

HEAVY METALS: ENVIRONMENTAL POLLUTION AND IMPACT ON HUMAN HEALTH

Abstract

The industries that produce batteries, metal plating, chemical synthesis, catalysis, fertilizer, paint, paper, and mining are responsible for the presence of heavy metals in aquatic systems and the atmosphere. Industrial releases and human activity both contribute to the soil's contamination with heavy metals. They are absorbed by the body through vegetables and plants. In humans, heavy metals can lead to a variety of acute and chronic illnesses. Fish and other aquatic species that consume heavy metals have an impact on aquatic life, as well as humans who eat them.

Heavy metals are widely recognized as environmental contaminants due to their toxicity, long-lasting presence in the environment, and ability to accumulate in living organisms. They have both natural sources, such as the weathering of metal-rich rocks and volcanic eruptions, and human-induced sources, including mining and various industrial and agricultural activities. Mineral resource extraction, exploitation, and further processing for commercial, industrial, and agricultural reasons have increased the amount of these elements released into the environment, upsetting their normal biogeochemical cycles. Toxic heavy metal pollution of terrestrial and aquatic ecosystems is a serious environmental and public health risk. These persistent pollutants pose a health concern to consumers, including humans, since they build up in the environment and pollute food systems.

This page provides a thorough analysis of the many dangerous properties of heavy metals, emphasizing their toxicity to living things, ability to accumulate in the environment, and persistence in the environment. The bioaccumulation of these substances and its effects on human health are also discussed, with a focus on fish, rice, and tobacco. Researchers in the environmental sciences as well as graduate and undergraduate

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students will find the article to be a useful educational resource. Lead (Pb), mercury (Hg), arsenic (As), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), chromium (Cr), and zinc (Ni) are notable toxic heavy metals and metalloids that are relevant to the environment. These elements have important effects on animal and human health when they move through terrestrial and marine food chains and webs. The amounts of potentially hazardous heavy metals and metalloids in different environmental compartments and resident biota must be evaluated and tracked. An in-depth analysis of these dangerous substances' environmental chemistry and ecotoxicology highlights the necessity of taking action to lessen their negative effects on the environment and human health.

Keywords: Heavy metals, metalloids, ecotoxicology, bioaccumulation, environment, anthropogenic sources, biogeochemical cycles.

I. INTRODUCTION

Heavy metals are chemical elements known for their toxicity even at relatively low concentrations, with some being classified as carcinogenic. These elements are typically characterized by their higher atomic mass, density, or atomic number. Common examples of heavy metals include lead (Pb), thallium (Tl), chromium (Cr), arsenic (As), cadmium (Cd), mercury (Hg), among others. When heavy metals are released into the ecosystem, it leads to a form of pollution referred to as heavy metal pollution. Heavy metals, as environmental contaminants, exhibit inherent toxicity, persistence, and the ability to accumulate within ecosystems.

The sources of heavy metal pollution encompass both natural and anthropogenic factors. Natural sources include events like volcanic eruptions and the natural weathering of rocks and soil. Anthropogenic sources, on the other hand, arise from human activities, such as those within the pharmaceutical, industrial, agricultural, and mining sectors. Additionally, domestic effluents also contribute significantly to heavy metal pollution.

Metallic elements with a relatively high density and toxicity, even at low concentrations, are referred to as "heavy metals" (2). This is a general phrase that includes metals and metalloids that have atomic densities greater than 4 g/cm³, which is greater than five times the density of water (2). At first glance, it can seem simple to define "heavy metals" as metals having a high specific weight. However, for plants and other living things, this physical characteristic is not very important. The main factor influencing a substance's classification as a heavy metal is its chemical makeup. Lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), chromium (Cr), copper (Cu), iron (Fe), and members of the platinum group are a few examples of heavy metals.

The term "environment" pertains to the complete set of circumstances surrounding an organism or group of organisms, encompassing external physical conditions that impact growth, development, and survival (3,4). This concept encompasses the biotic and abiotic components, spanning aquatic, terrestrial, and atmospheric habitats. The environment encompasses tangible elements like air, water, and food, as well as less tangible aspects such as the communities we inhabit.

Any chemical that has an unfavorable effect on the environment, lowers quality of life, jeopardizes environmental well-being, or even poses a risk of harm or death, is considered a "pollutant". It is necessary for a pollutant to surpass a specified tolerance limit, which may be acceptable or desired. Therefore, the term "environmental pollution" describes the existence of contaminants in the air, water, and soil that may be hazardous or poisonous and affect living things in the contaminated areas (5,6).

Substantial quantities of diverse heavy metals, regardless of their origin, can lead to soil degradation and a decline in crop yields, ultimately resulting in the production of low-quality agricultural goods. These effects pose significant health risks. Gilbert and Weiss (2006) (7) observed that "heavy metals tend to accumulate persistently in various environments, including soil and water, due to their non-biodegradable nature and resistance to natural decomposition." Bioconcentration is the process by which heavy metals are absorbed from the environment into organisms, representing a crucial stage in the contamination of the food chain. When bioconcentration and biomagnification levels surpass

what is considered tolerable, they become a substantial source of health concerns (8). Both natural processes and human activity contribute to the accumulation of heavy metals within the food web (9). Thus, this review's goal is to give a succinct yet insightful summary of environmental heavy metal pollution and how it affects different kinds of life. For environmental scientists and medical professionals dedicated to advancing environmental sustainability and improving public health, the study's findings are probably going to be a useful resource.

1. Three groups of Heavy Metals: The periodic table prominently includes a significant proportion of heavy metals characterized by their elevated density and atomic weight. Many of these heavy metals are abundantly present in the biosphere, including water, soils, and rocks. They are also introduced into the environment through anthropogenic sources, primarily originating from commercial and industrial activities. As previously demonstrated, it is impossible to forecast the toxicity of heavy metals or their compounds in plant systems based on their physical or chemical characteristics. Since the phrase "heavy metal" is frequently used in the field of plant sciences and is difficult to avoid, we propose defining it using the following elemental groups from the periodic table:

- All transition elements, except La and Ac (=Transition metals).
- Rare earth elements are classified into two groups: the actinide series, which includes La and Ac, and the lanthanide series, which includes the elements themselves.
- A heterogenous group of elements including the metal Bi, the amphoteric oxides forming elements Al, Ga, In, Tl, Sn, Pb, Sb and Po, and the metalloids Ge, As and Te.

Since there isn't a common term for these metal/metalloid p-element members, we propose classifying them as "lead-group elements." Since lead has been studied the most in toxicology, lead may be considered the representative of this third class of heavy metals.

Ia										VIIIa										
1	IIa										2									
H											He									
3	4											5	6	7	8	9	10			
Li	Be											B	C	N	O	F	Ne			
11	12											13	14	15	16	17	18			
Na	Mg	IIIb	IVb	Vb	VIIb	VIIIb					IIb	IIIb	Al	Si	P	S	Cl	Ar		
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr			
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54			
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe			
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86			
Cs	Ba	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
87	88	89	104	105	106	107	108	109	110	111	112	113	114	115	116					
Fr	Ra	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg											

Lanthanides:	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Actinides:	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Figure 1: The Periodic Table's elements. The category "heavy metal" includes both metal and some framed metalloids. The elements classified as "heavy metals" are the elements in the lead group on the right side of the table from the three forming subgroups, the rare earth elements (lanthanide and actinide series at the bottom), and the block of transition elements in the middle.

II. SOURCES OF HEAVY METAL POLLUTION

The numerous origins of heavy metals worldwide have been categorized into two groups: natural sources and human-made sources, which are also referred to as anthropogenic sources. Mining and smelting activities have significantly impacted substantial portions of the human environment. To gain a deeper insight into the critical concerns related to heavy metal pollution, Table 1 outlines the two primary sources, while subsequent sections provide detailed descriptions (see Figure 1).

Table 1: Natural and Anthropogenic sources of heavy metals, adapted from kanwar et al. (2020)

Natural Sources	Anthropogenic Sources
Rocking weathering	Chemical process industries
Atmospheric deposition	Metallurgy
Volcanic eruption	Mining
Erosion	Agrochemicals
	Dumpsites and landfills
	Sewage systems
	Power plants
	Research facilities
	Automobiles

1. Natural Sources: The processes that naturally occur and release heavy metals into the environment without the involvement of humans are referred to as natural sources. Mineral weathering, volcanic eruptions, and erosion are a few examples of natural processes (10). The most common and intrinsic natural sources of heavy metals are weathering and pedogenesis from exposed rock formations or geological parent materials. Mineral ores with structures that contain heavy metals can dissolve chemically through weathering, releasing minerals such as arsenopyrite, galena, cerussite, and cassiterite (11). The makeup and concentration of heavy metals in a particular location are determined by the type of rock and the surrounding conditions. Heavy metals like mercury (Hg), lead (Pb), nickel (Ni), manganese (Mn), cadmium (Cd), tin (Sn), zinc (Zn), cobalt (Co), chromium (Cr), and copper (Cu) are commonly found in high amounts in geologic plant materials (12). As observed by Rodríguez-Rodríguez et al. in 2013, "numerous erosion factors, including variables like rainfall intensity, volume, and frequency, vegetation, and soil physical properties, influence the release and dispersion of heavy metals from rocks into various environmental media." Additionally, volcanoes emit substantial quantities of aluminum (Al), zinc (Zn), manganese (Mn), lead (Pb), nickel (Ni), copper (Cu), and mercury (Hg), along with hazardous gases (12). According to research, windblown dust from desert regions, referred to as atmospheric deposition, contains elevated levels of iron (Fe) but lower levels of lead (Pb), zinc (Zn), manganese (Mn), nickel (Ni), and chromium

(Cr). Marine aerosols and forest fires also play a role in the dispersion of certain heavy metals across various ecosystems.

- 2. Anthropogenic Sources:** Although there are instances where heavy metals are discharged into the environment by nature, human activity is the primary and most dangerous source of environmental contamination. This is probably because these metals are unstable, soluble, and bioavailable (13). The production of steel alloys, vehicle exhaust emissions, battery manufacturing, biosolids and sewage sludge application, coating processes, cement and explosive manufacturing, electronic waste processing, burning fossil fuels, mining activities, inappropriate disposal of industrial solid wastes, tanning leather, use of agrochemicals (fertilizers and pesticides), textiles and dyes, farmland irrigation practices, photographic materials, steel printing pigments, electroplating, and smelting are examples of anthropogenic sources of heavy metals (14,15,16).

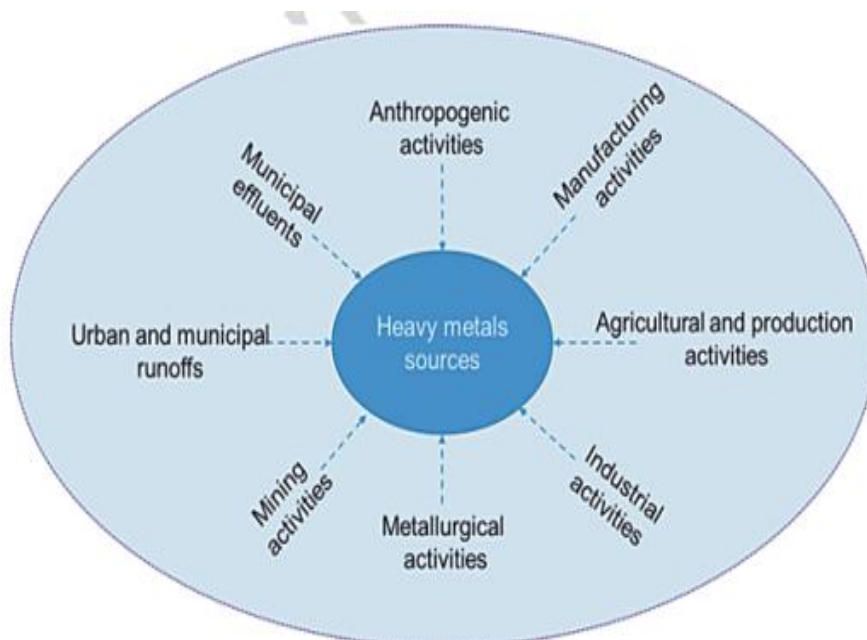


Figure 2: Man induced sources of heavy metals in the environment

The most prevalent types of heavy metals include oxides, hydroxides, sulfides, sulphates, phosphates, silicates, carbonates, and organic matrix, among others. The mechanism that demonstrates the various sources of heavy metals and their trans-sphere migration is depicted in Figure 3 below.

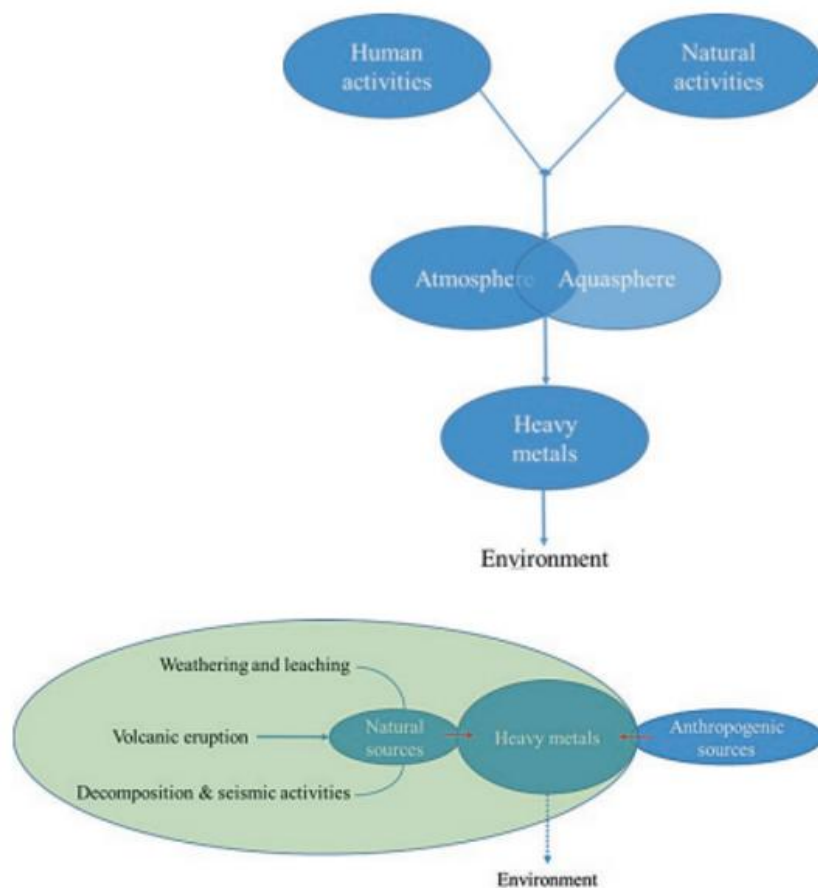


Figure 3: A schematic demonstrating the process different sources flow of heavy metals and their trans-sphere migration in a natural process

Among the various toxic substances, heavy metals such as Cadmium (Cd), Lead (Pb), and Mercury (Hg) are frequently found in the environment. These metals do not serve any biological function in animals, but their presence in tissues indicates the organism's contact with its surroundings. It is crucial to study the mechanisms of toxicity associated with these elements within animal biological systems, particularly the interactions between these heavy metals and essential dietary elements like Calcium (Ca), Zinc (Zn), Iron (Fe), Selenium (Se), and Copper (Cu). Generally, a deficiency in one of the essential elements increases the toxicity of heavy metals, while an excess appears to offer protection. This implies that the dietary presence of essential elements may contribute to shielding animals from the adverse effects of heavy metal exposure. The introduction of essential elements into the diet can be considered a potential approach for mitigating heavy metal toxicity (see Figure 4).

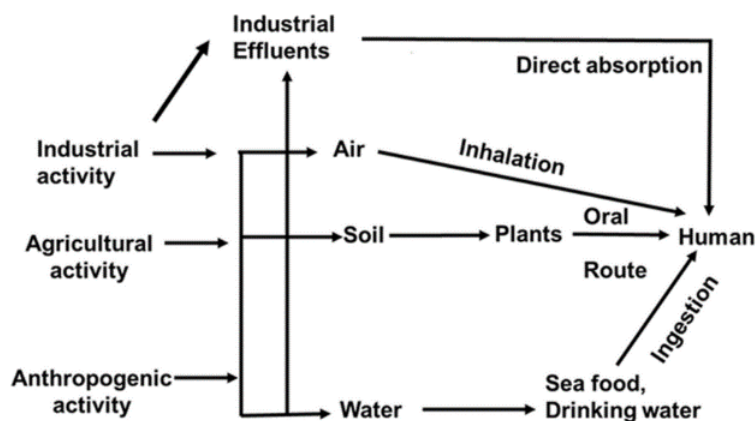


Figure 4: Heavy metal interactions with the environment and biological systems

III. IMPACTS OF HEAVY METALS ON THE ECOSYSTEM

Large amounts of heavy metals, organic pollutants, metalloids (elements like arsenic and antimony that have characteristics similar to those of conventional metals), hazardous wastes, and heavy metals are routinely released as a result of industrialization and technological growth. The environment has suffered as a result of these emissions. Ayangbenro and Babalola (2017) are ardent supporters of the claim that "heavy metals and metalloids continue to build up in soils and rivers, creating serious global health hazards owing to their inability to be converted into harmless forms and hence persist in the environment". According to the report, "all living things are at risk due to the excessively high level of heavy metal contamination in the environment" (17). This is backed by the information provided.

The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of the United States sets permissible limits of various heavy metals in water, which are as follows: 0.05, 0.002, 0.015, 0.01, 0.05, 0.015, 0.002, and 0.05 mg/L for Ag, Hg, Pb, Cr, Cd, and As, respectively (Chaturvedi et al., 2015). According to Indian heavy metal standards (18), the standards for Zn, Pb, Ni, Cu, and Cd in soil are 300-600, 250-500, 75-150, 135-270, and 3-6 mg/kg, respectively. These metals are significant environmental contaminants, and the impacts of their presence are growing increasingly concerning. Both plants and humans are frequently exposed to heavy metals and can become poisonous. Even in low quantities, heavy metals negatively impact plant growth due to their inherent phytotoxicity. This indicates that plant development is greatly hindered by large concentrations of heavy metals (19). Regulatory bodies like the Food and Agriculture Organization (FAO), World Health Organization (WHO), and United Nations Environmental Agency (USEPA) have established acceptable limits for heavy metals in drinking water, soil, and plants due to the health risks associated with these metals (20,21, 23). The maximum allowable limits for soil and plants are displayed in Table 3, while the maximum permitted limits for drinking water are provided in Table 2 (24, 25, 26). Additionally, Table 4 presents an overview of the origins and effects of heavy metals on various life forms (27, 28, 29).

Table 2: Maximum permissible and desirable limits of some heavy metals in drinking water

Heavy metals (mg/L)	WHO MPL	WHO MDL	USEPA max. perm. limits
Chromium, Cr	0.005	0.003	0.100
Manganese, Mn	1.000	2.00	0.050
Iron, Fe	1.000	0.10	3.000
Cobalt, Co	0.100	0.04	0.110
Nickel, Ni	0.070	NA	0.015
Lead, Pb	0.010	NA	0.015
Copper, Cu	3.000	0.05	1.300
Cadmium, Cd	0.100	0.50	0.005
Zinc, Zn	5.000	3.00	5.000
Arsenic, As	0.050	0.01	0.010
Mercury, Hg	0.001	NA	0.002

NA= Not available. MPL= Maximum Permissible Limit. MDL= Maximum Desirable Limit. USEPA= United States Environmental Protection Agency

Table 3: Maximum Permissible Limits of Heavy Metals in Soil and Plants/Vegetables

Heavy metals (mg/kg)	MPL in Soil	MPL in Plants/Vegetables
Cadmium, Cd	3	0.20
Iron, Fe	300	425.50
Zinc, Zn	300	99.40
Chromium, Cr	300	1.30
Lead, Pb	50	0.43
Copper, Cu	100	40.00
Arsenic, As	20	0.15
Mercury, Hg	2	NA
Manganese, Mn	2000	500.00
Cobalt, Co	100	50.00
Nickel, Ni	50	67.90
Selenium, Se	10	NA

Table 4: Summary of Heavy Metal Sources and Impacts on Living Things

Heavy metals	Sources	Humans	Plants	Microbes
Cd	Chemical process industries, Plastic, Pigments, Ni, batteries, agrochemical application, coal combustion mining, coating of metal, weathering of ingenious rocks, fuel, sewage/sludge, electroplating, nuclear plants.	Bronchitis, renal malfunction bone disease, cancer, hypertension, cancer, itai-itai, testicular atrophy, hypochromic anemia, kidney diseases, vomiting, and high blood pressure and cough.	Chlorosis, seed germination retardation, decrease in nutrient uptake, root and shoot growth inhibition	Protein denatures, cell division inhibition, decrease in carbon and nitrogen release, nucleic acid defects.
Pb	Paints, pigments, soldering, electroplating, Pb-battery, ceramic, oil, glass, lead mining, combustion of leaded gasoline, industrial wastes, metal ores, coal combustion, plumbing fixtures, municipal sewage.	Insomnia and brain damage, learning deficits, neuron damage, liver, and kidney failure, coma, anorexia, high blood pressure, hyperactivity, infertility, arthralgia, chronic nephropathy, renal system damage, central nervous system cancer, cramping and diabetes, skin disease, immuno-toxicity.	Growth and photosynthesis inhibition, seed germination suppression, chlorosis, decrease in height, biomass, number of leaves and leaf area, oxidative stress, protein deficiency, enzyme activity inhibition negatively impacting CO ₂ fixation.	Nucleic acid and protein denaturing, and enzyme activity inhibition and transcription
As	Ceramics and electrical production, pesticides, fungicides, herbicides usage diseases, against parasitic coal combustion in power plants,	Vascular complications, brain damage, muscle weakness, skin disease, immuno-toxicity and genotoxicity issues, melanosis and skin cancer, dermatitis, diarrhea,	Reduction in seed germination, inhibits of roots extension and proliferation, reduced leaf area, weight and dry matter production, metabolic processes	Deactivation of enzymes.

	mining, fireworks, volcanoes, fireworks, volcanoes.	vomiting, conjunctivitis, neurobehavioral disorder, and human hyper-pigmentation.	interference, reduced fruit yield, wilting, fertility loss, physiological disorders and chlorosis.	
Cr	Metal processing, electroplating, dyeing, leather tanning and textile, paints and pigment welding, boilers and cooking systems as anti-corrosives, sludge/solid waste.	Carcinogenic, dermatitis, bronchopneumonia, headache, migraine, skin ulceration, asthma, lung/respiratory tract cancer, itching of the respiratory tract, diarrhea, renal failure, nausea, kidney damage, emphysema, central nervous system disorder, liver diseases, reproductive toxicity.	Reduced plant shoot and root growth, stunted growth, decrease in plant biomass, chlorosis, reduced biosynthesis germination, wilting, biochemical lesions and decrease in plant nutrients acquisition, germination inhibition, oxidative stress, and senescence.	Inhibition of oxygen uptake, ag phase elongation and growth inhibition.
Ni	Geologic/rock weathering, bubble bursting, porcelain enameling, molds of glass (ceramics), surgical instruments, paints, catalyst, kitchen appliances, computer constituents, forest fires, non-ferrous metal and steel alloys, gas exchange in the ocean, volcanic eruptions.	Cancer-causing, cardiovascular diseases, dermatitis and skin diseases, dry cough, and breathing disorder, headache, kidney diseases, nausea, dizziness and chest pain.	Chlorophyll content reduction, reduction in stomata conductance, inhibition of root growth enzyme activities, and growth inhibition reduced nutrient uptake and chlorosis.	Disruption of the cell membrane, oxidative stress, inhibition of activities.
Hg	Rock weathering, volcano eruptions, forest fire,	Dysphasia, ataxia, reduced immunity, attention deficit gastrointestinal	Decrease in germination percentage, defects in antioxidative	Cell membrane disruption, reduction in population

	thermometers, metal extraction process, coal combustion, wood burning, mining, emissions from caustic soda producing industries, peat, dentistry, incinerators, batteries, switches.	toxicity, blindness, deafness, dizziness, loss of memory, decrease the rate of fertility and abortions, dementia, mutagenic effects, gingivitis, kidney, and renal problems, nervous system problem and neurotoxicity, pulmonary edema, sclerosis, circulation problems tremor.	system, reduction in plant height, overall growth, nutrient uptake, and yield reduction, decrease in the tiller and panicle formation, fruit development flowering suppression, loss of weight, photosynthesis activity reduction, chlorosis, bioaccumulation in roots and shoots of seedlings genotoxic effect inducement, homeostasis inhibition, oxidative stress, lipid peroxidation enhancement.	size, protein denature, enzyme function inhibition.
Zn	Brass manufacturing, polyvinyl chloride stabilizer, zinc alloy, mining, rubber and paint industry, biosolids, oil refinery, plumbing, electroplating, smelting and refining.	Lethargy, macular degeneration, ataxia, vomiting, depression, anxiety, gastrointestinal irritation, metal fume fever, hematuria, seizures, icterus, impotence, prostate cancer, liver and kidney failure.	Reduction in photosynthetic activity, plant growth reduction, decrease in chlorophyll content, decrease in germination percentage, and plant biomass, reduction in amino acid, sugar, carotenoid, and starch contents, the structure of chloroplast the alteration, decrease in plant.	Growth inhibition, reduction biomass, and death

Cu	Ingenious rocks, electroplating and copper polishing industry, chemical/pharmaceutical instruments, alloys, water pipelines, printing operations, roofing, mining, paint, production, biosolids smelting and refining.	Kidney complications, abdominal pain, diarrhea, sleeping disorder, anemia, nausea, liver, metabolic disorders, headache.	Chlorosis, biomass reduction, root and malformation resulting in root growth reduction, retard growth, oxidative stress, death, seed and production.	Cellular function disruption, enzyme activity inhibition.
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IV. TOXICOLOGICAL IMPACTS OF HEAVY METALS

It appears that these metals (or their derivatives) are poisonous because of the term "heavy metal." This is undoubtedly more of an opinion than a scientifically supported conclusion. It's important to remember two things: (1) Any substance's impact on biological systems is always a function of the concentration at which the cells can utilise it. As a result, unlike non-toxic substances, there are no toxic substances. Dose-response information, or quantitative dose-response connections, are what we require for the evaluation. (2) A number of metal ions are necessary for cell metabolism. Bell-shaped dose-response correlations result from their being harmful at large concentrations but required at low concentrations (30).

Heavy metals are released into the environment by both natural and man-made processes, and plants take up these metals through tainted water and soil. As a result of humans ingesting polluted plants and animals, inhaling contaminated air, and coming into contact with contaminated skin, heavy metals are deposited in human tissues and spread throughout the environment. Several regulatory agencies across the world have set limitations for the presence of certain metals in air, soil, and drinking water due to their detrimental effects. The health effects of exposure to concentrations over the prescribed limits can vary based on the heavy metal and exposure level and can be either acute, chronic, mutagenic, or carcinogenic (30). Table 4 displays the acceptable limits of several heavy metals in drinking water, as determined by the World Health Organization (WHO), Environmental Protection Agency (EPA) (United States), and Department of Water and Sanitation (South Africa). The table also illustrates the detrimental effects that continuous exposure to the various contaminants has on human health (31) (5 Tables)

The following series of phytotoxicity was determined using the averages of all evaluated parameters:

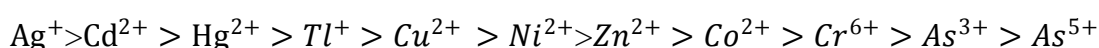


Table 5: Recommended Limits for Heavy Metals in Portable Water and Their Toxic Effect

Heavy metal	Chronic health limit ($\mu\text{g/L}$)			Health effects
	WHO (UN 2007)	EPA (EPA 2009)	DWS (DWS 2015)	
As	10	10	10	Cancer (skin, bladder, liver, Cardiovascular, kidney, Nervous system any problem.
Cd	3	5	3	Renal dysfunction, cadmium pneumonitis, bone disease, kidney disease.
Cr	50	100	50	Dermatitis, male reproductive system damage, lung cancer.
Cu	2000	1300	2000	Anemia, liver, and kidney damage.
Pb	10	15	10	Loss of memory, high blood pressure, short attention span.
Hg	1	2	6	Blindness, dementia, gastrointestinal problem, kidney damage, decreased fertility.
Ni	70	-	70	Increased risk of cancer, kidney failure and cardiovascular diseases.
Se	1000	50	30	Liver damage, hair and nail loss, numbness on fingers or toes.
Zn	3000	5000	5000	Anemia, kidney and liver failure, prostate cancer.

V. EXPOSURE TO HEAVY METALS AND ENVIRONMENTAL POLLUTION

By attaching to sulfhydryl groups and producing reactive oxygen species (ROS), heavy metals cause toxicity in biological systems (see Figure 5). As a result, important macromolecules become inactive, oxidative stress starts, and glutathione levels drop. Toxic metal exposure and subsequent body entry cause a number of reactions, including interference with or suppression of particular metabolic pathways (32). Consequently, numerous adverse effects on both humans and animals become evident. These effects encompass specific organ dysfunctions, metabolic abnormalities, disruptions in hormone regulation, congenital disorders, compromised immune system function, and an increased risk of cancer (33,34).

In response to these risks, many international organizations have established standards pertaining to the permissible levels of metals in the environment, foods, and drinking water. Risk assessment studies involve the evaluation and analysis of the presence of heavy metals in food and water. For example, a study conducted on 193 Ayurvedic medicinal products,

well-known Indian herbal medicines, revealed that nearly one-fifth of them contained Mercury (Hg), Lead (Pb), and Arsenic (As). Notably, all the products containing these metals exceeded one or more standards for acceptable daily metal intake. This could potentially result in Pb and/or Hg ingestion levels that are 100 to 10,000 times higher than the acceptable limits (35). Moreover, regulations are in place to limit the daily intake of these heavy metals (in micrograms per day), as presented in Table 6. Regulatory authorities should establish daily dosage limits for heavy metals in dietary supplements, and manufacturers are required to assess their products for compliance with these standards.

Even pristine and isolated areas are experiencing environmental contamination. For example, heavy metals like Pb, Cd, Cr, As, and Hg have been found in remote locations like Mount Everest. Yeo and Langley-Turnbaugh (36) discovered that the levels of As and Cd in all Everest snow samples were higher than those recommended by the USEPA for drinking water. Furthermore, As was present in high concentrations in every soil sample (36).

Table 6: Summary of the toxic effects of heavy metals on human health

Pollutants	Major sources	Effect on human health	Permissible levels (mg/L)
As	Pesticides, fungicides, metal smelters	Bronchitis, dermatitis, poisoning	0.02
Cd	Welding, electroplating, pesticides, fertilizer	Renal dysfunction, lung diseases, lung cancer, bone defects, kidney damage, bone marrow	0.06
Pb	Paint, pesticides, smoking, automobile emission, mining, burning of coal	developmental delay, fetal infant encephalopathy, chronic nervous system damage, liver damage, renal damage, and mental retardation in children	0.1
Mn	Welding, fuel addition, ferromanganese production.	injury to the central nervous system through inhalation or touch	0.26
Hg	Pesticides, batteries, paper industries	Tremors gingivitis, protoplasm poisoning, damage to nervous system, spontaneous abortion	0.01
Zn	Refineries, brass manufacturing, metal plating	Damage to nervous system, dermatitis	15
Cr	Mine, mineral sources	Damage to nervous system, irritability	0.05
Cu	Mining, pesticides production, chemical industry	Anemia, liver and kidney damage, stomach irritation	0.1

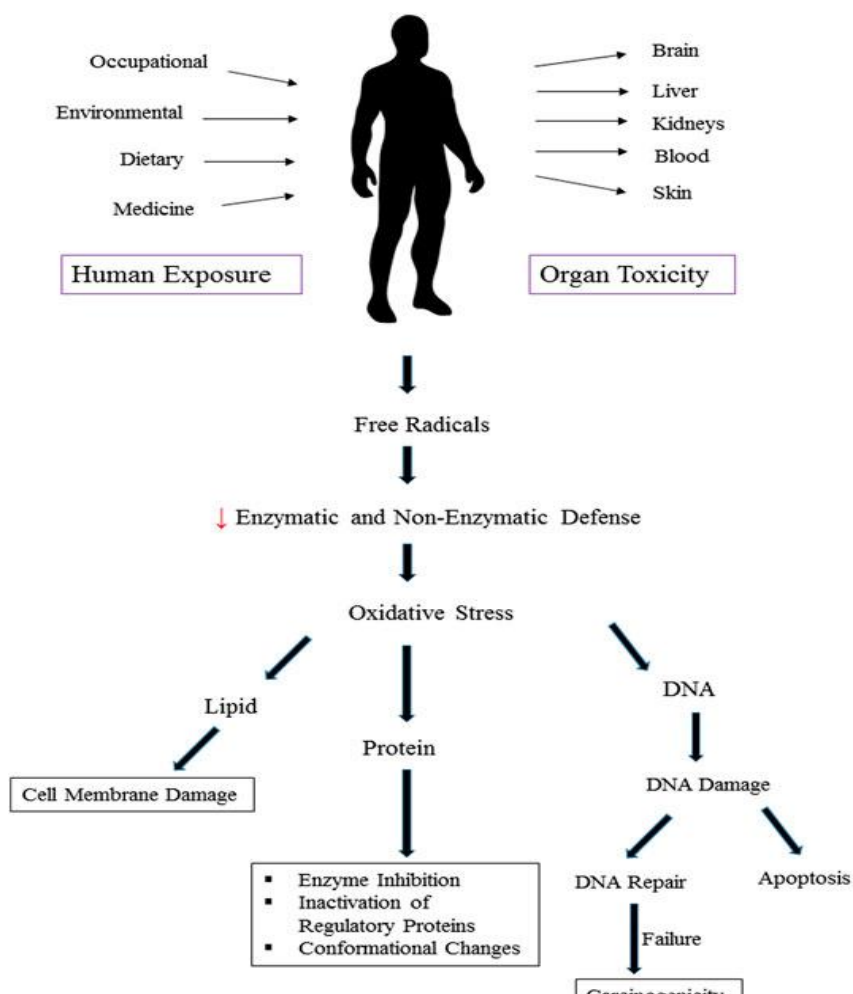


Figure 5: Human Exposure and human organ toxicity

VI. POLLUTION ABATEMENT TECHNIQUES

Various methods have been employed to control the amount of heavy metals released into the environment. By doing this, heavy metal pollution of the environment is avoided. These procedures limit heavy metal pollution of the environment by utilizing a variety of mechanisms, including complexation, adsorption, precipitation, and absorption.

- 1. Stabilization:** Various methods have been employed to control the amount of heavy metals released into the environment. By doing this, heavy metal pollution of the environment is avoided. Heavy metals in soil are stabilized using various chemicals. This is primarily a mechanism driven process. For instance, three amendments consisting of natural minerals and industrial byproducts—red mud, apatite, and a red mud/apatite composite—were used to assess the chemical stabilization of heavy metals. Furthermore, these substances either adsorb the pollutants or produce an atmosphere that is not conducive to metal leaking into the environment (37, 38).
- 2. Reaction Control:** In some cases, preventing the presence of elements that could encourage the reaction controls the release of heavy metals into the environment. For example, the oxidation of oxygen and metalliferous rich tailing can be controlled by

installing a clay lining to stop water intrusion. By doing so, the environment would not have been contaminated by heavy metals, as water and oxygen encourage the leaching of heavy metals into various receiving habitats (39, 40). By removing one of the components from a chemical reaction, this technique prevents the reaction from occurring since there are insufficient precursors (41).

- 3. Phytoremediation:** Utilizing plant species that have a particular affinity for heavy metals is part of this procedure. In essence, plants use the heavy metals in the soil as nutrients, which they then take to grow. The chemical stability of heavy metal ions in the soil's vadose zone is greatly influenced by plant metabolism, which also serves to restrict the leaching, mobility, bioavailability, and potentially harmful effects of heavy metals. This mechanism, which is essentially referred to as phyto-stabilization, is triggered by heavy metals that are absorbed and accumulate on the roots. Moreover, heavy metal oxidative state alterations and adsorption onto organic compounds can cause heavy metals to precipitate in the rhizosphere zone. In a nutshell, cations such heavy metals attach to anionic charged plasma membranes and pectin found in plant cell walls (42, 43).

VII. POLLUTION TREATMENT TECHNIQUES

Many processes, including leaching, weathering, and oxidation, occur after pollution removal. As a result, heavy metal pollution of the environment occurred. To get rid of the pollutants, environmental managers, process engineers, and experts in water quality use several treatment techniques. These methods employ a variety of processes, including filtration (47), electrolysis (48), ion exchange (46), precipitation (44), adsorption (45), phytoremediation (49), and crystallization (50). It is possible to remove heavy metals by combining different methods.

- 1. Precipitation:** This process depends on pH. various pH gradients cause various metals to precipitate. Water that is high in heavy metals will react with an alkaline producing agent to accomplish that. After a while, the water's pH will rise and impurities will start to appear at different pH gradients. Researchers have looked into how metals can be recovered at various pH gradients. Chemicals used to elevate the pH of water include lime, limestone, soda ash, caustic soda, periclase, brucite, and different waste products. However, these materials contain high concentrations of Mg, Ca, and Na components among other contaminants.
- 2. Adsorption:** This is a surface phenomena in which impurities are adsorbed onto the material's surface. Exchangeable fractions, the point of zero charge, and charge difference are only a few of the variables that affect this. A variety of materials experience detrimental surface modifications when heavy metals are adsorbed onto them. The amount of heavy metals that have been adsorbed onto the adsorbent can be measured using the grams of heavy metals on the grams of the adsorbent. It is the result of an adsorbent and an adsorbate interacting. Two of the many techniques used to pinpoint the mechanisms of heavy metal adsorption are the Freundlich and Langmuir adsorption isotherms. This phenomena is also dependent on a number of variables, including ionic strength, temperature, pH, co-existing ions, concentration, and time. Researchers have employed a variety of materials, including waste materials, zeolite, base minerals, powdered activated carbon (PAC), granular activated carbon (GAC), and clays (bentonite, vermiculite, and kaolinite) (51, 52). Other materials can be blended together as a

composite to create materials with a variety of functions and mechanisms in order to achieve a synergy (53).

- 3. Ion Exchange:** This is also a surface phenomena, in which the material's cation and anion exchange capability causes impurities to be adsorbed onto its surface. The majority of the time, high ion exchange capacity media or ion exchange resins are employed together. By virtue of their high ion exchange capacity, clay minerals attenuate heavy metals. The density and charge variance are used in place of the elements. It is called the cation exchange capacity (CEC) process. Several techniques can be used to ascertain this (54, 55).
- 4. Filtration:** Filtration membranes can be used to extract heavy metals from aqueous media. A driving power is necessary for the membrane to extract heavy metals from an aqueous solution. It may be influenced by the pressure differential or concentration gradient. Various membrane types are employed for the removal of heavy metals, including membrane distillation, reverse osmosis, ultrafiltration, nano-filtration, microfiltration, and electro-dialysis (ED) (56,57).
- 5. Phytoremediation:** The method of eliminating heavy metals from aqueous solutions by means of biological elements of the environment (plants) is known as phytoremediation. The phenomenon has been thoroughly studied in relation to the removal of heavy metals from contaminated soil and land ecosystems. It has been said that this technique works incredibly well. The fact that plants take up heavy metals as nutrients from the soil and the soil/water contact justifies this. As a result, heavy metal levels in the soil environment are lessened (58). Plant-based materials can be utilized in phytoremediation, phytoextraction, and phytostabilization processes. One of the technique's challenges is how long it takes to cleanse the area. It also needs a large amount of land (59).

VIII. HEAVY METALS IN BIOLOGICAL SYSTEMS

Heavy metals comprise a highly diverse group of elements known for their wide-ranging chemical properties and biological roles. These elements are typically found in trace amounts within the Earth's crust but have extensive applications in various aspects of our daily lives, including golf clubs, self-cleaning ovens, automobiles, antiseptics, plastics, mobile phones, solar panels, particle accelerators, and numerous other products and technologies (60).

Even in tiny amounts, a few heavy metals are vital to biological functions. Examples of essential elements include copper and iron for electron transport systems, cobalt for complex synthesis and cellular metabolic processes, zinc for hydroxylation, manganese and vanadium for the regulation and operation of particular enzymes, chromium for glucose utilization, nickel for cell growth, arsenic for certain animal metabolic growth, selenium for hormone production and antioxidant activity, molybdenum for catalytic activity of redox reactions, cadmium for similar functions in some diatoms, and tin for the optimal growth of some marine species (61).

Among the heavy metals, chromium, mercury, arsenic, cadmium, and lead are widely distributed throughout the environment. Some heavy metals are essential for plants in trace amounts but can pose a hazard if their concentration exceeds the required levels (62). Due to

their extensive use and toxic nature in various forms, these heavy metals present a potential threat to living organisms (63). Certain heavy metals have a pronounced affinity for sulfur and bind through thiol groups ($-SH$) within the human body (64). They typically form sulfur-metal bonds with enzymes, which are crucial for regulating the pace of metabolic reactions (60). These $-SH$ bonds can impede enzyme function, resulting in health deterioration in affected individuals, sometimes leading to severe consequences in prolonged exposures. Hexavalent chromium and arsenic, for instance, are known carcinogens (65). Elevated cadmium levels can lead to degenerative bone diseases (66), while high concentrations of lead and mercury can damage the central nervous system (CNS) in the human body (67).

There are two ways in which heavy metals disrupt metabolic processes: Initially, they build up in key glands and organs such the liver, heart, brain, kidneys, and bones, impairing their regular operations. Second, they impede the biological responsibilities of vital nutritional minerals by moving them from their natural places. However, living in a completely heavy metal-free environment is not feasible. Ingestion of tainted food and drink, contact with the skin, and breathing in contaminated air are just a few of the ways that these toxins can enter the body.

IX. CONCLUSION AND FUTURE PERSPECTIVES

This chapter emphasized that both natural and artificial sources are the main causes of pollution in the environment. It was also noted that a variety of factors facilitate the release of heavy metals from various environmental components; nevertheless, pH, temperature, solubility, redox, and precipitation potential control the release of heavy metals. It has been determined that the primary cause of the heavy metal pollution is mining and metallurgical activities. Therefore, it may be concluded that the primary cause of heavy metal pollution in the environment is human activity. The leaching and weathering of various mineral-rich environmental components can cause natural pollution of the environment, thereby enriching it with heavy metals. These metals, which include elements in the platinum group, Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Ni, and Zn, are found in the crust of the earth. Because these metals don't break down, they might build up in the environment. Like all other living things, humans need specific levels of metals like copper for good health, and a lack of these elements can lead to a variety of diseases. Exposure to high quantities of metals can have deleterious consequences on health, such as cancer and cardiovascular illnesses. These elements are genotoxic, carcinogenic, mutagenic, and teratogenic to living things, and their consumption can have immediate impacts on health. Regulations have been put in place to limit the quantity of heavy metals that human activities can release into the environment, thereby preventing their buildup in the environment and reducing human consumption and inhalation. Therefore, a variety of technologies are employed by various pollution sources to regulate the discharge of heavy metals into the environment. One of these technologies is the ability to regulate the entry of molecules that may aid in a chemical process that releases heavy metals. Should pollution abatement methods prove ineffective, alternative institutions may employ alternative technology to mitigate the environmental effects of heavy metals. These technologies, which include filtration, ion exchange, precipitation, adsorption, and phytoremediation, rely on several processes to remove heavy metals from the environment. These technologies help to keep heavy metal pollution out of the environment, which enables these sectors to comply with various regulations. Industries are concentrating on the beneficiation and valuation of streams and effluents rich in metals as a means of preparing for the future. They recover and valorize heavy metals in various streams. This is a sensible

strategy since it would reduce waste production in an eco-friendly manner. Additionally, this will address the circular economic phenomenon.

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