Heavy Metals' Impact on Health, Including Soil, Plants, and Humans and Their Bioremediation

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Abstract

Environmental contamination is mostly caused by unplanned municipal garbage disposal, mining, and the use of pesticides and agrochemicals. Heavy metals, including cadmium, copper, lead, chromium, manganese, iron, and mercury, are significant soil contaminants, especially in places with high anthropogenic pressure. Heavy metal deposition in soils is an issue in agricultural production due to its negative impact on food safety, crop development, phytotoxicity, and soil organism health. Bioremediation involves using microbes and beneficial plants to remediate metal-polluted soils. Heavy metals undergo transformation from one organic complex or oxidation number to another, resulting in decreased toxicity, easier volatilization, increased water solubility, and removal from contaminated soils. The Ayurvet studies Foundation conducts studies to improve soil health and educate farmers about the negative impact of herbicides, insecticides, fungicides, and chemical fertilisers on crop yield and food safety. The organisation showcases organic farming methods, such as using high-quality irrigation water, vermicompost, and zero-tillage techniques, to promote agricultural yield and environmental sustainability.

Keywords: Soil, Bioremediation, Biochar, Heavy Metals

INTRODUCTION

The ability of soil to continue serving as a vital living ecosystem that supports people, animals, and plants is known as soil health. A healthy soil functions as a dynamic living system that provides a variety of ecosystem services, such as maintaining plant production and water quality, managing the breakdown and recycling of soil nutrients, and eliminating greenhouse emissions from the environment. Since the majority of the components of soil health are the variety and activity of soil microorganisms, it is strongly tied to sustainable agriculture.

For ecological, evolutionary, nutritional, and environmental causes, heavy metal toxicity may pose an enormous threat to the ecosystem [1]. Heavy metals are important environmental contaminants. Because metal pollution is non-biodegradable and remains in the soil for a considerably longer time than other components of the biosphere, eliminating it may be a difficult undertaking. Increased metal contamination of all environmental components is a result of rapid industrialization and inadequate control of company effluents [2]. The group of inorganic chemicals known as heavy metals, which include lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni), are the most often detected in polluted locations [3]. The primary sink for heavy metals released into the environment by the aforementioned human activities is soils. Most metals do not degrade chemically or by microbes, in contrast to organic pollutants, which are oxidised to carbon (IV) oxide by microbial activity [4]. For the benefit of farmers and society at large, the public trust Ayurvet Research Foundation (ARF) carries out a number of projects aimed at the sustainable integration of agriculture and livestock. Understanding the health index of the agricultural soil in the various districts of Haryana and educating farmers about the negative effects of pesticides, insecticides, fungicides, and excessive use of chemical fertilisers on crop yield and food safety are two of the ARF's key goals. The Organisation periodically conducts demonstrations of nil tillage, vermicomposting, organic farming methods, and the use of high-quality irrigation water with the purpose of maximising agricultural yield and environmental sustainability.

1. Source of heavy metals in soil:

At trace (<1000 mg/kg) and scarcely hazardous levels, heavy metals are naturally found in the soil environment as a result of pedogenetic weathering processes of parent materials. The majority of soils in rural and concrete environments may accumulate one or more heavy metals above specified background values high enough to pose risks to human health, plants, animals, ecosystems, or other media [5]. This is because man has disrupted and accelerated nature's slowly occurring geochemical cycle of metals. The heavy metals are essentially transferred from mines to random environmental locations where there is a higher potential for direct exposure, (i) their rates of generation via man-made cycles are faster than those of natural cycles, (ii) the concentrations of the metals in discarded products are relatively higher than those in the receiving environment, and (iv) the chemical form (species) within which a metal is found within the receiving environmental system may render it more bioavailable [6].

1.1 Fertilisers:

In intensive farming systems, large amounts of fertilisers are routinely put to the soil to provide enough N, P, and K for crop development. The substances used to provide these nutrients include trace levels of heavy metal contaminants, such as Cd and Pb, which may greatly increase the quantity of these metals in the soil following continuous fertiliser application [7].

1.2 Biosolids and Manures:

Applying a lot of biosolids (such as composts, animal manures, and municipal sewage sludge) to land unintentionally causes heavy metals including As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Mo, Zn, Tl, Sb, and so on to accumulate in the soil. Agricultural manures from pigs, cattle, and poultry are examples of animal wastes that are often added to crops and pastures in the form of solids or slurries. The most common heavy metals identified in biosolids are Pb, Ni, Cd, Cr, Cu, and Zn. The concentrations of these metals are determined by the kind and level of business activity, as well as by the process design used in the biosolids treatment [8].

1.3 Waste water:

The use of industrial and municipal wastewater is becoming commonplace in many regions of the globe. The main concern of farmers is increasing their yields and income; they are often unconcerned about environmental risks or advantages. Even while wastewater effluents typically have relatively modest metal concentrations, long-term irrigation of such land might ultimately cause heavy metal deposition in the soil [9].

2. The effects of heavy metals on soil:

In the industrialised world, soil pollution by heavy metals is a major source of concern. In addition to having a negative impact on a number of factors related to plant quality and production, heavy metal pollution also alters the size, makeup, and activity of the microbial population. As a result, heavy metals are regarded as one of the main causes of soil contamination. Many metals, including Cu, Ni, Cd, Zn, Cr, and Pb, are responsible for heavy metal contamination of the soil. It is well known that heavy metals have detrimental impacts on the biological and biochemical characteristics of soil. The degree to which metals affect biological and biochemical qualities is largely determined by the characteristics of the soil, such as its organic matter level, pH, and clay content [10]. Certain heavy metals, such as Co, Cu, Fe, Mn, Mo, Ni, V, and Zn, are necessary for life in trace amounts. Nevertheless, organisms may suffer damage from these components in excess. Other heavy metals, such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As, a metalloid but often referred to as a significant metal), are very detrimental to both plants and animals and have no positive impact on other creatures. For this reason, they are regarded as the "main threats." High levels of Cd in the soil cause apparent symptoms in plants, such as chlorosis, growth inhibition, browning of the root tips, and finally death [11,12,13].

3. Impact of heavy metals on seed:

The number of healthy seedlings guarantees more crop exchange in the sphere and, therefore, higher output, making seed germination and seedling growth crucial phases of development in the flora cycle. According to a number of studies, heavy metals either prevent or hinder seed germination by decreasing water absorption or harming or killing the embryo [6]. Depending on the metal's concentration, germination is affected by high concentrations while low concentrations have no discernible effect [7, 8].

Depending on the specific heavy metal involved in that process, the impact of heavy metal toxicity on plant growth and development varies. According to reports, nickel (Ni) is poisonous to the majority of plant species and affects the activity of the enzymes ribonuclease, amylase, and protease, which delays the development and germination of many crops. It has been noted to have an impact on the mobilisation and digestion of food reserves, such as proteins and carbohydrates, in seeds that are germinating. It has also been shown to decrease plant height, root length, fresh and dry weight, chlorophyll content, and enzyme carbonic anhydrase activity, while increasing electrolyte leakage and malondialdehyde content (MDA). It has been shown that lead (Pb) significantly alters the morphology and physiology of seeds. It prevents the production of chlorophyll, transpiration, germination, root elongation, seedling development, plant growth, and water and protein content. It also modifies the chloroplast, obstructs the electron transport chain, inhibits the Calvin cycle enzymes, impairs the uptake of Mg and Fe, two essential elements, and causes a CO2 shortage due to stomatal closure [4].

Copper stress results in a decreased rate of germination and causes biomass mobilisation via the release of glucose and fructose, which inhibits the activities of alpha amylase and invertase isoenzymes, preventing the breakdown of starch and sucrose in reserve tissue [8]. According to proteomics research, copper poisoning inhibits seed germination via suppressing alpha amylase activity. According to reports, it interferes with water absorption, general metabolism, and the inability to mobilise stored food [11]. It has been demonstrated that cadmium (Cd) delays germination, damages membranes, hinders the mobilisation of food reserves by increasing the ratios of total soluble sugars, glucose, fructose, and amino acids in cotyledons to embryos, leaks minerals and causes nutrient loss, accumulates in seeds, and causes an excess of lipid peroxidation products [14, 15] in seeds. It has been shown to suppress the activities of alpha amylase and invertases, as well as to reduce the germination percentage, embryo development, and biomass distribution.

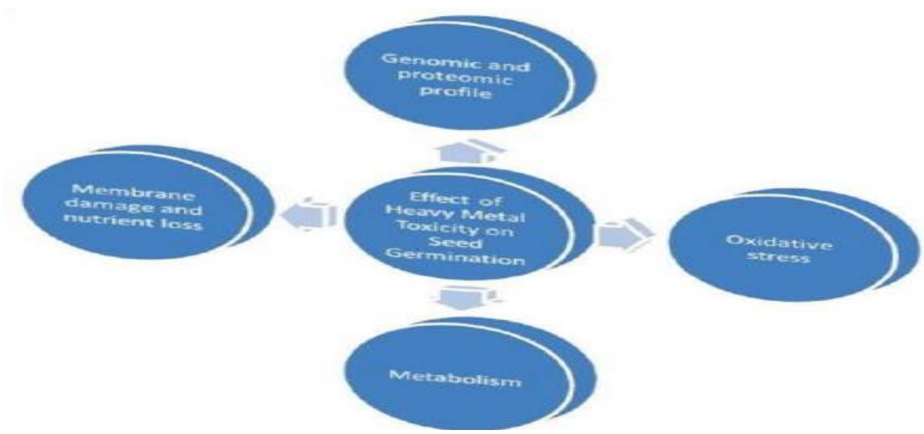

Figure 1:- Different effects of heavy metals on seed germination

4. How heavy metals affect plants

Certain heavy metals, such as As, Cd, Hg, Pb, or Se, don't seem to be necessary for the development of plants since they don't carry out any recognised physiological functions in plants. Other elements, such as Co, Cu, Fe, Mn, Mo, Ni, and Zn, are necessary for plants to grow and function normally, but when concentrations of these elements are higher than ideal levels, poisoning is a possibility. In addition to morpho-physiological and oxidative damage in plants with a higher transfer factor of cadmium from soil to plants, lead (Pb) is one of the heavy metals that is known to bio-magnify in animal bodies through contaminated crops. Cadmium concentrations are primarily found in fruits and vegetables [18]. Composting waste materials to improve soil for vegetable growth may be an issue, since most composts are used to raise agricultural productivity without considering potential harmful impacts. Given that most vegetable species have edible plant parts, the potential for heavy metals to be transferred from the soil to people may be concerning. The natural occurrence of plants absorbing heavy metals and their eventual buildup might pose a risk to the health of humans and animals. Plant roots are one of the main channels of entry for the absorption of heavy metals found in natural phenomena. These parameters include temperature, moisture, organic matter, pH, and the availability of nutrients. Plant species determine how well different plants absorb heavy metals, and plant absorption or soil-to-plant metal transfer factors are two ways to measure how well different plants do this. A very low Pb content may impair several essential plant activities, including as photosynthesis, mitosis, and water absorption, with toxic symptoms including dark green leaves, withering of older leaves, stunted foliage, and brown short roots. Elevated Pb in soils may also reduce soil production. In addition to causing chlorosis, sluggish plant development, yield depression, and perhaps reduced nutrient absorption, plant metabolic problems, and a decreased capacity for fixing molecular nitrogen in leguminous plants, heavy metals have the potential to be poisonous and phytotoxic to plants [19].

5. How heavy metals affect human health

Considering the effects on the food chain, plants that absorb large quantities of heavy metals from soil may provide a genuine health danger. Another major natural phenomena that exposes people to heavy metals is the use of food crops polluted with these pollutants. Food plants with a system of inspection based on thorough and ongoing cultivation are very good at pulling nutrients out of the soil. Since the vegetative cells of these plants may absorb heavy metals, growing them in polluted soil may be dangerous. When heavy metals build up in soft tissues and don't seem to be metabolised by the body, they become poisonous. Toxic metal consumption at a chronic level has negative effects on people, and these effects don't become apparent for years after exposure. Possibly one of the most well-known heavy metal toxicants, cadmium (Cd) has a specific gravity 8.65 times higher than that of water. It has been shown that the liver, placenta, kidneys, lungs, brain, and bones are the target organs for Cd poisoning. Depending on how severe the exposure was, nausea, vomiting, cramping in the abdomen, dyspnea, and weakening in the muscles are among the consequences. Death and pulmonary odema are possible outcomes of severe exposure.

Subchronic inhalation exposure to cadmium and related compounds may have consequences on the kidneys and lungs, including emphysema, bronchiolitis, and alveolitis. The world became aware of the dangers of environmental CD due to the Itai-itai sickness in Japan.

Many clinical disorders, such as anosmia, heart failure, malignancies, cerebrovascular infarction, emphysema, osteoporosis, proteinuria, and cataract development in the eyes, have been linked to mercury exposure to varying degrees. However, it has been challenging to establish clear connections between environmental exposures and both morbidity and death [15]. Particularly when given orally, zinc is thought to be largely non-toxic. On the other hand, an overabundance may lead to system malfunctions that impede development and reproduction. Clinical symptoms of zinc toxicosis include nephrosis, anaemia, icterus (yellow mucus membrane), vomiting, diarrhoea, and red urine. Because it is a part of metalloenzymes and functions as an electron giver or acceptor, copper (Cu) is an essential component of mammalian nutrition. On the other hand, exposure to elevated Cu levels may result in a range of detrimental health consequences. Humans are largely exposed to copper via the intake of food and beverages.

Acute copper poisoning is often linked to unintentional consumption; yet, some individuals are more vulnerable to the negative consequences of excessive copper consumption due to inherited traits or illnesses. A high consumption of copper by humans may cause significant mucosal irritation and corrosion, extensive capillary damage, damage to the liver and kidneys, and irritation of the central nervous system that is followed by depression.

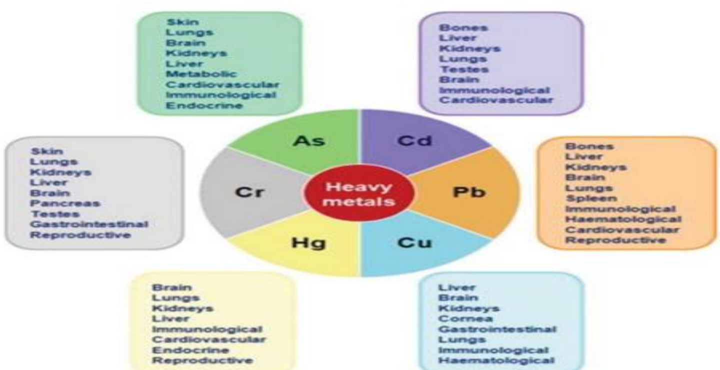

Figure 2:- Impacts of heavy metals on the environment

There is also a chance of developing severe gastrointestinal distress and necrotic liver and kidney abnormalities. Exposure to nickel may have a range of effects, from skin irritation to disruption of the lungs, system, and mucous membranes. Lead (Pb) poisoning affects human physiology and neurology. Acute lead poisoning may culminate in disease and death due to malfunctions in the kidney, reproductive system, liver, and brain. Pb is the most dangerous element even at very tiny amounts. The teratogenic impact of lead poisoning is one of its most dangerous side effects. Along with circulatory system injury and acute and long-term harm to the central and peripheral neurological systems, plumbism also inhibits the production of haemoglobin [19].

5. The use of bioremediation

Techniques for Remediating Heavy Metals

Using beneficial plants and microorganisms to remediate soil contaminated with metals is known as bioremediation. It is a widely used technique for remediating soil since it is evident that natural processes are at play. For the repair of heavy metal-polluted soils, it is a cost-effective and non-disturbing technique. During bioremediation, heavy metals may only change from one organic complex or number to a unique one; they cannot be broken down. Heavy metals often undergo changes in their oxide levels that lead them to become less volatile, less poisonous, or more soluble in water, which allows for leaching, while less soluble in water precipitates and is more readily removed from contaminated soils. A mixture of microorganisms and plants is used for the bioremediation of heavy metal-polluted soils [20, 21]. Numerous microorganisms, particularly bacteria (Pseudomonas putida, Enterobacter cloacae, and Bacillus subtilis) are effectively used to reduce the highly hazardous Cr (VI to III) to the less harmful Cr. There is evidence that Bacillus thuringiensis may enhance zinc and cadmium extraction from soil that is rich in cadmium and from soil contaminated by metal industrial effluent. It is thought that the building of siderophores, or Fe complexing molecules, by bacteria may have made it easier to remove these metals from the soil. These bacteria also generate siderophores, which has an impact on the metals' bioavailability. Through bioprecipitation by sulfate-reducing bacteria (Desulfovibrio desulfuricans), which transforms sulphate into hydrogen sulphate, which then interacts with heavy metals like Cd and Zn to generate insoluble forms of these metal sulphides, bioremediation may happen indirectly.

The present bioremediation strategy is severely limited by the debates surrounding genetically engineered organisms and, therefore, the undeniable fact that the heavy metal is still present in the soil.

Gram-negative bacteria have the ability to withstand and sequester copper from polluted environments. It has been found that the P. aeruginosa strain's biomass is very effective in recovering and removing Cd, Pb, and Cu from contaminated soil. Furthermore, Cd was successfully eliminated by the genetically modified P. aeruginosa. Furthermore, because of their high biosorption effectiveness, Pseudomonas strains have been shown to possess the ability to generate obviate Cd. The majority of microorganisms use a variety of tactics to combat the stress caused by heavy metals, including as enzymatic detoxification, metal ion sequestration, active efflux of metals, and Cd accumulation. Although there are many chemical techniques available to remove the bulk of chromium from industrial effluent, these procedures frequently fall short of meeting environmental laws. During chemical processing, poisonous and environmentally hazardous substances are released into the atmosphere. For this reason, microbial therapy of CTLS is also a preferable option than chemical treatment since the latter increases environmental contamination [22]. In order to reduce the amount of chromium, a variety of microbes, including bacteria, fungi, and certain species of bacteria like Pseudomonas, Bacillus, and Arthrobacter, are used in microbial treatment. In polluted sites, the processes of complex formation, oxidation-reduction, and precipitation all depend on microbial activities. On the other hand, prolonged exposure to chromium may lower microbial population, variety, and activity. Numerous bacterial species that have been shown to be very resistant to chromium and are considered crucial for chromium removal have survived for years in polluted places where chromium has been present.

5.1 Methods of Physicochemistry

Processes that use physical-chemical approaches to force heavy metals out of any polluted environment are included in this category. They will be used with metal-containing or metal-particulate-containing particles. Electrochemical treatment, electrokinetics land filling, solvent extraction, chemical precipitation, chemical reduction, isolation (mechanical) separation of metals, precipitation, reverse osmosis, evaporative recovery, solvent extraction, filtration, chemical oxidation, chemical leaching, and electrokinetics are some of the physical and chemical processes used in this remediation [23].

5.2.2. Biological Approaches

The term "biological remediation" or "biodegradation" refers to a variety of techniques used to remove or break down heavy metals using biological activity. These biological treatments may be used to remove heavy metals and can use either anaerobic (lack of oxygen) or aerobic (presence of oxygen) processes.

(5.2.1) Bioremediation in-situ

Without removing soil, in situ bioremediation techniques address the pollution at the site. Utilising these particular techniques relies on a number of variables, including the polluted area, the characteristics of the chemicals involved, the concentration of the pollutants, and the amount of time needed to complete the bioremediation [24]. Because it may be less costly and requires transporting fewer things, this procedure is often advised.

(5.2.2) Bioremediation in-situ

Excavating and treating soil before restoring it to its natural form is known as ex situ bioremediation.

Excavating the contaminated material will let it to be cleaned either on-site or off-site, which is often a quicker way to clean the planet. Systems for ex situ bioremediation may be divided into solid phase and slurry phase. Land farming, composting, biopiles, and bioreactors are among the most significant methods [25].

5.3 Charcoal

This particular organic substance is now being used due to its potential in managing soils contaminated with heavy metals.

The amount of heavy metals in the soil determines how different biochar additions perform. Since these results are uncommon in the literature, further study is needed to fully understand how biochar affects soil microorganisms and how the interaction between biochar and soil microbes affects the remediation of heavy metal-polluted soils.

Conclusion:-

Heavy metals are important environmental contaminants, and their toxicity may pose an increasingly serious threat for reasons related to ecology, evolution, nutrition, and the environment. Because metal pollution is non-biodegradable and may move soil for a significantly longer amount of time than other components of the biosphere, eliminating it may be a difficult undertaking. Plants that are grown in soil contaminated with heavy metals exhibit reduced growth due to altered physiological and biochemical processes. Different processes are used by plants to remediate soil contaminated with heavy metals. The most popular phytoremediation technique for treating soil contaminated by heavy metals is phytoextraction. It guarantees that the contaminant is completely removed. Utilising beneficial plants and microorganisms to remediate soil contaminated with metals is known as bioremediation. It's a widely used technique for remediating soil since it's obvious that natural processes are at play. For the restoration of heavy metal-polluted soils, it is a cost-effective and non-destructive technique.

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