industries, irrigation, drainage, mining and metallurgical processes, as well as runoff, also contribute to the release of pollutants into various compartments of the ecosystem. For certain metals, anthropogenic heavy metal processes have been noted to go beyond natural fluxes. In wind-blown dust, metals naturally released are mainly from industrial areas. Car exhaust that releases lead; smelting that releases arsenic, copper and zinc; insecticides that release arsenic and the burning

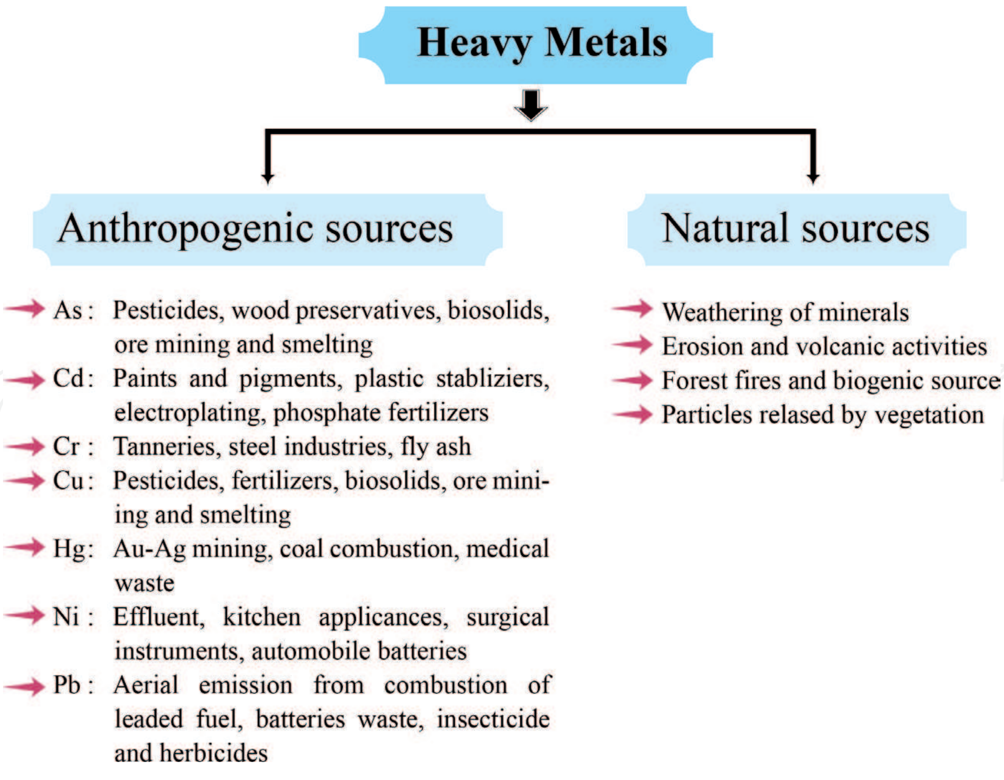

Figure 3.
Sources of heavy metals in the environment.

of fossil fuels that release nickel, vanadium, mercury, selenium and tin are some essential anthropogenic causes that contribute significantly to heavy metal pollution in the environment. Because of the everyday manufacture of products to meet the demands of the large population, human activities have been found to contribute more to environmental pollution.

3. Contamination of heavy metals

Harmful trace metals are a significant threat to both aquatic and terrestrial ecosystems [31]. Upon release from both natural and anthropogenic sources, HMs contaminates natural aquatic bodies, sediments and soils. Ultimately, during volcanic eruptions and complex industrial emissions, heavy metals released into the atmosphere often return to the soil and cause water and soil contamination. They either collect in biota or leach down into ground water because heavy metals in the atmosphere are irreversible. There are significant public health effects of the contamination of biota and groundwater with potentially harmful heavy metals. In riverine settings, the degree of heavy metal pollution can be measured by observing the concentrations and distribution of these elements [32]. **Figure 4** provides a conceptual schematic of the contamination of the marine (riverine) environment with heavy metals. Various physicochemical and climatic effects affect the overall dynamics and biogeochemical cycling of heavy metals in the atmosphere.

3.1 Water

Water is regarded as the life-blood of the biosphere as well. It can dissolve distinct organic and inorganic chemicals and environmental contaminants, as water is a common solvent. They are vulnerable to pollution in both freshwater and marine aquatic environments. Heavy metals are important contaminants in the pollution of

Figure 4.
A conceptual schematic of contamination of heavy metals in aquatic ecosystem.

the marine environment. Water contamination by HMs is a critical environmental issue that adversely affects plants, animals and human health [33]. Also at very low levels, heavy metals are highly harmful to marine species [34]. These elements may cause significant physiological changes in the body and histopathological changes in the tissues of aquatic organisms, such as fish [35]. There are several sources of heavy metal pollution in water. Two main culprits of this industrialization and urbanization are the increased degree of concentration of heavy metal in water. Heavy metals from factories, municipalities and urban areas are carried by runoff [36]. This release of untreated industrial waste into marine bodies is a significant cause of surface and groundwater contamination [37]. Due to the environmental persistence, bioaccumulation, and biomagnification of food chains and the toxicity of these elements, contamination of water bodies with heavy metals is a global issue [38].

3.2 Sediments

The contamination of sediments with HMs is a very important environmental problem with implications for marine life and human health. Sediments act as the main source of HMs in the aquatic environment. Their quality can indicate the contamination status of water [39]. Sediments act as a sink and heavy metal source, releasing them into the column of water [40]. Continued heavy metal accumulation in sediments can also contribute to groundwater pollution of these contaminants [41]. Many physicochemical variables such as temperature, hydrodynamic conditions, redox status, organic matter and microbe content, salinity, and particle size influence the adsorption, desorption, and subsequent concentrations of heavy metals in sediments [42]. The distribution of heavy metals in sediments is influenced by the sediment's chemical composition; grain size and total organic matter content [43]. The pH is an important determinant of the bioavailability of metals in sediments. A decrease in pH increases the competition between metal ions and H^+ for sediment binding locations and may contribute to the dissolution of metal complexes, thereby releasing free metal ions into the water column [44]. Higher toxic heavy metals concentrations in riverine sediments can pose an ecological risk to benthos (bottom-dwelling organisms) [45].

3.3 Soils

Heavy metals and metalloids are released into soils from activities and sources such as manufacturing activities, mine tailings, high metal waste disposal, leaded gasoline and paints, fertilizer land application, animal manures, sewage sludge, pesticides, irrigation of waste water, residues of coal combustion and petrochemical spillage, resulting in soil contamination by heavy metals [46]. Most HMs does not typically experience microbial or chemical degradation and thus, after being released to the atmosphere, their total concentrations last in the sail for a long time. The composition of the parent rock, the degree of weathering and physical, chemical and biological characteristics of soil and environment conditions are factors influencing the presence and distribution of heavy metals in soils [47]. Compared to virgin soils and soils with low inputs, substantial heavy metal enrichment has been recorded in soils receiving more fertilizer input and Cu fungicide [48]. Soils may be polluted with heavy metals from heavy vehicular activity on roads in urban areas. In urban areas, soil samples have elevated levels of Pb, of which 45–85% is bioaccessible [49]. The bioavailability of heavy metals in soils is of great importance for their environmental fate and for their plant uptake. Different HMs has different soil bioavailability and this bioavailability depends on the speciation of metals and the different soil physicochemical characteristics.

3.4 Fish

Aquatic biota is exposed to heavy metals by water, sediments and food on various routes [50]. Different toxic HMs released to freshwater bodies from various natural and anthropogenic sources are introduced to freshwater fish. Heavy metal pollution of fish has become a major global concern because it poses a danger to fish and poses health hazards to buyers of fish [51]. Assessment of the bioaccumulation of HMs in fish species from various aquatic ecosystems is very significant [52]. Assessing the amount of heavy metals in fish tissues is important for the conservation of marine environments and the human consumption of fish [53]. There are high levels of unsaturated fatty acids and low cholesterol levels in fish. They are a major protein source [54].

It is advantageous to use edible fish in human diets and is also recommended in healthy diets. Contamination of fish by toxic heavy metals is considered a risk to human health and has raised concerns about their consumption, especially among more vulnerable groups of people, such as women, children and people at risk of other diseases.

Heavy metal bioaccumulation in freshwater fish depends on different factors, including the characteristics of the fish and the external environmental factors. Fish-related factors include fish age, size (weight and length), feeding habits and physiology of the body, while external environmental factors include water column metal concentration and bioavailability, water physicochemical properties and other climatic factors. Depending on the structure and function of the tissues, the degree of accumulation of heavy metals in the various tissues of fish is usually different. Metabolically active tissues such as the gills, liver and kidneys typically have higher heavy metal accumulations than other tissues such as the skin and muscles. The comparatively higher accumulation of heavy metals in metabolically active fish tissues is normally explained by the induction/occurrence in these tissues of metal-binding proteins called metallothioneins (MTs) upon exposure to heavy metals. Fish gills have been observed as the target tissue for heavy metals such as Ni to accumulate and eliminate [38]. While fish muscles are the tissue of poor heavy metal accumulation [55], from a human consumption point of view, they are essential. Trace metal bioaccumulation in fish muscles is typically species-specific [56].

The bioaccumulation of toxic HMs in freshwater fish has significant environmental, ecological and social consequences; it affects the carnivorous species and human by eating fish [57, 58]. Waterborne HMs are absorbed into fish and penetrate the human body through the food chain, thereby impacting human health [59]. In addition, poisonous HMs affects the health and well-being of fish as well.

4. Trophic transfer of heavy metals

As HMs in the atmosphere is permanent, they accumulate in living organisms and are passed in the food chains from one trophic stage to another. The degree to which heavy metals are deposited in biota depends on their accumulation rate and their removal rate from the body.

Heavy metals, i.e. water, sediments and soil, may enter the body of an organism directly from the abiotic system, or may enter the body of the organism from its food/prey. For example, heavy metals may reach the body of the fish directly from water or sediments through the gills/skin of the fish or from the food/prey of the fish through its food canal. Over successive trophic levels in a food chain, the concentration of a heavy metal can increase or decrease. The retention of heavy metals in an organism's body depends on a variety of factors, such as the speciation of the metal concerned and the physiological mechanisms established by the organism for heavy metal control, homeostasis and detoxification. Because of their lipophilicity, methylated forms of heavy metals like Hg are accumulated to a greater extent in biota and also biomagnified in food chains. In metal-rich environments, such plants have the potential to survive and are called metallophytes. Special mechanisms for

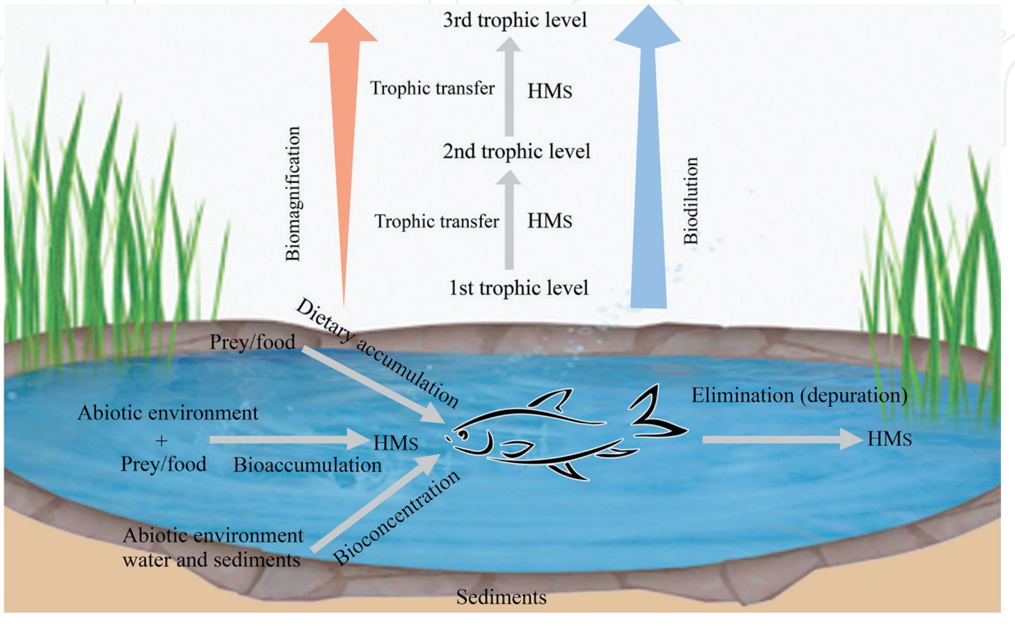

Figure 5.
Trophic transfer of heavy metals in the environment.

dealing with higher heavy metal concentrations in soil have been established by these special plants and are classified into three groups, i.e. excluders, markers, and hyper accumulators [57]. To define the trophic transfer of heavy metals, certain words are used (**Figure 5**).

5. Quantification of trophic transfer

The degree or extent of accumulation of HMs in biota has been quantified using some terminology. Bioconcentration factor (BCF), bioaccumulation factor (BAF), bioaccumulation coefficient (BAC) and so on are some of these quantitative terms. Below, some of these terms are discussed.

5.1 Bioconcentration factor (BCF)

Bioconcentration Factor is representative of the degree of heavy metal enrichment in an organism as opposed to that in its habitat. The ratio of the concentration of a heavy metal in the tissue of an organism to its concentration in the abiotic medium is known as' (water and sediments).

It is calculated by the following equation [60]:

$$BCF = \mathrm{C}_{\text{organism tissue}} / \mathrm{C}_{\text{abioitic medium}} \tag{1}$$

Where, C_{organism} is the metal concentration in the organism tissue and $C_{\text{abiotic medium}}$ is the metal concentration in the abiotic medium.

The alternative words transfer factor (TF), metal transfer factor (MTF), accumulation factor (AF), bioaccumulation factor (BAF), and biota sediment accumulation factor (BSAF) are used by some writers and measured accordingly. All these indexes, however, indicate the extent of a heavy metal's accumulation in the organism compared to that in the world where it grows/lives.

5.2 Bioaccumulation coefficient (BAC)

Bioaccumulation Coefficient is calculated by the following equation [61]:

$$BAC = \mathrm{C}_{\text{plant}} / \mathrm{C}_{\text{soil}} \tag{2}$$

Where, $\mathrm{C}_{\text{plant}}$ is the metal concentration in plant and C_{soil} is the metal concentration in soil.

The values of BCF, BAF, BAC, etc. are obviously dependent on the concentration of the HM in the organism and the environmental medium in question. In view of the fact that the values of these indices are inversely related to the concentration of metals in the environmental medium (water, sediments and soil), the values of these indices should be used with caution to measure the contamination of heavy metals in biota. For example, because of the lower metal content in the environment of the former fish, the BCF value of a heavy metal in the muscles of a fish living in less polluted water may be higher than that of a fish living in more contaminated water. The bio-concentration factor (BCF) values of seven common HMs in crop grains have been shown to decrease exponentially with average soil metal concentrations [62].

6. Effects of heavy metals in human health

A big source of exposure for the human population to heavy metals is food and drinking water. The intensification of HMs in industrial and agricultural activities has led to much industrialization, modern urbanization and rapid economic development around the world [63]. These activities can cause pollution of toxic HMs in water, air, and soils. Heavy metal-contaminated media contribute to the bioaccumulation of these elements from the environment in the human food chains, eventually reaching the human body. There are some health impacts of HMs on the human body depending on the amount and duration of exposure (**Figure 6**).

Among different HMs, Cd is considered as seventh most hazardous and noxious metal that causes an indirect oxidative stress and have carcinogenic and mutagenic effect resulting severe health problem in human body such as kidney damage, prostate dysfunction, bone diseases and cancer [64, 65]. It can also responsible for kidney dysfunction and proteinuria if Cd has prolonged exposure to kidneys.

Arsenic is also causes skin damage, cancer and marked problems with circulatory system [66]. When As cross its permissible limit in drinking water is also causes developmental abnormalities, neurobehavioral sicknesses, cardiovascular diseases and hearing sickness, together with anemia, leukopenia, eosinophilia and carcinoma [67, 68].

Chromium is known as highly toxic HM as it can cross the cell membrane via sulfate transport system and causes denaturation and mutation of nucleic acids and proteins. It also creates critical health issues like skin problems, nasal irritation, hear impairment and lung carcinoma [65, 69, 70].

Lead can also create different health problems like decrease in intelligent quotient, memory loss, infertility, mood swing, weakness of joints, nausea, insomnia, anorexia, or even death [65]. Young and infants are more sensitive to Pb poisoning than adults. Details about effects of different HMs on human health were described in **Table 1**.

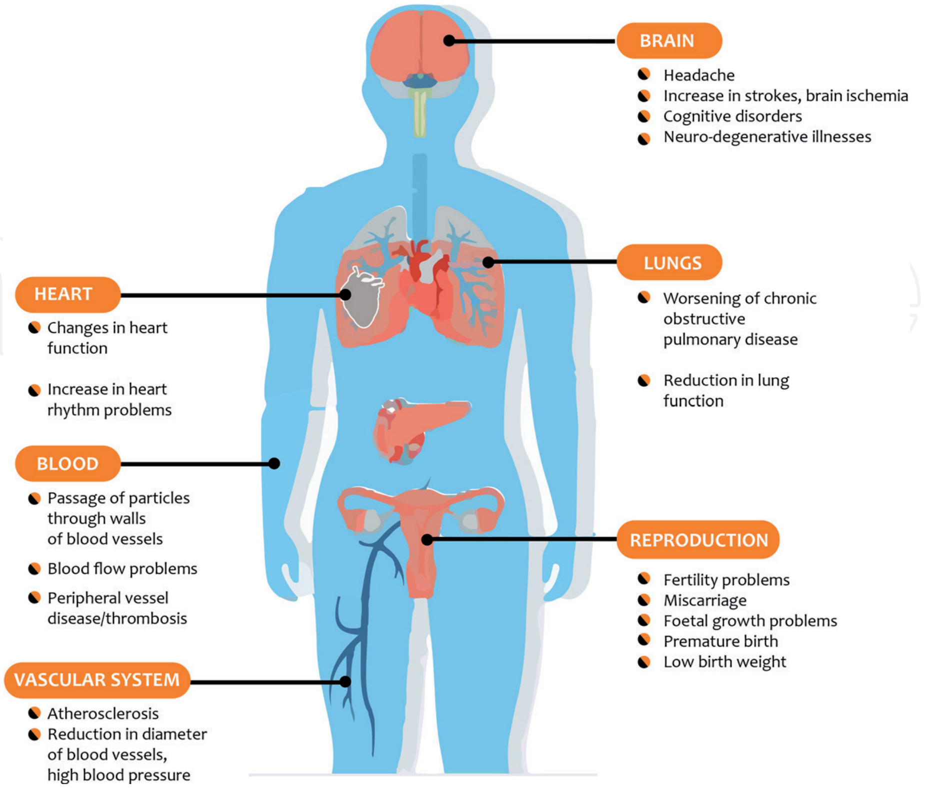

Figure 6.
Effects of heavy metals in different vital organs of human health.

Heavy metals	EPA regulatory limit for drinking water (ppm)	OSHA limit for workplace air (μg/m³)	Toxic Effects	References
Arsenic (As)	0.01	10.0	**Lower level exposure** Nausea and vomiting Decreased production of red and white blood cells Abnormal heart rhythm Damage to blood vessels A sensation of "pins and needles" in hands and feet also cause muscle damage **Long-term low level exposure** Darkening of the skin and the appearance of small "corns" or "warts" on the palms, soles and torso Diffuse or spotted hyper-pigmentation of the skin Benign skin lesions (hyperkeratosis) and cancer of the skin Liver disease reflected by abnormal porphyry metabolism Chronic inhalation can cause lung cancer Chronic exposure via water can cause cancer of internal organs, particularly the urinary bladder, lung, liver, and kidney **Others** Affects essential cellular processes such asoxidative phosphorylation and ATP synthesis	[28, 63, 71, 72]
Barium (Ba)	2.0	500	**Short term exposure** Gastrointestinal dysfunction (vomiting, abdominal cramps, diarrhea) Difficulties in breathing Increased or decreased blood pressure Numbness around the face and Muscle weakness **High level exposure** High blood pressure Changes in heart rhythm and cardiac arrhythmias Muscle twitching Paralysis Respiratory failure and Possibly death	[63, 73, 74]
Cadmium (Cd)	5.0	5.0	**High level exposure to cadmium fumes** Cause acute bronchitis or even chronic disease, such as emphysema or pulmonary fibrosis and lung cancer Severe irritation in the stomach, leading to vomiting and diarrhea **Long-term low level exposure** Buildup kidney disease, lung damage, and fragile bones **Chronic exposure** Kidney tubular dysfunction Osteoporosis (elderly women with iron deficiency) Lung cancer (only in chronic inhalation) **Others** Carcinogenic Mutagenic Endocrine disruptor Fragile bones Affects calcium regulation in biological systems	[75–81]

Heavy metals	EPA regulatory limit for drinking water (ppm)	OSHA limit for workplace air (μg/m^3)	Toxic Effects	References
Chromium (Cr)	0.1	0.5 to 1000	**Breathing high levels** Irritation to the lining of the nose Nose ulcers and runny nose Breathing problems, such as asthma, cough, shortness of breath, or wheezing **Skin contact can cause** Skin ulcers Allergic reactions consisting of severe redness and swelling of the skin Hair loss **Long term exposure** Damage to liver, kidney circulatory and nerve tissues Skin irritation	[73, 75]
Silver (Ag)	0.10	10.0	**Long-term high level exposure** Arygria, a blue-gray discoloration of the skin and other body tissues Mild allergic reactions such as rash, swelling, and inflammation in some people Breathing problems Lung and throat irritation and Stomach pains	[73, 82]
Mercury (Hg)	2.0	100 for organic Hg 50 for metallic Hg	**Effect on brain** Brain damage Tremor Temper outbursts Loss of memory Disturbance of vision Psychiatric disturbances Restlessness Depression Altered behavior **Renal toxicity of mercury** Glomerulnephritis Kidney failure **Effect on unborn fetus** Paresthesia Blindness Deafness Fetal death and abortion **High level Exposure** Damage the brain resulting irritability, shyness, tremors, changes in vision or hearing, and memory problems Damage kidneys and Developing fetuses **Short-term high levels exposure** Lung damage Gastrointestinal dysfunction (nausea, vomiting, diarrhea) Increases in blood pressure or heart rate Skin rashes and Eye irritation **Others** Autoimmune diseases Drowsiness Fatigue Hair loss Insomnia Lung failure	[28, 83–87]

Heavy metals	**EPA regulatory limit for drinking water (ppm)**	**OSHA limit for workplace air (μg/m^3)**	**Toxic Effects**	**References**
Lead (Pb)	15	50	**High level exposure to Pb** Severely damage the brain and kidneys Miscarriage in pregnant women Damage the organs responsible for sperm production In children causes impaired development, reduced intelligence, short-term memory loss, disabilities in learning and coordination problems, risk of cardiovascular disease Finally death **Chronic high level exposure** Produce anemia Effects in central nervous system, including impaired motor function and cognitive function and even seizures, coma, and death with markedly elevated blood lead levels Impaired heme synthesis Chronic kidney disease Lethargy Impairment of cognitive function Lead produces tumors in experimental animals, but there is not enough evidence to regard lead as a human carcinogen	[75, 88–92]
Selenium (Se)	15	200	**Short-term high level exposure** Nausea Vomiting and Diarrhea **Chronic high level exposure** Produce selenosis; major signs of selenosis are hair loss, nail brittleness, and neurological abnormalities Respiratory irritation Bronchitis Difficulty breathing Coughing Stomach pains **Others:** Dietary exposure of around 300 μg/day affects endocrine function Impairment of natural killer cells activity Hepatotoxicity	[63, 93]
Copper (Cu)	1.3		Brain and kidney damage Liver cirrhosis Chronic anemia Stomach and intestine irritation	[63, 75, 88]
Nickel (Ni)	0.2		Allergic skin diseases such as itching Cancer of the lungs, nose, sinuses, throat through continuous inhalation Immunotoxic, neurotoxic, genotoxic effect Affects fertility Hair loss	[75, 94, 95]
Zinc (Zn)	0.5		Dizziness Fatigue	[63, 96]

Environmental Protection Agency (EPA), Parts Per Million (ppm), Occupational Safety and Health Administration (OSHA).

Table 1.
Toxic effects of heavy metals on human health.

7. Conclusions

Heavy metals and metalloids are critical environmental contaminants for both marine and terrestrial environments and ecosystem. The danger of an environmental chemical is a function of its persistence, toxicity and bioaccumulative ability in the environment. Due to these three characteristics: persistence, bioaccumulation, and toxicity; HMs are considered as harmful. The most dangerous heavy metals and metalloids that are environmentally important include Cr, As, Cd, Pb, Hg, Ni, Cu and Zn. In aquatic and terrestrial food chains, the trophic transition of these elements has major consequences for different lives of ecosystem and human health. So contamination of environment of heavy metals is of great concern, and its treatment from the soil and water around industrial areas is needed urgently in every place. The assessment and monitoring of the concentrations of potentially toxic heavy metals and metalloids in the various environmental segments and in the resident biota is very significant. A detailed environmental chemistry and ecotoxicology analysis of dangerous heavy metals and metalloids demonstrates that steps should be taken to mitigate the effects on human health and the environment of these elements.

Author details

Mir Mohammad Ali[1], Delower Hossain[2*], Al-Imran[3], Md. Suzan Khan[4], Maksuda Begum[5] and Mahadi Hasan Osman[4]

1 Department of Aquaculture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

2 Department of Medicine and Public Health, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

3 Rural Microenterprise Transformation Project, Palli Karma-Sahayak Foundation, Dhaka, Bangladesh

4 Fisheries and Livestock Unit, Palli Karma-Sahayak Foundation, Dhaka, Bangladesh

5 Department of Poultry Science, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

*Address all correspondence to: delowervet@gmail.com; delowervet@sau.edu.bd

References

[1] Zhu G, Noman MA, Narale DD, Feng W, Pujari L, Sun J. Evaluation of ecosystem health and potential human health hazards in the Hangzhou Bay and Qiantang Estuary region through multiple assessment approaches. Environmental Pollution 2020;114791.

[2] Nour HE, El-Sorogy AS, Abd El-Wahab M, Mohamaden M, Al-Kahtany K. Contamination and ecological risk assessment of heavy metals pollution from the Shalateen coastal sediments, Red Sea, Egypt. Marine pollution bulletin 2019;144:167-72.

[3] Liu P, Hu W, Tian K, Huang B, Zhao Y, Wang X, et al. Accumulation and ecological risk of heavy metals in soils along the coastal areas of the Bohai Sea and the Yellow Sea: A comparative study of China and South Korea. Environment International 2020;137:105519.

[4] Kahal A, El-Sorogy AS, Qaysi S, Almadani S, Kassem OM, Al-Dossari A. Contamination and ecological risk assessment of the Red Sea coastal sediments, southwest Saudi Arabia. Marine Pollution Bulletin 2020;154:111125.

[5] Khan MB, Dai X, Ni Q, Zhang C, Cui X, Lu M, et al. Toxic Metal Pollution and Ecological Risk Assessment in Sediments of Water Reservoirs in Southeast China. Soil and Sediment Contamination: An International Journal 2019;28:695-715.

[6] Ustaoğlu F, Islam MS. Potential toxic elements in sediment of some rivers at Giresun, Northeast Turkey: A preliminary assessment for ecotoxicological status and health risk. Ecological Indicators 2020;113:106237.

[7] Zhang C, Shan B, Tang W, Wang C, Zhang L. Identifying sediment-associated toxicity in rivers affected by multiple pollutants from the contaminant bioavailability. Ecotoxicology and Environmental Safety 2019;171:84-91.

[8] Omwene PI, Öncel MS, Çelen M, Kobya M. Heavy metal pollution and spatial distribution in surface sediments of Mustafakemalpaşa stream located in the world's largest borate basin (Turkey). Chemosphere 2018;208:782-92.

[9] Lian M, Wang J, Sun L, Xu Z, Tang J, Yan J, et al. Profiles and potential health risks of heavy metals in soil and crops from the watershed of Xi River in Northeast China. Ecotoxicology and environmental safety 2019;169:442-8.

[10] Weber AA, Sales CF, de Souza Faria F, Melo RMC, Bazzoli N, Rizzo E. Effects of metal contamination on liver in two fish species from a highly impacted neotropical river: A case study of the Fundão dam, Brazil. Ecotoxicology and Environmental Safety 2020;190:110165.

[11] Ali MM, Ali ML, Proshad R, Islam S, Rahman Z, Tusher TR, et al. Heavy metal concentrations in commercially valuable fishes with health hazard inference from Karnaphuli river, Bangladesh. Human and ecological risk assessment: an international journal 2020;26:2646-62.

[12] Wang Z, Zhou J, Zhang C, Qu L, Mei K, Dahlgren RA, et al. A comprehensive risk assessment of metals in riverine surface sediments across the rural-urban interface of a rapidly developing watershed. Environmental Pollution 2019;245:1022-30.

[13] Yang QQ, Wang SL, Liu WJ, Yang YW, Jiang SQ. Spatial distribution of perfluoroalkyl acids (PFAAs) and

their precursors and conversion of precursors in seawater deeply affected by a city in China. Ecotoxicology and Environmental Safety 2020;194: 110404.

[14] Ding L, Zhao K, Zhang L, Liang P, Wu S, Wong MH, et al. Distribution and speciation of mercury affected by humic acid in mariculture sites at the Pearl River estuary. Environmental Pollution 2018;240:623-9.

[15] Kinimo KC, Yao KM, Marcotte S, Trokourey A. Distribution trends and ecological risks of arsenic and trace metals in wetland sediments around gold mining activities in central-southern and southeastern Côte d'Ivoire. Journal of Geochemical Exploration 2018;190:265-80.

[16] Lee P-K, Yu S, Jeong Y-J, Seo J, Choi S, Yoon B-Y. Source identification of arsenic contamination in agricultural soils surrounding a closed Cu smelter, South Korea. Chemosphere 2019;217:183-94.

[17] Varol M, Canpolat Ö, Eriş KK, Çağlar M. Trace metals in core sediments from a deep lake in eastern Turkey: Vertical concentration profiles, eco-environmental risks and possible sources. Ecotoxicology and Environmental Safety 2020;189: 110060.

[18] Timofeev I, Kosheleva N, Kasimov N. Contamination of soils by potentially toxic elements in the impact zone of tungsten-molybdenum ore mine in the Baikal region: A survey and risk assessment. Science of the total environment 2018;642:63-76.

[19] Simpson SL, Spadaro DA. Bioavailability and chronic toxicity of metal sulfide minerals to benthic marine invertebrates: implications for deep sea exploration, mining and tailings disposal. Environmental science & technology 2016;50:4061-70.

[20] Singh UK, Kumar B. Pathways of heavy metals contamination and associated human health risk in Ajay River basin, India. Chemosphere 2017;174:183-99.

[21] Nour HE, El-Sorogy AS. Distribution and enrichment of heavy metals in Sabratha coastal sediments, Mediterranean Sea, Libya. Journal of African Earth Sciences 2017;134: 222-9.

[22] Bhuyan MS, Bakar MA, Akhtar A, Hossain MB, Ali MM, Islam MS. Heavy metal contamination in surface water and sediment of the Meghna River, Bangladesh. Environmental nanotechnology, monitoring & management 2017;8:273-9.

[23] El-Sorogy A, Al-Kahtany K, Youssef M, Al-Kahtany F, Al-Malky M. Distribution and metal contamination in the coastal sediments of Dammam Al-Jubail area, Arabian Gulf, Saudi Arabia. Marine pollution bulletin 2018;128:8-16.

[24] Tian K, Huang B, Xing Z, Hu W. Geochemical baseline establishment and ecological risk evaluation of heavy metals in greenhouse soils from Dongtai, China. Ecological Indicators 2017;72:510-20.

[25] Lee P-K, Kang M-J, Yu S, Ko K-S, Ha K, Shin S-C, et al. Enrichment and geochemical mobility of heavy metals in bottom sediment of the Hoedong reservoir, Korea and their source apportionment. Chemosphere 2017;184:74-85.

[26] Duffus JH. " Heavy metals" a meaningless term?(IUPAC Technical Report). Pure and applied chemistry 2002;74:793-807.

[27] Liu R, Bao K, Yao S, Yang F, Wang X. Ecological risk assessment and distribution of potentially harmful trace elements in lake sediments of Songnen

Plain, NE China. Ecotoxicology and environmental safety 2018;163:117-24.

[28] Duruibe JO, Ogwuegbu MOC, Egwurugwu JN. Heavy metal pollution and human biotoxic effects. International Journal of physical sciences 2007;2:112-8.

[29] Hoodaji M, Ataabadi M, Najafi P. Biomonitoring of airborne heavy metal contamination. Air Pollut.–Monit., Model., Health Control 2012;21.

[30] Ali H, Khan E. What are heavy metals? Long-standing controversy over the scientific use of the term 'heavy metals'–proposal of a comprehensive definition. Toxicological & Environmental Chemistry 2018;100:6-19.

[31] Slaveykova VI, Cheloni G. Preface: special issue on environmental toxicology of trace metals. 2018;

[32] Islam MS, Proshad R, Ahmed S. Ecological risk of heavy metals in sediment of an urban river in Bangladesh. Human and ecological risk assessment: an international journal 2018;24:699-720.

[33] Rezania S, Taib SM, Din MFM, Dahalan FA, Kamyab H. Comprehensive review on phytotechnology: heavy metals removal by diverse aquatic plants species from wastewater. Journal of hazardous materials 2016;318:587-99.

[34] ABRAR M, HUSSAIN Z, AKIF M, SOK K, Muhammad A, KHAN AR, et al. Textile effluents and their contribution towards aquatic pollution in the Kabul River (Pakistan). Journal of the Chemical Society of Pakistan 2011;24:106.

[35] Ahmed MK, Parvin E, Islam MM, Akter MS, Khan S, Al-Mamun MH. Lead-and cadmium-induced histopathological changes in gill, kidney and liver tissue of freshwater climbing perch *Anabas testudineus* (Bloch, 1792). Chemistry and Ecology 2014;30:532-40.

[36] Zhuang P, Li Z, McBride MB, Zou B, Wang G. Health risk assessment for consumption of fish originating from ponds near Dabaoshan mine, South China. Environmental Science and Pollution Research 2013;20:5844-54.

[37] Afzal MS, Ashraf A, Nabeel M. Characterization of industrial effluents and groundwater of Hattar industrial estate, Haripur. Advances in Agriculture and Environmental Science: Open Access (AAEOA) 2018;1:70-7.

[38] Rajaei G, Mansouri B, Jahantigh H, Hamidian AH. Metal concentrations in the water of Chah nimeh reservoirs in Zabol, Iran. Bulletin of environmental contamination and toxicology 2012;89:495-500.

[39] Zahra A, Hashmi MZ, Malik RN, Ahmed Z. Enrichment and geo-accumulation of heavy metals and risk assessment of sediments of the Kurang Nallah—feeding tributary of the Rawal Lake Reservoir, Pakistan. Science of the Total Environment 2014;470:925-33.

[40] Fernandes LL, Nayak GN. Heavy metals contamination in mudflat and mangrove sediments (Mumbai, India). Chemistry and Ecology 2012;28:435-55.

[41] Sanyal T, Kaviraj A, Saha S. Deposition of chromium in aquatic ecosystem from effluents of handloom textile industries in Ranaghat–Fulia region of West Bengal, India. Journal of advanced research 2015;6:995-1002.

[42] Zhao S, Shi X, Li C, Zhang H, Wu Y. Seasonal variation of heavy metals in sediment of Lake Ulansuhai, China. Chemistry and Ecology 2014;30:1-14.

[43] Ali Azadi N, Mansouri B, Spada L, Sinkakarimi MH, Hamesadeghi Y, Mansouri A. Contamination of lead (Pb) in the coastal sediments of north

and south of Iran: a review study. Chemistry and Ecology 2018;34:884-900.

[44] Nowrouzi M, Mansouri B, Nabizadeh S, Pourkhabbaz A. Analysis of heavy metals concentration in water and sediment in the Hara biosphere reserve, southern Iran. Toxicology and industrial health 2014;30:64-72.

[45] Pacle Decena SC, Sanita Arguelles M, Liporada Robel L. Assessing Heavy Metal Contamination in Surface Sediments in an Urban River in the Philippines. Polish Journal of Environmental Studies 2018;27.

[46] Alloway BJ. Sources of heavy metals and metalloids in soils. In: Heavy metals in soils. Springer; 2013. page 11-50.

[47] Arunakumara K, Walpola BC, Yoon M-H. Current status of heavy metal contamination in Asia's rice lands. Reviews in Environmental Science and Bio/Technology 2013;12:355-77.

[48] Semu E, Singh BR. Accumulation of heavy metals in soils and plants after long-term use of fertilizers and fungicides in Tanzania. Fertilizer research 1995;44:241-8.

[49] Mackay AK, Taylor MP, Munksgaard NC, Hudson-Edwards KA, Burn-Nunes L. Identification of environmental lead sources and pathways in a mining and smelting town: Mount Isa, Australia. Environmental Pollution 2013;180:304-11.

[50] Youssef DH, Tayel FT. Metal accumulation by three Tilapia spp. from some Egyptian inland waters. Chemistry and Ecology 2004; 20:61-71.

[51] Rahman MS, Molla AH, Saha N, Rahman A. Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi River, Savar, Dhaka, Bangladesh. Food chemistry 2012;134:1847-54.

[52] Yousafzai AM, Ullah F, Bari F, Raziq S, Riaz M, Khan K, et al. Bioaccumulation of some heavy metals: analysis and comparison of *Cyprinus carpio* and *Labeo rohita* from Sardaryab, Khyber Pakhtunkhwa. BioMed Research International 2017;2017.

[53] Ariyaee M, Azadi NA, Majnoni F, Mansouri B. Comparison of metal concentrations in the organs of two fish species from the Zabol Chahnimeh Reservoirs, Iran. Bulletin of environmental contamination and toxicology 2015;94:715-21.

[54] Malakootian M, Mortazavi MS, Ahmadi A. Heavy metals bioaccumulation in fish of southern Iran and risk assessment of fish consumption. 2016;

[55] Khaled A. Trace metals in fish of economic interest from the west of Alexandria, Egypt. Chemistry and Ecology 2009;25:229-46.

[56] Kumar B, Senthil Kumar K, Priya M, Mukhopadhyay D, Shah R. Distribution, partitioning, bioaccumulation of trace elements in water, sediment and fish from sewage fed fish ponds in eastern Kolkata, India. Toxicological & Environ Chemistry 2010;92:243-60.

[57] Ali H, Khan E. Assessment of potentially toxic heavy metals and health risk in water, sediments, and different fish species of River Kabul, Pakistan. Human and Ecological Risk Assessment: An International Journal 2018;24:2101-18.

[58] Ali H, Khan E. Trophic transfer, bioaccumulation, and biomagnification of non-essential hazardous heavy metals and metalloids in food chains/webs—Concepts and implications for wildlife and human health. Human and

Ecological Risk Assessment: An International Journal 2019;25:1353-76.

[59] Dwivedi AC, Tiwari A, Mayank P. Seasonal determination of heavy metals in muscle, gill and liver tissues of Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) from the tributary of the Ganga River, India. Zoology and Ecology 2015;25:166-71.

[60] Ali H, Khan E. Environmental chemistry in the twenty-first century. Environmental Chemistry Letters 2017;15:329-46.

[61] Liang S, Gao N, Li Z, Shen S, Li J. Investigation of correlativity between heavy metals concentration in indigenous plants and combined pollution soils. Chemistry and Ecology 2016;32:872-83.

[62] Wang S, Wu W, Liu F, Liao R, Hu Y. Accumulation of heavy metals in soil-crop systems: a review for wheat and corn. Environmental Science and Pollution Research 2017;24: 15209-25.

[63] Dixit R, Malaviya D, Pandiyan K, Singh UB, Sahu A, Shukla R, et al. Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. Sustainability 2015;7:2189-212.

[64] Adamis PDB, Panek AD, Leite SGF, Eleutherio ECA. Factors involved with cadmium absorption by a wild-type strain of *Saccharomyces cerevisiae*. Brazilian Journal of Microbiology 2003;34:55-60.

[65] Mishra S, Bharagava RN, More N, Yadav A, Zainith S, Mani S, et al. Heavy metal contamination: an alarming threat to environment and human health. In: Environmental biotechnology: For sustainable future. Springer; 2019. page 103-25.

[66] Scragg A. Environmental biotechnology. 2nd editio. Oxford: Oxford University Press; 2006.

[67] Tchounwou PB, Centeno JA, Patlolla AK. Arsenic toxicity, mutagenesis, and carcinogenesis–a health risk assessment and management approach. Molecular and cellular biochemistry 2004;255:47-55.

[68] Centeno JA, Tchounwou PB, Patlolla AK, Mullick FG, Murakata L, Meza E, et al. Environmental pathology and health effects of arsenic poisoning. Managing Arsenic in the Environment: From Soil to Human Health 2006;311-27.

[69] Stern BR. Essentiality and toxicity in copper health risk assessment: overview, update and regulatory considerations. Journal of Toxicology and Environmental Health, Part A 2010;73:114-27.

[70] Mishra S, Bharagava RN. Toxic and genotoxic effects of hexavalent chromium in environment and its bioremediation strategies. Journal of Environmental Science and Health, Part C 2016;34:1-32.

[71] Tripathi RD, Srivastava S, Mishra S, Singh N, Tuli R, Gupta DK, et al. Arsenic hazards: strategies for tolerance and remediation by plants. Trends in biotechnology 2007;25:158-65.

[72] NAS (National Academy of Sciences/National Research Council). Arsenic in drinking water. National Research Council, Washington, DC 1999;

[73] Martin S, Griswold W. Human health effects of heavy metals. Environmental Science and Technology briefs for citizens 2009;15:1-6.

[74] Jacobs IA, Taddeo J, Kelly K, Valenziano C. Poisoning as a result of barium styphnate explosion. American

journal of industrial medicine 2002;41:285-8.

[75] Salem HM, Eweida EA, Farag A. Heavy metals in drinking water and their environmental impact on human health. ICEHM2000, Cairo University, Egypt 2000;542-56.

[76] Sobha K, Poornima A, Harini P, Veeraiah K. A study on biochemical changes in the fresh water fish, *Catla catla* (Hamilton) exposed to the heavy metal toxicant cadmium chloride. Kathmandu University Journal of Science, Engineering and Technology 2007;3:1-11.

[77] Davison AG, Taylor AJN, Darbyshire J, Chettle DR, Guthrie CJG, O'Malley D, et al. Cadmium fume inhalation and emphysema. The Lancet 1988;331:663-7.

[78] Järup L, Berglund M, Elinder CG, Nordberg G, Vanter M. Health effects of cadmium exposure–a review of the literature and a risk estimate. Scandinavian journal of work, environment & health 1998;1-51.

[79] Goyer R. Issue paper on the human health effects of metals. US Environmental Protection Agency; 2004.

[80] Lalor GC. Review of cadmium transfers from soil to humans and its health effects in the Jamaican environment. Science of the total environment 2008;400:162-72.

[81] Liu J, Goyer RA, Waalkes MP. Toxic effects of metals. Casarett and Doull's Toxicology: The Basic Science of Poisons, seventh edition (CD Klaasen, Editor). McGraw-Hill Medical, New York, NY, USA 2008;931-79.

[82] ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological Profile for Silver. U.S. Department of Health and Human Services, Public Health Service: Atlanta, GA, USA 1990;

[83] Neustadt J, Pieczenik S. Patient Handout: Toxic Metal Contamination: Mercury. Integrative Medicine-Innovision Communications 2007;6:36.

[84] Ainza C, Trevors J, Saier M. Environmental mercury rising. Water, Air, and Soil Pollution 2010;205:47-8.

[85] Gulati K, Banerjee B, Lall SB, Ray A. Effects of diesel exhaust, heavy metals and pesticides on various organ systems: Possible mechanisms and strategies for prevention and treatment. 2010;

[86] NAS (National Academy of Sciences/National Research Council). Toxicological Effects of methyl mercury. National Research Council, Washington, DC 2000;

[87] ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological profile for Mercury. U.S. Department of Health and Human Services, Public Health Service: Atlanta, GA, USA 1999;

[88] Wuana RA, Okieimen FE. Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. Isrn Ecology 2011;2011.

[89] Padmavathiamma PK, Li LY. Phytoremediation technology: hyper-accumulation metals in plants. Water, Air, and Soil Pollution 2007; 184:105-26.

[90] Odum HT. Background of Published Studies on Lead and Wetlands. In: Heavy Metals in the Environment. CRC Press; 2016. page 34-53.

[91] ATSDR (Agency for Toxic Substances and Disease Registry). Multiple lead and cadmium exposure study with biological markers incorporated. U.S. Department of

Health and Human Services, Public Health Service: Atlanta, GA, USA 1995;

[92] IPCS, (International Programme on Chemical Safety WHO. Inorganic lead. Environmental Health Criteria Document No. 165. World Health Organization 1995;152-92.

[93] Vinceti M, Wei ET, Malagoli C, Bergomi M, Vivoli G. Adverse health effects of selenium in humans. Reviews on environmental health 2001;16:233-52.

[94] Duda-Chodak A, Blaszczyk U. The impact of nickel on human health. Journal of Elementology 2008;13: 685-93.

[95] Khan MA, Ahmad I, Rahman IU. Effect of environmental pollution on heavy metals content of *Withania somnifera*. Journal of the Chinese Chemical Society 2007;54:339-43.

[96] Hess R, Schmid B. Zinc supplement overdose can have toxic effects. J. Paediatr. Haematol./Oncol 2002;24:582-4.