

Sources, Environmental Impact, And Human Health Risks of Heavy Metal Contamination in Aquatic Ecosystems

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ABSTRACT

Natural and artificial heavy metal pollution in aquatic habitats is a major environmental concern. Metals enter waterways via volcanic eruptions and rock weathering, but industrial discharge, agricultural runoff, mining, electroplating, and poor waste disposal enhance their concentration. Non-biodegradable metals accumulate in water, sediments, and aquatic creatures. By altering physiological and metabolic processes, bioaccumulation and biomagnification harm aquatic flora and wildlife. Fish and other aquatic species are fragile and ecological indicators. Heavy metals in polluted water and food systems cause neurological problems, organ damage, and cancer. Long-term exposure may cause chronic illnesses, underscoring the necessity for pollution monitoring and management.

Keywords: *Heavy, Metals, Toxicity, Pollution, Aquatic.*

I. INTRODUCTION

Heavy metal pollution in aquatic habitats is a global environmental issue owing to its toxicity, persistence, and non-biodegradability. Lead, mercury, cadmium, arsenic, and chromium are heavy metals. Some of these metals are needed for biological processes in tiny levels, while greater doses are hazardous. As the last sinks for pollutants, aquatic ecosystems including rivers, lakes, and groundwater systems are especially sensitive to heavy metal contamination.

Heavy metals in water come from natural and manmade sources. Rock weathering, volcanic eruptions, and soil erosion discharge metals into aquatic systems. However, growing industrialization, urbanization, and population expansion have increased heavy metal human input. Industrial effluents, agricultural runoff, mining, electroplating, and inappropriate electronic and biomedical waste disposal introduce dangerous metals into waterways. Without treatment, these contaminants reach aquatic systems and degrade water quality.

Heavy metals remain in aquatic environments for lengthy durations. They are distributed between water, sediments, and live creatures after complicated physical, chemical, and biological processes. Under changing environmental circumstances, sediments release heavy metals into the water column. This dynamic activity raises the danger of protracted pollution and aquatic life exposure.

Heavy metals may bioaccumulate and biomagnify in the food chain. Fish, algae, and invertebrates absorb metals from water or diet. Thus, metal concentrations rise at higher trophic levels, impacting predators like humans. This harms aquatic biodiversity, food safety, and public health.

Heavy metals harm aquatic creatures by altering physiological, biochemical, and reproductive activities. Long-term exposure may affect aquatic organisms' growth, metabolism, and mortality. Humans are mostly exposed to heavy metals via polluted water and marine food. Exposure may cause neurological diseases, renal damage, respiratory troubles, and cancer.

Heavy metal pollution is a growing problem, thus understanding its origins, behavior, and effects on aquatic ecosystems and human health is crucial. Monitoring, pollution control, and sustainable environmental management are essential to reduce their damage and preserve water resources for future generations.

II. SOURCES OF HEAVY METAL CONTAMINATION IN AQUATIC ENVIRONMENT

Surface water heavy metals may be natural or manmade. Volcanic eruptions, weathering of metal-containing rocks, sea-salt sprays, forest fires, and natural weathering processes may release metals from their native skies to diverse environmental areas. Heavy metals are present in oxides, sulfides, phosphates, silicates, and organic molecules.

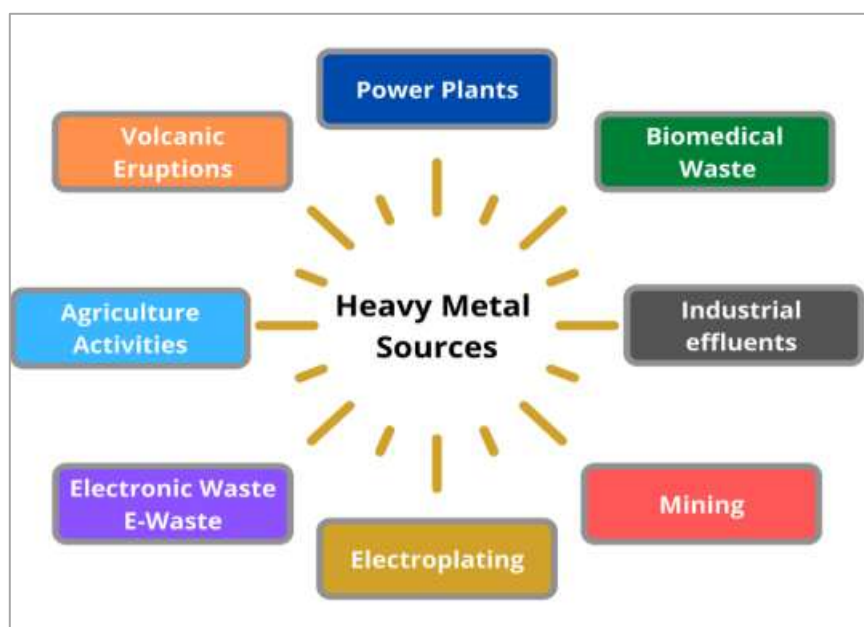


Figure 1: Different Sources of Contamination Heavy Metal in Water & Aquaculture

Volcanic Eruptions

Water turbidity, acidity, and low pH result from volcanic ash falling on the system. The plume of aerosols of the strong mineral acids H_2SO_4 , HCl , and HF acidifies new volcanic ash surface coatings. Thus, freshly-erupted ash may reduce water pH beyond tolerable limits for aquatic life. Human-caused atmospheric heavy metals have increased due to global industrialization and urbanization.

Industrial Effluents

Municipal, household, and industrial waste directly released into natural water systems are important pollutants. Untreated wastewater pollutes water. Manufacturing effluents untreated into surface and groundwater are the main cause of pollution.

Agriculture Activities

The growing need for food has extended and intensified agricultural systems. Overuse and abuse of agrochemicals, water, animal feeds, and productivity-boosting medications have polluted rivers, lakes, aquifers, and coastal waterways.

Mining

Environmental contamination by heavy metals is high in mining and historic mine sites and decreases with distance. Mining extracts minerals and other geological materials from earth.

Electroplating

Electroplating uses electrical flow to reduce cations of a desired substance from a solution and coat a conductive device with a thin coating of the material, such as metal.

Electronic Waste/E-Waste

Uncontrolled e-waste disposal and recycling endanger human and environmental health. E-waste contains heavy metals including lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and nickel (Ni) and persistent organic compounds like brominated flame retardants (BFRs) and phthalates. E-waste contains PCBs, NP, and TPPs, among others.

Biomedical Waste

Medical waste includes used needles, syringes, and other sharps, as well as body parts, organs, tissues, blood, and body fluids. It carries unseen pathogens in bulk. Water contamination may be biological, chemical, or radioactive. Pathogens may contaminate water and cause illnesses.

Power Plants

Water is thermally polluted by nuclear and fossil fuel facilities. Water quality degrades owing to ambient water temperature fluctuation. Thermoelectric power stations alone generate 50–60% of all harmful pollutants emitted to surface waterways by all industrial categories under the Clean Water Act, according to the EPA.

III. EFFECT OF HEAVY METAL ON AQUATIC ENVIRONMENT & AQUATIC HEALTH

Biodegradability is killed by most metals, which cannot be converted into less harmful molecules. Metals are redistributed in the water column, stored in sediments, or consumed by aggregation in aquatic environments. Due to metal activity and remobilization, sediments give semi-permanent contamination to natural phenomena. Metal residues in polluted environments may bioaccumulate in aquatic ecosystems, flora, and fauna, which might cause health issues in humans.

Metal accumulation in sediments depends on the physical and chemical conditions of the sediment and water column, including precipitation of positive compounds, binding fine solid particles, association with organic molecules, and co-precipitation with metal or Mn oxides or carbonates. Because of the percentage of the metal's general concentration that might accumulate in the body, bioavailability is public. Organism biology (metals assimilation efficiency, feeding ways, size or age, generative stage); metal natural science (distribution in water—sediment, suspended matters, and metal speciation); and physical and chemical factors (temperature, salinity, pH, ionic strength, dissolved organic carbon concentration, total suspended solids) affect metal bioavailability.

Metal bioavailability regulates aquatic metal buildup. Metals are absorbed via the receptive stratum if dissolved or by dietary intake if particulate. Metal toxicity is primarily affected by biological processes, organic or inorganic complexes, pH, temperature, salinity, and reaction conditions. Feeding pace, enteral transit duration, and digestion efficiency affect intake uptake. Although exceptions exist, free hydrated metallic particles are the most accessible form of metal, Cd, Zn, and elements.

Thus, chemical types of dissolved metals and complexes with compatible organic ligands with low relative molecular mass are important. Organic binders boost Cd bioavailability in mussels and fish by increasing hydrophobic chemical transport in the lipid membrane. Organic metal compounds are more bioavailable than ions. Unlike corrosive sublimate, mercurial chemical substances are macromolecule-soluble and easily enter lipid membranes, enhancing toxicity.

Effect of Heavy Metal on Aquaculture

Heavy metals are the main source of water pollution because they destroy commercially valuable species by dissecting the biological chain or chemically altering water. Fish bodies absorb heavy metals via their gills, skin, and digestive tracts. Gills immediately absorb metals from the water, whereas fish bodies are thought to absorb less. By altering enzyme and metabolite activity, metal concentrations in tissues produce several biochemical, physiological, and histological changes in fishes and other freshwater fauna. Fish are widely spread in aquatic ecosystems, and their susceptibility to metal poisoning may indicate the biological impact of metal contamination.

IV. HEAVY METALS TOXIC EFFECT ON HUMAN HEALTH

Heavy metals contribute to diabetes, Alzheimer's, and several cancers. In addition to specific metal toxicity signs, copper, lead, aluminum, zinc, mercury, cadmium, and arsenic poisoning can cause GI dysfunctions, diarrhea, stomatitis, shivering, hemoglobinuria causing a rust-red depression, and pneumonia. Virulent (acute, chronic, or sub-chronic), mutagenic, teratogenic, neurotoxic, or carcinogenic consequences may occur. Extended exposure may progress muscular dystrophy, Parkinson's, and MS. Long-term metal allergies or their compounds may cause cancer.

Lead (Pb)

The body rapidly accumulates lead, a dangerous metal. It is heavy and soft as sulfide, cerussite (PbCl_2), and galena. The major reason lead appears in industrial effluent is lead-acid battery discharge. Lead is often found in effluent from electroplating, electrical, steel, explosives, etc. sectors. Lead is often found in aquatic systems from electrical trash. Lead is dangerous. Lead dominates industrial effluents.

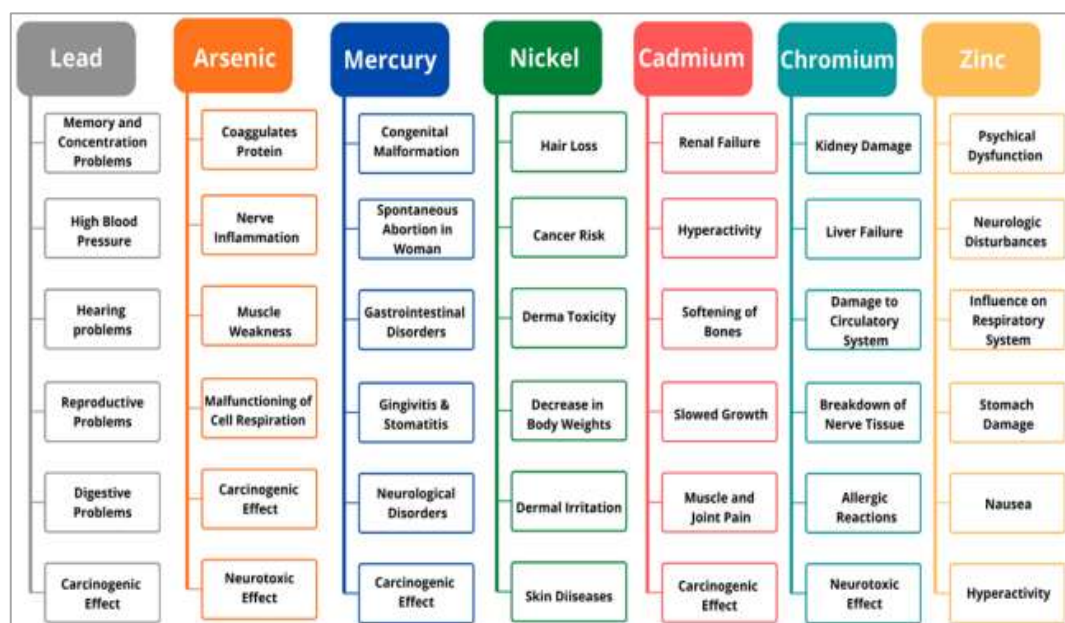


Figure 2: Heavy Metal Toxic Effect on Human Health

Arsenic (As)

Arsenic is released during lead, copper, and zinc smelting. Chemistry and glass also create arsenic. Arsine gas is released during arsenic pesticide manufacturing. Arsenic comes from industrial, metals, and other wastes. Arsenic weakens muscles, coagulates protein, and damages the neurological system.

Mercury (Hg)

Mercury vapours attack the CNS and cause neurotoxicity when flashed. When mercury levels rise, pregnant women often have involuntary abortions. Numerous cognitive, personality, sensory, and motor problems exist. Long-term elemental mercury vapor exposure may cause unsteadiness, poor focus, tremulous speech, impaired vision, and psychomotor skill decline. Weeks of elemental mercury vapor exposure may cause chronic cough.

Cadmium (Cd)

Cadmium is found in sediments with other elements. It is the most hazardous heavy metal in industrial effluents. It is crucial in sectors such as plating, cadmium-nickel batteries, phosphate fertilizers, stabilizers, and alloys. Cadmium compounds are very damaging and accumulate in the environment at low concentrations. Cadmium buildup may cause “Itai-Itai” illness. It tempers bones and fractures humans.

Nickel (Ni)

Volcanic dust and rock and soil weathering are natural sources of atmospheric nickel. In nickel and nickel alloy manufacturing facilities, welding, electroplating, grinding, and cutting, inhalation, ingestion, and skin association occur. Nickel causes several pathologies and is carcinogenic. Nickel or soluble nickel compounds may cause allergic dermatitis.

Chromium (Cr)

This metal pollutes natural water due to human activity. Some fish species deplete chromium. Various studies show that chromium composites increase lung cancer risk. Nerve tissue breakdown and circulatory damage are also seen. Cr's residency with other metals increased glycogen levels in various tissues stressed by metal exposure.

Zinc

Zinc waters come from human activities or geological rock weathering, such as industrial and home wastewater outflows and animals, where they preserve cytoplasmic integrity. Immune responses need zinc. Zinc raises cardiovascular disease risk. Hypertension, nausea, and stomach damage might result. Neurotoxic effects on human health are its responsibility. Overuse of zinc may induce mental illness. Zinc intake causes many neurological alterations.

V. CONCLUSION

Heavy metal pollution in aquatic habitats is a chronic environmental issue with major ecological and human health consequences. Natural processes and, more importantly, human activities like industrial discharge, agricultural runoff, mining, and inappropriate waste management cause harmful metals in water bodies. Non-biodegradable heavy metals accumulate in water, sediments, and aquatic creatures for extended durations. Their bioaccumulation and biomagnification in the food chain make them harmful because even low quantities may be deadly at higher trophic levels. Aquatic creatures have physiological, metabolic, and reproductive deficiencies that disrupt ecological equilibrium and biodiversity. Exposure to polluted water and food may cause neurological abnormalities, organ damage, and chronic illnesses. Controlling heavy metal contamination requires good monitoring, rigorous environmental rules, and sustainable waste management. Maintaining ecological balance and clean water for future generations requires protecting aquatic environments.

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