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A brief overview on heavy metal pollution

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ABSTRACT:

The detrimental consequence of environmental heavy metal poisoning on human health has recently received a significant amount of global attention. The most alarming effect is due to the negligence of human beings, who's exploitation as a result of uncontrolled urbanization and industry have become the most potent source of heavy metal contamination.Consequently, there is a higher concentration of heavy metals in the air, soil, and water.Every metal that is poisonous is a heavy metal, whether it has a large atomic mass or density or not. Heavy metals not only occur in soil caused by natural erosion of parent material but also through pedogenic processes.They also accumulate from anthropogenic activities like fossil fuel combustion, waste disposal, energy production, and vehicular emissions. Elevated amounts of metal contamination in the soil can be absorbed by plants, which may subsequently be ingested by various organisms at different trophic levels thus integrating into the food chain. High quantities of heavy metals can adversely affect the metabolism of vital organs and glands, posing risks to both humans and plants. Furthermore, heavy metals impair their biological functions by depleting necessary minerals from the natural environment. Although living necessitates exposure to heavy metals, amounts beyond those recommended by many national and international organizations can adversely affect health. Due to increased human activity, it is essential to regularly test and monitor heavy metal concentrations in an ecosystem to evaluate human exposure and ensure ecological sustainability. Surpluses of these substances can infiltrate aquatic ecosystems via numerous processes and channels from both man-made and natural sources. It can be harmful for living organisms to build-up these non-biodegradable heavy metals. This review analyzes the prevalence of heavy metals in the environment, their sources, factors and impacts on organism and plants.

Keywords: Heavy metal, pollution, health, biomagnifications, stomatal function, environmental pollution, diseases

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1. INTRODUCTION

The hazard of heavy metal contamination is rather alarming because of the increasing anthropogenic and geological activities, increased traffic volume, industrialization and urbanization which is posing at a threat to the biological diversity of that particular region and as result the ecological balance of both animals and plants are being disturbed[1].Point source industries such as mining, smelting, and foundries, along with other metal-based industrial activities, are significant contributors to environmental pollution. Crops cultivated in contaminated soil have reduced yield, performance, and growth due to altered physiological and biochemical processes. Reduced height, biomass, net productivity, and diminished leaf blade area have been seen in plants located in regions with elevated heavy metal pollution. Recent study indicates that heavy metals can modify the structure and function of stomata, hence affecting the physiological processes of the plant [2, 3]. Nonetheless, although scientists have gathered some information concerning the possible influence of heavy metals on the functioning of stomata, there is a lack of comprehensive understanding about the detailed mechanism. Recent discoveries indicate that different plant species may undergo stomatal closure in reaction to diverse heavy metal exposures. This is likely one of the compensating mechanisms by which plants respond to heavy metal stress [2].

The detrimental impacts on plants are frequently evidenced by an increased degree of damage as a heavy metal advances along the food chain. Individuals residing near the origin of heavy metal contamination may be directly impacted by the poisons via airborne particulates or alternative pathways. Farmlands in the nearby proximity may be the source of contaminants that find their way into the food chain due to the absorption of edible plants and this may compromise human health to a large extent, a situation that has worsened considerably in recent years.The possibility of the soil-crop system to assimilate heavy metals is a major route by which individuals can be exposed to these contaminants. Heavy metal toxicity leads to the production of reactive oxygen species causing oxidative damage which adversely affects health. Their toxicity is dependent on several factors, including the person's age, sex, genetics, diet, as well as the kind of chemical compound, dosage, and method of exposure [4]. Arsenic, cadmium, chromium, lead, and mercury are the few metals which cause serious health damage owing to their elevated toxicity levels [5]. Even at reduced exposure levels, these metallic elements are recognized for causing multi-organ damage and are categorized as systemic toxicants. Every heavy metal has its own peculiarities and physicochemical properties that govern its biological function. This review investigates the environmental prevalence, sources of heavy metals, and their possible impact in order to gain a better understanding in this aspect.

2. HEAVY METAL

Heavy metals denote any metallic element with a relatively high density, typically exceeding 4 g/cm^3. The toxicity of heavy metals may differ based on their type [6]. Although many metals induce acute and chronic ailments, only a limited number of metals are essential for the metabolic functions of the human body. Heavy metals encompass actinides, lanthanides, certain metalloids, and transition metals. Both metals and metalloids are categorized as heavy metals. Of the ninety naturally occurring elements, 53 are designated as heavy metals, some of which pose significant environmental toxicity concerns, including arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, and thallium. They pose a significant concern due to their inability to degrade and their persistence in the environment. These metals exhibit positive valencies and are located in Group I and Group III of the periodic chart.

3. SOURCES OF HEAVY METALS

Various processes can result in the increase of heavy metals in aquatic environment from both natural and man-made sources [7-9] (Figure 1). Natural sources include the interaction between water and rock, along with the wet and dry deposition of atmospheric salts. The swift industrialization and urbanization of the earth exemplify anthropogenic factors. The geochemical properties, hydrogeology, and local geology of the aquifer are the natural sources of heavy metal pollution in water. Sandstone, limestone, dolomite, and shale are types of sedimentary rocks whose weathering mostly contributes to the contamination of water reservoirs with elements. The interaction of water with igneous rocks produces major elements such as basalt, andesite, and granite. Various minerals or ores enhance the elemental composition of magnetite, hematite, goethite, and siderite (iron); calcite, cuprite, malachite, and azurite (Copper); chromite (Chromium); kaolinite, montmorillonite, arsenic trioxide, orpiment, and arsenopyrite (Arsenic); calamine and smithsonite (Zinc); and pyrolusite and rhodochrosite (Manganese) during dissolution. Trace elements such as cadmium, cobalt and manganese are found in the Earth's crust alongside various minerals. Additionally, dry or wet atmospheric aerosol deposition from wind-blown dust, volcanic emissions, forest fires, and vegetation introduces nickel, lead and mercury into aquatic systems.

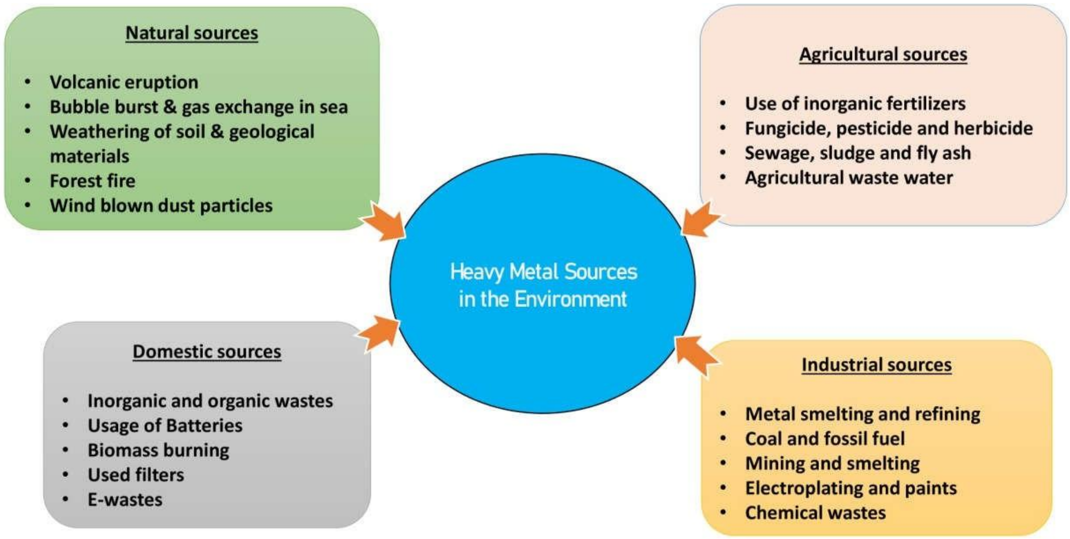

Figure 1 Sources of heavy metals in the environment

Metal smelting facilities coal-fired power plants and petroleum combustion nuclear power facilities high-voltage transmission lines plastics, textiles, microelectronics, insecticides, wood preservation and paper processing facilities exemplify industrial sources. The majority of nations possesses arable land and utilizes cattle. Use of inorganic fertilizers, pesticides and discharge of waste water sludge are also significant sources of heavy metals. Heavy metals are also present in the walls of gasoline tanks, engines, fuel, various vehicle components, and catalytic converters. Traffic activity is a primary contributor to the accumulation of heavy metals in roadside soils over time. A significant source of pollution for agricultural ecosystems adjacent to roadways is the release of heavy metals from vehicular activities. Reports indicate that fuel comprises anti-knock chemicals, including cadmium, zinc, and nickel, which are present in emissions from heavy traffic. Heavy metals are released by car emissions and various industrial activities, exposing inhabitants near busy highways and industrial zones to increasing amounts of heavy metal contamination in their soil, vegetation, and aquatic environments. The anthropogenic source of nickel is corroded metallic containers and pipelines. The principal sources of lead in aquatic habitats include paints, fuel additives, and aerosols resulting from high-temperature industrial activities such as coal combustion, smelting, and cement production. The water system may become contaminated with lead due to industrial discharge and the failure of galvanized pipes.

Cadmium found in phosphate fertilizers, also contribute to water body contamination [10]. Copper is frequently identified in copper pipes, compounds used to prevent algal proliferation and in potable water sourced from industrial effluents. Iron and manganese in water originates from sewage, landfills, leachate, acid mine drainage and industrial effluents. Mineral extraction for additives in poultry and swine feed, nonferrous mining, fossil fuel combustion and pesticide applications are contributing reasons for arsenic contamination in aquatic ecosystems. A common industrial activity that substantially contributes to soil heavy metal contamination is mining. Research has demonstrated that mining operations contribute to increased levels of Copper and Cadmium in soil. Most soil pollution is usually directly linked to mining activity and the erosion of the coal-bearing sandstone. The concentrations lead, zinc, Manganese, Cadmium, mercury, nickel and iron were found to be above the permissible level. Cadmium pollution was related to severe contaminated soils in coalfield areas and constituted the main source of pollution. Heavy metals in soils often serve as contributors to environmental and atmospheric pollution, thus they can cause a wide array of problems to plants and animals as they get integrated in the food chain. The heavy metals can be incredibly toxic and harm water, soil, and air. In addition, the ever expanding industrial, residential, agricultural, scientific, and technical ventures are littering the environment with heavy metals affecting the health of people and ecological systems. The effect of heavy metals on living organisms is closely related to various factors like the dosage, time, route of exposure, the form of the chemical, as well as the physiological conditions and diet of the individuals. Arsenic, cadmium, chromium, lead, and mercury are detrimental in the order of their decreasing toxicity. Substances with toxicities that affect the systemic health of the body are known as systemic toxicants. The critical aspect included in the assessment of the impact of heavy metals on the ecosystem is the presence of heavy metals in both soil and vegetation. Metal ions are released from soil into water bodies through environmental processes such as acid rain and industrial effluents. These are the major causes of aquatic pollution that affects the aquatic fauna and flora. Point source locations like smelters, mining operations, and other metal-based industrial activities are among the major contributors of heavy metal induced environmental pollution [11]. Heavy metals are known to damage to cellular organelles like cell membrane, mitochondria, lysosomes, endoplasmic reticulum and nucleus. They also disturb the fine balance between metabolism and different physiological processes associated with detoxification, and repair. Several studies have documented significant morphological, metabolic, and physiological abnormalities in plants, including shoot chlorosis, lipid peroxidation, and protein denaturation as result of heavy metal induced toxicity. Each heavy metal possesses an own molecular pathway for inducing toxicity, although a detailed understanding of the mechanisms are not thoroughly understood.

4. FACTORS AFFECTING ACCUMULATION OF HEAVY METALS

Various factors, including parent material, soil features, and anthropogenic activities such as industrial production, transportation, agriculture, and irrigation, affect the accumulation of heavy metals in an environment [5, 12]. Heavy metals from smelters, waste incinerators, industrial effluents, sludge or municipal compost applications, pesticides, and fertilizers can contaminate extensive areas of land. A number of issues, inclusive of traffic load, street circumstances, highway and roadside topography, roadside proximity, direction of the breeze, precipitation, vegetative cover, and local economic conditions have an influential impact on the heavy metal concentrations. However the factors can be categorized as:

- Source of contamination: Industrial activities, mining, agricultural practices (like the use of chemical pesticides and fertilizers), and urban runoff can introduce heavy metals into the environment.
- Soil properties: Soil pH, organic matter content, and texture can affect metal solubility and mobility. Acidic soils tend to increase metal solubility, leading to higher accumulation.
- Water chemistry: The presence of dissolved organic matter, pH, and ionic strength can influence the bioavailability of heavy metals in aquatic environments.
- Biological factors: The presence of microorganisms and plants can impact metal uptake. Certain plants can hyper-accumulate metals, while microbes can facilitate metal transformation and mobility.
- Climate and weather: Rainfall, temperature, and wind can influence the dispersion and deposition of heavy metals. Heavy rains can lead to runoff, increasing metal concentration in water bodies.
- Geological factors: Natural mineral composition of the soil and rock can contribute to background levels of heavy metals. Areas near mineral deposits may have higher natural concentrations.
- Land use and management practices: Agricultural practices, industrial waste disposal, and urbanization can alter the landscape and contribute to heavy metal accumulation.

- Biomagnification: Heavy metals can accumulate higher up in the trophic level of the food chain leading to higher concentrations in predators [13].
- Sediment resuspension: In aquatic systems, disturbances can resuspend sediments containing heavy metals, leading to increased bioavailability.
- Regulatory and mitigation measures: Effective environmental policies and cleanup efforts can reduce heavy metal accumulation by managing sources and minimizing exposure.

Understanding these factors can help in assessing the risks associated with heavy metal pollution and in developing strategies for remediation and prevention.

5. EFFECTS OF HEAVY METAL ON ORGANISMS

An excess of metal pollutants in soils can migrate to vegetation, subsequently transferring to humans, animals, and other organisms [1]. Humans can be exposed to heavy metals via three primary routes: ingestion, dermal absorption, and inhalation. The limited environmental mobility of hazardous metals, even under intense precipitation, coupled with their long-term persistence, intensifies the threat they present to human and animal health. Moreover, due to their exponential proliferation across many industrial, agricultural, domestic, and technological applications, human exposure has significantly escalated. In elevated quantities, all metals pose a risk. The organism may be adversely affected by elevated quantities. Additional toxic heavy metals devoid of any recognized beneficial or essential impacts on living organisms include lead, plutonium, and mercury. Over time, these metals can bioaccumulate in animal bodies and induce severe sickness. Heavy metals disrupt metabolic processes in two manners: firstly, they accumulate and induce malfunction in essential glands and organs such as the liver, heart, brain, kidneys, and bones [14]. They disrupt the biological function of key dietary minerals by displacing them from their normal positions. Nevertheless, existing in a world free from heavy metals is impractical. These poisons can infiltrate the body through several routes, including inhalation, ingestion of food and beverages, and dermal contact. A primary method by which humans encounter heavy metals in the food chain is via the transfer from soil to plants. Moreover, inhalation of heavy metals might directly jeopardize public health via soil and dust exposure, dermal contact, or respiratory intake (Figure 2). Human exposure to heavy metals in agricultural areas may predominantly arise from the intake of heavy metals through the soil-crop system. Elevated ambient levels of heavy metals generally result in health complications that adversely affect the neurological, hematopoietic, cardiovascular [15], renal [16], and reproductive systems [17]. Heavy metal exposure results with diminished intelligence quotient, attention deficit disorder, behavioral problems, and an elevated risk of cardiovascular disease in adulthood. Although many trace metals, such as copper and zinc, are benign in minimal amounts, the majority, including lead, arsenic, mercury, and cadmium, are detrimental even at minor concentrations and may function as cofactors, initiators, or promoters in various illnesses, including an elevated risk of cancer.

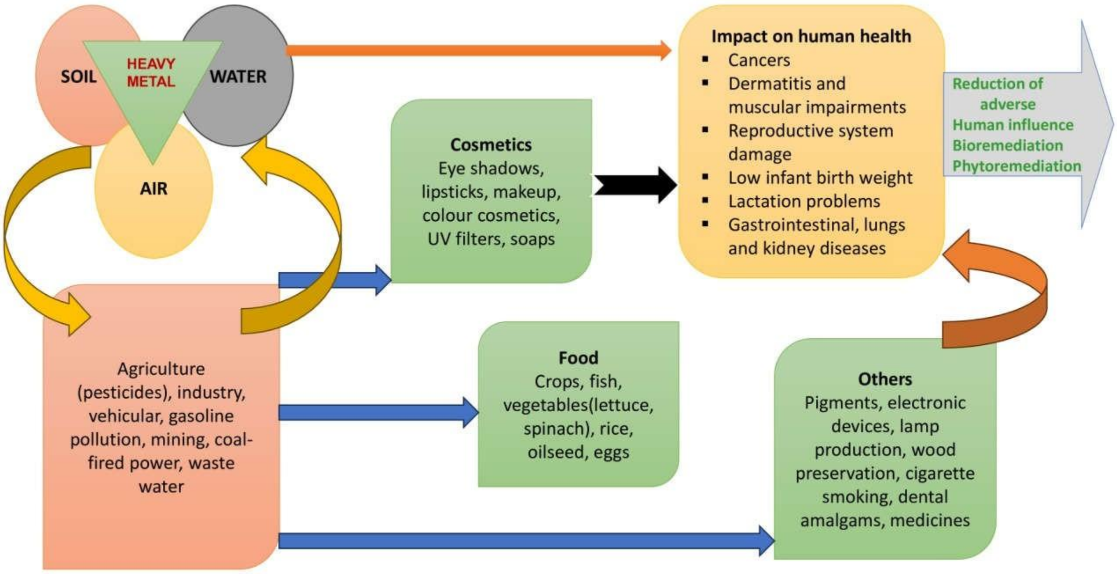

Figure 2 Impact of heavy metals on human health

Nevertheless, the permanent immobilization of heavy metals within distinct soil components renders their extraction from soils challenging. Excessive consumption of heavy metals from plants by an animal beyond the bio-recommended thresholds may result in adverse effects. Although distinct metals may exhibit varying toxicological symptoms, cadmium, lead, iron, zinc, and copper poisoning have been associated with gastrointestinal disorders, diarrhea, stomatitis, tremors, hemoglobinuria (resulting in rust-red stool), ataxia, paralysis, vomiting, and convulsions. Inhaling volatile fumes and vapors may result in pneumonia and despondency. Effects may be neurotoxic, carcinogenic, mutagenic, teratogenic, or exhibit acute, chronic, or sub-chronic toxicity. Lead is a trace metal that can impair human brain development and inhibit growth, especially in young children.

6. EFFECT OF HEAVY METALS ON PLANTS

Exposure to heavy metals induces oxidative stress in plants, resulting in cellular damage and disruption of ionic equilibrium. Plant detoxification processes, especially involving subcellular compartmentalization and chelation, have evolved to mitigate the detrimental effects of heavy metal exposure and accumulation. Plants are recognized for synthesizing phytochelatins, a principal category of heavy metal chelators. Phytochelatins are synthesized by a transpeptidation reaction catalyzed by the enzyme phytochelatin synthase utilizing reduced glutathione [18]. Consequently, the availability of glutathione is essential for the formation of phytochelatin in plants, particularly when subjected to heavy metals. Excessive lead in plants interferes with several biological enzymes, modifying standard metabolic processes and perhaps inhibiting photosynthesis. High quantities of heavy metals can induce oxidative stress, DNA degradation, and interfere with biosynthetic processes. Plant contamination by heavy metals may occur by direct air deposition onto plant surfaces or via absorption by roots from contaminated soils. Heavy metal contamination can alter the chemical composition of plants, adversely affecting the efficacy and quality of natural products derived from medicinal plant species. Heavy metal toxicity inhibits plant development, enzymatic activity, stomatal functions, photosynthetic activity, and the accumulation of other nutrient elements, while also damaging the root system [2, 19, 20]. Heavy metal accumulation can adversely affect the quality of agricultural products, crop yield, and soil health.

7. CONCLUSIONS

In most major cities, the problem of environmental pollution from toxic metals is a primary concern. The introduction of toxic metals into the environment can lead to biomagnification, geoaccumulation, and bioaccumulation. The global challenge of heavy metal pollution arises from the metals' persistence and their toxic effects on flora and fauna at quantities exceeding certain thresholds. The weathering of parent materials through pedogenetic processes leads to the natural occurrence of heavy metals in soil. Anthropogenic sources of heavy metals encompass car emissions, industrial and energy generation, traffic pollutants, waste management, and the incineration of coal and fuel. Increased levels of heavy metals can degrade soil quality, resulting in diminished crop yields and inferior agricultural products. This may present significant hazards to the health of humans, animals, and ecosystems.Therefore, to assess human exposure and maintain a sustainable ecosystem, it is essential to consistently analyze and monitor the levels of heavy metals in the environment due to the increase in anthropogenic activities. In ecosystems affected by heavy metals, systematic remediation methods include phytoremediation, microbiological remediation; integrated remediation, soil and crop management approaches and chemical and physical remediation should be employed to eliminate the accumulated metals.

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