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Impact of Heavy Metal Pollution on the Biotic and Abiotic Components of the environment

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Abstract: The environment includes biotic and abiotic components interacting as a system and also contains organic and inorganic minerals in optimal concentration that are required by living organisms for their growth, development, and metabolic activities.Due to natural and anthropogenic activities the availability of these elements has drastically increased in the ecosystem causing pollution.Heavy metal (HM) is one of the naturally occurring elements that generally threaten plant, animal, and human health.However, some heavy metals are biologically essential elements required in the body/plant or as constituents of important enzymes although in trace amounts while others are non-essential and are ranked as priority metals due to their high level of toxicity with no biological importance even at low concentrations. The non-degradability property of heavy metals contributes to its persistence and subsequent accumulation in the biota and the food chain which is of public health significance to humans and animals. The soil environment is highly prone to HM contamination due to physiological, biochemical, metabolic, and biogeochemical processes that occur within the environment mostly mediated by microbes.

Keywords: Heavy metal; pollution; environment; microorganisms; ecotoxicology.

INTRODUCTION

Heavy metals are metallic elements known to have a density higher than that of water [Zhang X et al(2019)].They are present naturally in water and land in very small concentrations with a ppb of < 10ppm and are therefore referred to as trace elements [Duruibe et al(2007)].Although heavy metals can occur naturally in the environment, they can also be introduced or their concentrations increased in the environment through anthropogenic activities such as mining, smelting operations, agricultural activities, and the use of other metal-containing compounds [Shrestha R et al(2021)]. Other natural sources of HM pollution include volcanic eruptions, weathering of metal-bearing rocks, and metal corrosion.In addition, some of the severe environmental consequences of heavy metal contamination occur through metal ion soil depletion, sediment re-suspension, and heavy metal leaching.However, weathering and volcanic activities have been shown to contribute considerably to heavy metal contamination [Shrestha R et al(2021)].Other ‘industrial sources of heavy metal pollution include the combustion of coals and petroleum in power plants, quarries, metal processing in refineries, nuclear power plants, high-tension lines, plastics, textile, and paper processing industries [Duffus Y &Jiang Y et al(2012)].Heavy metals can be categorized into essential and non-essential metals based on their uses and requirements by biological entities.The essential heavy metals act as macronutrients such as zinc (Zn), copper (Cu), nickel (Ni), cobalt (Co), and chromium (Cr) and they also play a key role in oxidation-reduction reactions [Bruins MR et al(2016)] while non-essential heavy metals include cadmium (Cd), lead (Pb), plutonium (Pu) and mercury (Hg).These metals have no biological importance and are thus regarded as environmental pollutants [Concas A et al(2006)]. Although, plants, humans, and microorganisms

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utilize heavy metals for metabolic and physiological functions, at high concentrations they are toxic and could be damaging to organs. Various biological and toxicological effects of heavy metals in the environment occur as result of the diverse forms in which heavy metals interact and exist in the environment. The consequence of elevated levels of HM contamination sometimes leads to the overall reduction in microbial activity, population, and diversity in the environment [Turpeinen R(2002)].Again, increased HM toxicity can result in the modification of the structure of proteins or nucleic acids in living organisms. Mercury, cadmium, and silver can hinder the activity of certain enzymes that are necessary for microbial metabolism by attaching to the sulfhydryl (SH) groups [Smejkalova M et al (2003)].The impacts of the heavy metals can range from the inhibition of microbial metabolism, morphology, growth, and destruction of the integrity of bacterial plasma membrane [Smejkalova M et al(2003)].Other impacts of elevated heavy metal concentrations in soil and water may include a reduction of soil protein activity, soil microbial activity, and thus a reduction in the soil microbial community. Soil microbes are essential in soils because they support ecosystem functioning and mediate several metabolic and physiological processes in the environment. Some of these roles include decomposition of soil organic matter, regulation of biogeochemical cycles, biotransformation and bioconversion of elements, nutrient uptake, bioremediation, and others. Hence, any slight decline in the abundance or diversity of these microbes could have a profound impact on the ecosystem and its components [Chakravarty et al(2008)].To understand the dynamics of soil microbial communities, it is important to first identify their structure, abundance, and distribution. Additionally, in-depth knowledge of the microbial arrangement and their response to changes in environmental conditions due to heavy metal contamination is also important to understand the soil microbial community and response [Ndeddy Aka RJ, Babalolaoo (2016)]. In soil, when HM pollution occurs, it is transported around the soil and its fate is dependent significantly on the speciation and chemical nature of the metal.The initial step involves a very swift reaction (minutes, hours) immediately followed by a slow adsorption reaction occurring for days or months.The HM is subsequently redistributed into various chemical forms with different toxicity levels, bioavailability, and mobility.It is believed that the several reactions of the heavy metals in soil control distribution such as plant uptake, mineral precipitation and dissolution, biological immobilization and mobilization, ion exchange, and aqueous complexation [Wuana RA, Okieimen FE(2011)]. In addition to adverse impacts on plants and soil, heavy metals pose threat to human health due to their persistence in nature.For instance, Pb is one of the most toxic heavy metals that have a soil retention time of 150–5000 years and have been reported to maintain its high concentration for as long as 150 years [Nandankumar PBA et al (1995),Yang X et al(2005)

Plants growing in heavy metal-contaminated sites generally accumulate a high quantity of heavy metals, and thus, contamination of the food chain occurs which can result in the entry of heavy metals into animal and human tissues, making them prone to several diseases that range from dermatitis to various types of cancers.

HEAVY METAL POLLUTION

Environmental pollution caused by heavy metals is considered to be one of the foremost challenges in modern human society [Lenart A, Wolny-Koladka K(2013)]. Technological advancement, urbanization, and industrialization have led to a drastic increase in heavy metal contamination. Some of the natural sources by which heavy metals are introduced into the environment include volcanic eruptions and the weathering of metal-containing rocks while anthropogenic sources include mining, smelting, release from industrial effluents, domestic activities, and other agricultural activities which include the use of metal- containing fertilizers and pesticides [Lasota J et al (2020), D'amore J et al (2005)]. According to Cullen JT et al (2013)the combustion of fossil fuels could also lead to an increase in the release of cadmium (Cd) into the environment. Due to their toxicity, heavy metals remain in the environment, pollute food chains, and create a variety of health concerns.Long-lasting exposure to heavy metals in very high concentrations in the environment can pose a serious threat to humans, plants, animals, and microbes. Copper, arsenic, zinc, silver, chromium, molybdenum, mercury, gold, vanadium, cadmium, and lead are examples of heavy metals [Khan F I et al(2004),Annan E et al(2018)].The properties of some selected heavy metals will be discussed as follows:

a. Lead (Pb): Lead is a common contaminant found in soil and unlike other metals, it is toxic to biotic elements and has no biological role in the environment. Uptake of lead in food, water, and air are the most significant ways by which lead enters the human body and the constant exposure to these metals can lead to severe effects on the health of plants and humans [Jyothi NR(2020)]. Exposure of humans to a very high level of lead may produce encephalopathy [Mohammadyan M et al(2019)].In most cases, repetitive or continued exposure to lead can cause toxic stress on the kidney, which if untreated may result in irreversible and chronic intestinal nephritis [Mohammadyan M et al (2019)].Lead exposure has also been reported as a major factor that may contribute to the development of hypertension.[Wildemann TM et al.(2016)] also discovered that increased lead exposure can heighten the risk of hypertensive heart disease and cerebrovascular diseases.

b. Nickel (Ni): Nickel can cause several damages to the environment, plants, humans, and microorganisms. Nickel damage to humans has long been associated with oxidative reactions involving lipids, proteins, and DNA, it has also been found to attach to biomolecules and thus alter their properties [Nieminen TM et al(2007)]. Some of the mechanisms by which nickel affects microbial cells include: replacing essential metals, binding to non-metal enzyme residue, binding outside the

Catalytic sites of an enzyme, and causing oxidative stress in lipids, DNA, and proteins [Kasprzak KS et al(2011)].

c. Zinc (Zn): Zinc is the fourth most produced metal and it is essential to modern living.Its uses ranges from application in rubber production and pharmaceuticals, metal coatings to protect iron and steel from corrosion, and as an important element for enhanced growth in animals, plants, and humans [Hemand H F, Fechner (2014), Fallah A et al (2018)].Although zinc is important for human health and development, it can also be harmful to the environment if found in excess. During anthropogenic activities such as mining, chemical, pulp, and paper production, $Zn2+$ is usually emitted and can be extremely harmful to the environment and creatures exposed to it [Hambidge M(2003)].

d. Copper (Cu): Copper is one of the most utilized metals in the world and on the list, it is third. Copper is one of the essential heavy metals and it is categorized as a micronutrient. Its application cuts across humans, animals, and plants.It is required in the growth of plants and animals and in humans, it assists in the formation of blood hemoglobin. Again, in plants, Cu is specifically important in areas that support plant growth such as disease resistance, seed production, and water regulation. Notwithstanding, Cu even as an essential metal can cause a number of health issues such as kidney damage, stomach, and intestinal irritation, anaemia, regulation of water, liver and kidney damage when present in elevated concentrations [Jyothi N R(2020)].It has been reported that there is a complex but defined interaction between copper and the environment [Nevzorova T et al(2019)].When Cu is introduced into an environment, it immediately becomes stable and takes up a form that is not toxic, harmful, or poses any risk to the environment, unlike some other metals.In addition, Cu does not bioaccumulate in the food chain which is one of the public health challenges in heavy metal pollution and also it is not magnified in the body.This essential heavy metal forms strong complexes with soil which indicates only a small fraction is present in soil solution and they occur as Cu (II) [Nevzorova T et al(2019)].

e. Mercury (Hg): Mercury (Hg) is a non-essential HM and it is found on the periodic table with Zinc and Cadmium. Mercury is characterized by atomic weight of 200.6, atomic number of 80, melting point of −13.6°C, and boiling point of 357°C, density of 13.6 g cm−3, and is usually recovered as a byproduct of ore processing. There are several sources of Hg in the environment but the major source of Hg contamination is the release from coal combustion. Another contributor to Hg contamination is the release from manometers at pressure-measuring stations along gas/oil pipelines.In the environment, Hg exists in different forms such as mercurous (Hg22+), mercuric (Hg2+), alkylated (methyl/ethyl mercury), or elemental form (Hgo) [Wuana RA, Okieimen FE(2011)]. These various forms are initiated based on the pH and redox potential of the system. Organic and inorganic mercury could be reduced to elemental Hg and further converted to other alkylated forms by abiotic and biotic processes.

f. Arsenic (As): Arsenic has a low crustal abundance (0.0001%) in nature and is frequently associated with metal ores such as copper, lead, and gold [Oremland RS, stolz J F(2003)].Arsenic is a common element that is found in abundance in the earth's crust, seawater, and the human body [Mandal BK, suzuki KT(2002)].Arsenate, As (V), Native elemental arsenic As (0), Arsenite As (III), and As(-III) are the four oxidation states of arsenic [Oremland RS, stolz JF(2003)].Although elemental arsenic is rare, toxic arsines can be found in gases emitted by anoxic environments. In aqueous, aerobic environments, arsenate is the most common form of inorganic arsenic. Certain pollutants, such as arsenic (As), can persist in the environment for a long time.They eventually build up to levels that can harm the physiochemical properties of soils, resulting in a loss of soil fertility and crop yield.When arsenic is not detoxified, it can cause a chain reaction that inhibits growth, disrupts the photosynthetic and respiratory systems, and stimulates secondary metabolism [Garg N, singla P(2011)].Arsenic contamination of water and soil can also have a negative impact on food safety.Accumulated arsenic in plants affect the growing mechanisms and hence the yield of crops, as well as the accumulation of arsenic in crops may impact on health of living beings.Also, the accumulation of As in soil caused by the use of As-contaminated irrigation water has been shown to result in elevated levels of As in paddy soil and soil solution [Dittmar J et al(2007)].Results indicated a decline in yield progressive from 7–9 to 2–3 t ha−1 with increasing soil-As concentration.

g. Cadmium (Cd): It has been reported that high Cd concentrations reduces cell growth as well as overall plant growth.In a study by Al-Yemens et al.[A I Yemens MN(2001)], Vigna ambacensis was treated with a low concentration of Cd, and the root and shoot mass decreased significantly.High Cd content in soil can affect soil fertility, plant physiology, and metabolism, resulting in plant growth retardation and decreased yield [Mitra S et al(2018)].Cd also disrupts ion homeostasis by inhibiting the absorption of basic ions such as iron and magnesium, influencing nitrogen metabolism, and reducing water and mineral uptake [Afzal M et al(2019)].It also has a negative impact on photosynthesis, mineral element uptake, and transportation, resulting in a decrease in yield [Chen Q et al(2018)].In addition, Cd can cause morphological, physicochemical, and structural changes in plants, such as inhibiting lateral root formation, chlorosis, and stomatal density [Huybrechts M et al(2020)].Cadmium interferes with mitochondrial function by impairing redox regulation, which damages membrane lipids and disrupts plant metabolism.

THE FATE OF HEAVY METALS IN THE ECOSYSTEM

A few heavy metals have been designated as essential metals because they are beneficial to the growth of organisms and can also play major roles in a number of physiological and biochemical processes [Gautam P K et al(2016)].These heavy metals have been widely employed in industries, agriculture, medicine, and other fields resulting in their dispersion into the environment, including the air, water, and soils.Heavy metal toxicity rises as a result of the concentration of a large amount of the metal in one place and hence can lead to limited vegetation of the location and a reduction in the diversity of the organisms in such environment to only heavy metal tolerant species [Yang Y et al (2018)].

EFFECT OF HEAVY METAL CONTAMINATION ON THE ENVIRONMENT

Heavy metals contaminate freshwater bodies, sediments, and soils once they are released from both natural and human activities, hence both terrestrial and aquatic ecosystems are threatened by toxic metals [IslamMS et al(2018)]. Heavy metals discharged into the atmosphere as a result of volcanic eruptions and various industrial emissions eventually fall to the ground, contaminating water and soils.These metals accumulate in biota or leach into groundwater and their presence and persistence in these environments have serious consequences for public health [Rezania S et al(2016)].Different physicochemical and climatic factors affect the overall dynamics and biogeochemical cycling of heavy metals in the environment and it is therefore critical to determine the extent of heavy metal contamination in the ecosystem by examining theconcentrations and distribution of these elements on the different biotic and abiotic environmental compartments [Zhuang W GaoX(2014)].

EFFECT OF HEAVY METAL ON WATER

Water is a universal solvent and hence it can dissolve diverse environmental contaminants including inorganic and organic chemicals. Aquatic ecosystems such as the marine and freshwater systems are easily contaminated and termed "the ultimate sink for contaminants". Contamination of the water environment results majorly from anthropogenic activities such as agriculture (pesticides, fertilizers), urbanization (deforestation, automotive activities), and industrialization (mining, construction, refining of fossils, use of diesel engines).Heavy metal pollution is a serious environmental issue and can adversely affect humans, animals, plants, and microbes [Rajaei G(2012)].Even at very low concentrations, some heavy metals are toxic to organisms that inhabit the aquatic ecosystem. The effects of heavy metals in the aquatic systems can range from causing a significant his topathological alteration in fishes to high mortality rates of all aquatic organisms in cases of very high heavy metal concentrations. There are several sources through which aquatic ecosystems can be contaminated as earlier mentioned but one of the major sources of heavy metal release into water bodies is via effluents from mining operations [Ali H, Khan E(2018)]. Different industrial effluents, agricultural run-offs, and sewage from residential areas have all been reported as sources of heavy metal contamination in water bodies with the discharge of untreated effluents from industries ranking as the foremost source of heavy metal pollution in both groundwater and surface water.Heavy metal pollution of water bodies is a global issue due to the metals' toxicity, persistence in the environment, bioaccumulation, and biomagnification in food chains [Chen Q et al (2022)]. Most rivers, especially those that flow through mining and industrial areas are majorly polluted.The water flows down into the sea and can further sink to the sea bottom as a result of slowing of the tide.Since the solubility of metals is mainly determined by the water or solvent pH, when there is a rise in the acidity of river water, the ability of the metals to solubilize decreases, and thus they are precipitated towards the sea and can cause more harm to the organisms in these habitats [Rajaei G(2012)].

EFFECT OF HEAVY METAL CONTAMINATION ON SOILS

Heavy metals and metalloids enter soils from a variety of anthropogenic and lithogenic sources [Alloway BJ(2013)].Smelting and mining activities emit localized pollution into the atmosphere, which eventually settles on the land.The presence and distribution of heavy metals in soils are influenced by factors such as the composition of the parent rock, climatic circumstances, biological, chemical, and physical characteristics of the soil, and the degree of rock weathering.Soils that receive high input of chemical fertilizers and heavy metal-containing pesticides showed considerable enrichment of heavy metals when compared to soils with minimal or no inputs [Alloway BJ(2013)]. Because of the substantial amount of automotive activity on roadways, utilization of diesel engines for power generation, and other industry-based activities, heavy metal pollution of soils occurs significantly in urban areas.Heavy metal bioavailability in soils is critical for their fate in the environment and uptake by plants.Different heavy metals have varying bio availabilities in soils due to metal speciation as well as soil physicochemical factors. Heavy metals such as zinc, cadmium, copper, lead, and chromium have been identified in significant concentrations in the soil of agricultural lands [Gupta DK et al(2014)].Some regions where smelting occurs lack the inhabitation of living organisms such as earthworms (which play a major role in the decomposition of organic matter) and vegetation

EFFECT OF HEAVY METAL CONTAMINATION ON SOIL MICROORGANISMS

Heavy metals have a direct and indirect impact on microorganisms, which is why they are the first biota to be affected.Metals such as Fe, Zn, Cu, Ni, and Co are essential for certain microbial functions such as metabolism and redox reactions and are therefore required in very minute concentrations.Microorganisms are responsible for a number of soil biochemical reactions responsible for soil quality maintenance, decomposition of xenobiotics, formation of soil organic matter, and generally support ecosystem functioning.Heavy metals in high concentrations can have inhibitory or even toxic effects on living organisms such as reduced soil enzymatic activity and reduced rate of soil respiration [Chen X et al(2020)].

CONCLUSION

Environmental pollution by heavy metals is a global menace with consequences transcending beyond abiotic to biotic.Most of the biotic components play significant roles in driving ecosystem functions and balance.This study has extensively analyzed and highlighted the fate of heavy metals in the environment with special reference to the soil environment and its possible roles in supporting biological entities and mediating certain biochemical processes at low or permissible limits.It has been revealed in ths study that HM at high concentrations is highly toxic and could disrupt the metabolic function and activities of microbes as well as damage soil structure and integrity.In addition, several mechanisms have been designed to remediate and decontaminate HM polluted environment and in recent times, the integrated system of plant- microbe interaction has been applied in a technology known as phytoremediation. More recently, bio-technological studies have been applied in genetically modifying microorganisms with the selective advantage of HM resistance to promote phytoremediation of HM more efficiently.Despite the successes gained in the application of this technology, more research is required to improve the activities of microorganisms to be HM-specific and to facilitate removal within the shortest time duration.

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