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HAZARDOUS EFFECTS OF HEAVY METAL TOXICITY ON SOIL AND PLANTS AND THEIR BIOREMEDIATION: A REVIEW

Muneeb Ur Rehman[1*], Naseer Ahmad[2], Aziz Ullah[1], Paul John Maningas Pangilinan[1], Endalamaw Dessie Alebachew[1]

[1]Ondokuz Mayıs University, Department of Soil Science and Plant Nutrition, Samsun, Türkiye
[2] University of Agriculture Peshawar, Department of Agronomy, Peshawar, Pakistan
***Corresponding e-mail: rehmanmuneb@yahoo.com**

Abstract

Heavy metal-polluted soils have grown ubiquitous worldwide due to increased geologic and anthropogenic activity, and the plants growing in these soils exhibit decreased growth, performance, and yield. Contaminated soil with heavy metals has become a concern for agricultural scientists because of the progress made in agricultural product safety. Heavy metals are metalloids with biological toxicity. The most common are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn). These metals exist throughout the terrestrial environment and have spread out due to anthropogenic and natural activities. Soil heavy metal pollution leads to human health risks, groundwater pollution, plant phytotoxicity, and a decline in crop and soil production. Bioremediation is an effective method of treating heavy metal-polluted soils. It is a widely accepted method that is mostly carried out *in situ*; hence it is suitable for the establishment/reestablishment of crops on treated soils. Using plants in the treatment of polluted soils is a more common approach in the bioremediation of heavy metal-polluted soils. Bioremediation ensures a more efficient clean-up of heavy metal-polluted soils. However, the success of this approach largely depends on the species of organisms. This paper is aimed to review the hazardous effects of heavy metal toxicity on soil and plants and their bioremediation. This paper also discusses numerous strategies for addressing heavy metal contamination in soil.

Keywords: heavy metals, anthropogenic sources, natural sources, bioremediation

INTRODUCTION

The soil polluted with heavy metals (HMs) has become a global issue due to anthropogenic activities such as mining and processing minerals, industrial production, and automotive exhaust emissions. Its ongoing toxicity to the environment has heightened public concerns (Deng et al., 2018). Heavy metals are ubiquitous on earth and are generally recognized as metalloids and metals in the periodic table (Yadav et al., 2019). Heavy metals have a greater than five density and account for more than 35% of the elements in the periodic table. The most common environmental heavy metals are copper (Cu), nickel (Ni), chromium (Cr), lead (Pb), cadmium (Cd), mercury (Hg), iron (Fe), and arsenic (As) (Bakshi et al., 2018). They engage in redox reactions, osmoregulation, and act as enzyme cofactors (Silver & Phung, 2005). One of the most important tasks of soils is to meet people's fundamental requirements, particularly agricultural soils, which provide the essential nutrients for food crops (Diamond, 2002).

Heavy metals are regarded as a major contributor to soil contamination. Heavy metal contamination of soil is caused by various metals, including Cu, Ni, Cd, Zn, Cr, and Pb (Karaca et al., 2010). Certain heavy metals (such as Fe, Zn, Ca, and Mg) have been reported to be bio-important to humans, and daily medical and dietary limits for these metals have been advised. On the other hand, others have been reported to have no known bio-importance in human biochemistry and physiology, and their intake, even at extremely low doses, can be harmful (Duruibe et al., 2007). A healthy environment is associated with good human health. Some disposed materials containing heavy metals in open dumpsites are of concern and pose dangers to people who come in contact with the soil and plants contaminated by heavy metals due to bad waste disposal management (Ugurlu, 2004). Waste generation and disposal have been pointed as one of the driving forces of heavy metal contamination in the soil. Generally, the waste in landfills comes from different sources, composed of different materials, and is disposed of randomly in these dumpsites (Ekere et al., 2017). No guidelines are proposed for waste disposal, which causes waste mixture and creates leachate that relocates into soil and groundwater (Ekere et al., 2017). The decomposition of organic matter in municipal solid waste by microorganisms results in hazardous liquids called leachate, consisting of organic matter, macro-inorganic components, and heavy metals, polluting soil and aquatic environment (Kasam et al., 2018). Consequently, in developing countries, landfills with leachate are improperly managed, the uncontrolled leachate flows, diffuses and penetrates the groundwater, contaminating the surrounding environment and affecting the human beings in the vicinity of the landfill (Umutesi et al., 2018; Kasam et al., 2018). Besides, most landfills are located near settlements, and some wastes are dumped recklessly without paying attention to the environmental implications. Moreover, in some dumpsites, the wastes are burnt at the sites, resulting in an unhealthy environment (Srigirisetty et al., 2017).

Heavy metals hurt soil microorganisms, affecting their variety, population size, and general activity (Ashraf & Ali, 2007). Pb levels in soil may reduce soil production. A very low Pb concentration may hinder several critical plant activities, such as photosynthesis, mitosis, and water absorption, resulting in toxic symptoms such as dark green leaves, withering of older leaves, stunted foliage, and short brown roots (Bhattacharyya et al., 2008). Cadmium (Cd) can interrupt enzyme activities and inhibit the DNA-mediated transformation in microorganisms; its primary anthropogenic sources in soils are the direct input of waste material from mining, industry, and agricultural applications (Kabata-Pendias, 2000; Kubier et al., 2019). Lead (Pb) is a widely distributed toxic non-essential heavy metal that causes various negative effects. It includes living organisms at morphological, physiological, and biochemical levels due to their high persistence in water and soil, accumulation in the top eight inches of the ground, and immobility (Zeng et al., 2007; Pourrut et al., 2011; Tangahu et al., 2011). Arsenic (As) in the soil is present in both organic and inorganic forms, the latter is a highly toxic form (Shrivastava et al., 2015). The high concentration of As causes detrimental effects on plant growth by causing cell necrosis, chlorosis, and electrolyte leakage from cell membranes (Singh et al., 2006). The toxicity of As also leads to the formation of ROS that can damage nucleic acids and proteins and cause the peroxidation of the lipids present in the membrane (Moller et al., 2007). Heavy metals can cause ROS formation through various mechanisms, including Redox reactions: heavy metals such as cadmium and lead can undergo redox reactions, leading to the formation of reactive oxygen species (ROS) (Valko et al., 2005). Disruption of the mitochondrial function: heavy metals can disrupt the mitochondrial function, leading to accumulating electrons in the electron transport chain and forming (Flora & Mittal, 2007). Activation of the NADPH oxidase: heavy metals can activate the NADPH oxidase enzyme, which generates ROS (Chatterjee & Chatterjee, 2018). Depletion of cellular antioxidants: heavy metals can deplete cellular antioxidants such as glutathione, increasing ROS formation (Rahman et al., 2018). The metal plant uptake from soils at high concentrations may lead to significant health concerns due to food-chain consequences (Jordao et al., 2006). The heavy metal absorption by plants and the subsequent buildup in the food chain may endanger the human health. The consumption of heavy metal-contaminated food can severely deplete several vital nutrients in the body, resulting in decreased immunological defense, intrauterine development retardation, malnutrition-related impairments, and a high incidence of upper gastrointestinal cancer rates (Khan et al., 2008). Heavy metals cause the formation of ROS and free radicals that lead to uncontrolled oxidation and radical chain reactions, ultimately damaging cellular biomolecules like nucleic acids, lipids, and proteins (Phaniendra et al., 2015).

Plants, being the primary producers, form the base of the ecological pyramid; thus, the heavy metals entering the plant body make their way through the successive trophic levels of the food chain. The bio-accumulative heavy metals complicate the situation since they are neither destroyed in the environment nor easily digested by the plants. Some heavy metal-tolerant plant species, like *Brassica napus* and *Brassica Juncea* have the intrinsic ability to accumulate heavy metals in their body, thereby threatening the food webs with contamination (Gall et al., 2015; Mourato et al., 2015). Therefore, the present study aims to evaluate the sources of heavy metals and their harmful effect on soils and plants, and to propose the ways of treatment.

SOURCES OF HEAVY METALS

The concentration of heavy metals in the biosphere may occur through natural and human activities. While the weathering of rocks is the chief natural source of heavy metal contamination in the environment, the anthropogenic sources include mining, smelting operations, and agricultural activities (Herawati et al., 2000).

Natural sources of heavy metals

The heavy metals derived from rock materials represent the "lithogenic" component. The type of the parent rock is the factor that determines the concentration and composition of the heavy metals formed in soil. The primary heavy metal pollutants to which the parent rock contributes are Co, Cr, Fe, Mn, Ni, and Zn (Nagajyoti et al., 2010). Weathering and pedogenesis are the major natural sources of heavy metals. Mineral ores like galena, cerussite, cassiterite, and arsenopyrite can dissolve through chemical weathering, releasing heavy metals in their structure (Abdu, 2010). Heavy metals are constituents of primary and secondary minerals through the process of inclusion, adsorption, and solid solution formation, termed coprecipitation (Sposito, 2008). Acid rain and dew are also natural sources of heavy metal pollution (Nriagu, 1990). Atmospheric dust storms, wild forest fires, and volcanic eruptions are input routes for natural heavy metal pollution (Naidu et al., 1997). The effect of the pedogenic heavy metal pollution may override that of anthropogenic sources, especially when the parent material contains a high level of heavy metal concentration (Brown et al., 1999). Table 1 presents how heavy metals reach the soil through water from a natural source.

Anthropogenic sources

Anthropogenic events have increased the environmental damage by replacing natural forests and agricultural lands with human habitation. Such operations have polluted aquatic habitats, including the spring waters coming from rivers such as the Amala and Nyangores and the tributaries of the Mara River in Indonesia's Mau Complex. The vast majority of the forest land has been converted to serve the human development and agriculture.

Table 1. Natural sources of heavy metals

Heavy Metals	Natural Source	Reference
Cadmium (Cd)	1. Cd can be naturally found in Black shale. 2. Volcanic activity is also the main source of Cd in the soil and atmosphere, parent material, marine sedimentary rocks, and phosphates.	(Bakshi et al., 2018) (Khan et al., 2008)
Lead (Pb)	1. Soil: Lead can be found in soil where it has been naturally present. 2. Water: Lead can dissolve from rocks and soil into the water, especially in acidic or low pH areas. 3. Rocks and minerals: Some minerals and rocks contain high levels of lead, such as galena (lead sulfide) and cerussite (lead carbonate). 4. Air: Lead can be released from natural sources such as volcanoes and forest fires. 5. Food: Some plants can absorb lead from the soil, especially in areas with high levels of lead contamination. Animals can also ingest lead by eating contaminated plants or prey. 5. Volcanic activity, vents and eruptions and weathering of metal-containing rocks.	(Bakshi et al., 2018) (Garrett, 2000)
Zinc (Zn)	1. Zinc ores: Zinc is primarily extracted from sphalerite and wurtzite, commonly found in sedimentary rocks and hydrothermal veins. 2. Soil: Zinc is naturally present in soil and can accumulate in plants and animals that live in or eat from the soil. 3. Rocks: Zinc is naturally present in rocks like sandstone, limestone, and dolomite.	(Bakshi et al., 2018)
Copper (Cu)	1. Copper ores: Copper is primarily extracted from sulfide ores like chalcopyrite and bornite, commonly found in porphyry copper deposits, sedimentary exhalative deposits, and volcanic-hosted massive sulfide deposits. 2. Soil: Copper is naturally present in soil and can accumulate in plants and animals that live in or eat from the soil. 3. Water: Copper can be present in water in small amounts. It can dissolve in water from natural sources like rocks and soil and be transported in water by human activities. 4. Rocks: Naturally present in granite, basalt, and gabbro rocks.	(Bakshi et al., 2018) (Barceloux, 1999)
Mercury (Hg)	1. The igneous rocks, sedimentary rocks, and argillaceous sediments. 2. Cinnabar: This red mineral is the primary ore of mercury. It is commonly found in hydrothermal veins and hot springs. 3. Soil: Mercury is naturally present in soil and can accumulate in the food chain. 4. Water: Mercury can be present in water in its elemental form, but it can also combine with other elements like carbon and sulfur to form organic and inorganic compounds. 5. Fish: Certain species of fish like tuna, swordfish, and shark can contain high levels of mercury because they feed on smaller fish that have absorbed mercury from the water.	(Bakshi et al., 2018)

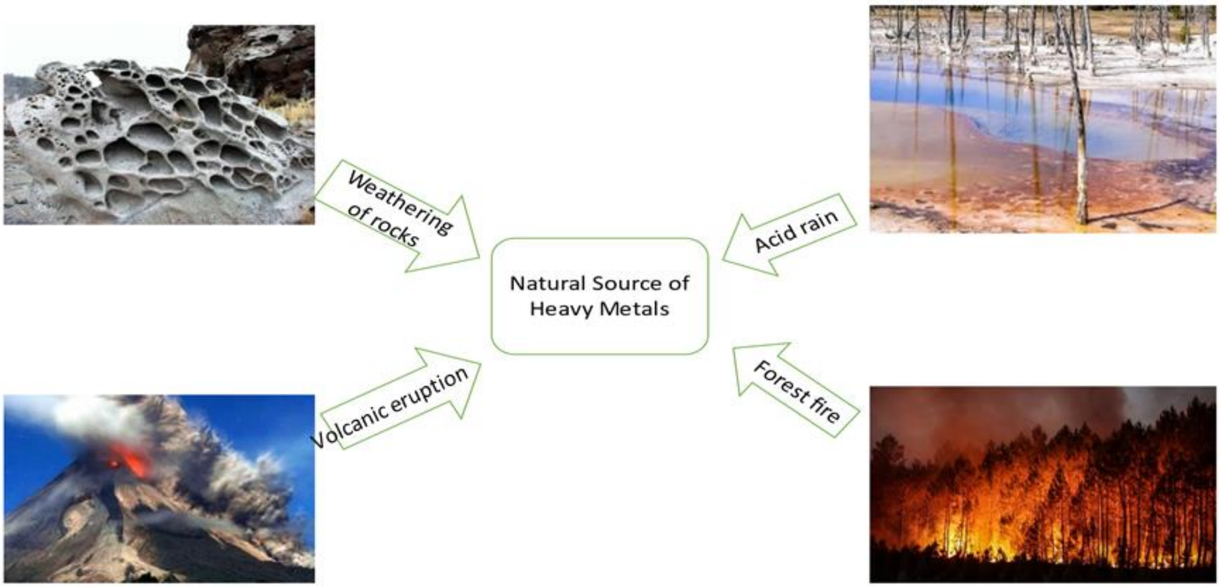

Fig.1. The main natural sources of heavy metals

People who live near the Mara River Basin use the spring water for cultivating livestock and agriculture. The rapid increase of industrialization and urbanization has decreased the water carrying capacity. Hg concentration in water has increased with agricultural and human activities. Activities such as flowing domestic sewage into the water, solid waste burning, coal and oil combustions, and pyrometallurgical processes and mining are the main reason behind it. By either snow or rain, water brings the contaminated soil with Hg into the adjacent water areas (Kowalski et al., 2007). The inorganic and organic fertilizers, manure, limes, pesticides, etc., used in agriculture contain variable amounts of Cr, Cd, Ni, Zn, Pb, and other heavy metals (Nriagu, 1989; Yanqun et al., 2005). Corroded metal pipelines and containers are the sources of Ni (Cempel & Nickel, 2006). The primary source of lead in water is paint additives and petrol, as well as the aerosol precipitation caused by the high temperatures used in industrial processes such as coal combustion, smelting, cement production, chloralkaline, batteries, fluorescent lamps, thermometers, and electronic switch production (Li, 2014). Table 2 shows how different heavy metals become part of the environment through anthropogenic sources.

EFFECTS OF THE HEAVY METAL TOXICITY ON SOIL

The heavy metal toxicity of soil is a major issue across the industrialized world (Hinojosa et al., 2004). The heavy metal pollution harms various parameters relating to plant quality and yield and causes changes in the microbial community's size, composition, and activity (Yao et al., 2003). Heavy metals are considered one of the major sources of soil pollution. The studies done by Hinojosa et al. (2004) reported that the heavy metal pollution of soil is caused by various metals, especially Cu, Ni, Cd, Zn, Cr, and Pb. The concentration of heavy metals in soil changes its quality and fertility, produces groundwater contamination and biomagnification, and ultimately causes irreparable damage to the soil biota (Borah et al., 2020).

Historically, soil systems were physically stressed by ingesting foreign substances like heavy metals. When heavy metals are abundant in soil, the result is unhealthy ecology, affecting living organisms' entire health.

Table 2. Anthropogenic sources of heavy metals

Heavy Metals	Anthropogenic Sources	Reference
Cadmium (Cd)	1. Cadmium is used in a variety of industrial processes, such as the manufacturing of batteries, pigments, and plastics. These processes can release cadmium into the air and water. 2. It is often found in zinc ores and, as a result, is released during the mining and smelting of zinc. This activity can contaminate soil and water sources near the mining and smelting operations. 3. Extraction and refining of non-ferrous metals. 4. Manufacture and application of phosphate fertilizers. 5. Burning of fossil fuel.	(Bakshi et al., 2018) (Somani et al., 2019) (Taylor et al., 1999) (Rezapour et al., 2018)
Lead (Pb)	1. Pb can be distributed in the soil from mining and smelter sites. 2. Paint, gasoline additives, smelting, automobile demolition, and pesticide application. 3. Pb can be released into the soil from manufacture/industrial effluent. 4. Storage batteries, solders, ceramic glazes, leaded crystal glassware, cosmetics, hair dyes, jewelry, gunshot and ammunition, relic fishing sinkers, tire weights, imported children's toys, traditional or folk cures, and candy/food packaging. 5. Burning coal and oil, domestic sewage effluent, and burning of waste.	(Bakshi et al., 2018) (Ekere, 2017) (Khan et al., 2008)
Mercury (Hg)	1. The burning of fossil fuel. 2. The production of steel, cement, and phosphate. 3. The smelting of metals from their sulfide ores.	(Bakshi et al., 2018) (Drasch et al., 2004) (Khan et al., 2008)
Zinc (Zn)	1. Mining activities. 2. Zinc production facilities and steel production. 3. Combustion of coal and fuel. 4. Waste disposal and incineration. 5. The use of fertilizers and pesticides containing zinc.	(Bakshi et al., 2018) (Khan et al., 2008) (Lundberg et al., 1997)
Copper (Cu)	1. Nonferrous metal production, copper smelters, and steel production. 2. The municipal incinerators. 3. The residue of copper mining, sewage sludge, mineral fertilizers, and pesticides. 4. The recycling of bio-solids; the application of bio-solids has been reported to add Cu into the soil. 5. In agricultural land, the contamination with Cu can also occur through the application of fungicides based on Cu.	(Bakshi et al., 2018) (Khan et al., 2008) (Barceloux, 1999)

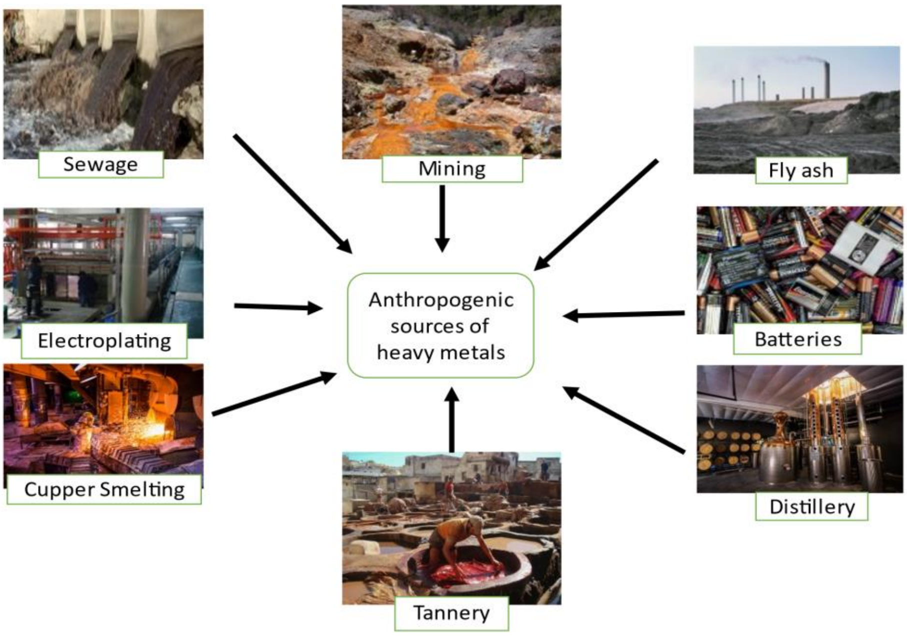

Fig.2. The most important anthropogenic sources of heavy metals

Table 3 shows the harmful impacts of heavy metals: lead (Pb) is a toxic metal with low mobility but high bioavailability. On soil's surface, Pb persists for a long time (Akanchise et al., 2020). Cadmium and its compounds can move through soil. However, its portability depends on several factors, including the soil pH and the amount of organic matter, which depends on the local environment. Besides, cadmium binds tightly to the organic material, becomes immobile in soil, is absorbed by plants, and eventually enters the food chain (Karaca et al., 2010). Among the heavy metals, Cd accumulation in soil is a ubiquitous problem because of the advanced agricultural technology, economic revolution, and the industry's rapid development. Usually, the soil pH and organic matter content are the major factors that Cd accumulation affects. With a decrease in the soil pH, Cd bioavailability increases, indicating a defect in the soil properties (Zeng et al., 2015). According to Singh and Kalamdhad (2010), the soil contaminated with heavy metals is associated with an excessive concentration of heavy metals, insufficient nutrient and organic content, low water retention capacity, and low cation exchange capacity. The main source of Pb contamination in soil is its geogenic contribution, which reduces soil microbial activities. The effects of Pb on soil are several, such as reducing soil nutrients, microbial diversity, and soil fertility. In agricultural soil, Cu availability is usually affected by several factors, such as the soil pH, since its availability is usually higher in acidic soil than in alkaline and organic matter (Dotaniya et al., 2020).

Furthermore, the increase of heavy metals concentration in soil has toxic effects on the soil biota by influencing important microbial processes and reducing microorganisms' number and activity (Singh & Kalamdhad, 2010). The heavy metal toxicity can harm soil microorganisms, essential for soil ecosystem functions such as nutrient cycling and organic matter decomposition. Heavy metals such as cadmium, copper, lead, and zinc can inhibit the microbial growth in soil by damaging cell membranes, enzymes, and metabolic processes (Wang et al., 2018). The high levels of copper can reduce the microbial biomass and activity in soil. Likewise, it was reported that heavy metals can also alter soil microbial communities' structure and diversity (Liu et al., 2018). Studies have shown that exposure to lead can reduce the diversity and abundance of soil bacteria and fungi. Panda et al. (2015) found that heavy metals can affect the microbial enzyme activities in soil, which are important for nutrient cycling and organic matter decomposition. Cadmium can inhibit the activity of soil enzymes such as dehydrogenase, urease, and phosphatase. Some heavy metals can induce stress response genes in soil microorganisms, affecting their growth and metabolism. For example, studies have shown that exposure to copper can increase the expression of the stress response genes in soil bacteria (Wang et al., 2018).

Table 3. Effects of heavy metal toxicity on soil

Heavy metal	Toxicity effect on soil	Reference
Lead (Pb)	Causes abnormalities in the metabolic function of organisms. Produces shortage of soil macronutrients like Phosphorus. Reduces soil productivity. Affects soil enzyme activities: decrease urease, catalase, invertase, and acid phosphatase activity. Interrupts water balance, enzyme activity and mineral nutrition.	Alloway et al. (1990) Fenn et al. (2006) Somani et al., (2019) Karaca et al., (2010)
Cadmium (Cd)	Causes abnormalities in the metabolic function of organisms. Harms the protease, urease, and alkaline phosphatase activity. Reduces the availability of soil N and S for crop production.	Akanchise et al., (2020) Karaca et al., (2010)
Zinc (Zn)	Phytotoxic and it can directly affect soil fertility. Decreases the microbial biomass N. Produces shortage of soil macronutrients like Phosphorus. Imbalanced mineral nutrition in soil.	Balkhair and Ashraf, (2016) Yao et al. (2003)
Copper (Cu)	Reduces the availability of soil N and S for crop production. Inhibits the activity of β-glycosidase more than the activity of cellulose. Copper toxicity can lead to soil acidification and infertility.	Bakshi et al., (2018) Karaca et al., (2010)
Mercury (Hg)	Causes abnormalities in the metabolic function of organisms. Inhibits the activity of soil microorganisms. Has a negative impact on soil biodiversity.	Akanchise et al., (2020)

The soil microbial biomass population is under tremendous pressure due to the contamination caused by various toxic substances - pesticides, heavy metals and organic pollutants such as sewage sludge and wastewater of environmental origin (McGrath et al., 1988; Chaudhary & McGrath, 1996). Soil microbes utilize some heavy metals as electron donors or acceptors during metabolism. In such cases, the microbes employ a high amount of the metal without the manifestation of toxicity. Such metals like chromium, vanadium, arsenic, selenium, copper, iron, and manganese usually have variable oxidation states. Despite the process of using heavy metals by soil microbes, microorganisms have been the most sensitive of all living soil organisms to heavy metal stress (Giller et al., 1998). High levels ofw metal pollution were reported to inhibit the activity of soil microorganisms through the accumulation of organic matter at the surface soil layer (Strojan, 1978; Freedman & Hutchinson, 1980). The adverse effects of heavy metals on soil microbial activities have been reported as early as the 1910s. However, the severe consequences of metal pollution on microbial diversity, processes, and the ecosystem became more glaring in the 1960s–1970s (Giller et al., 1998). The first documented report on heavy metal toxicity affecting soil microbial activities was the work of Lipman and Burgess (1914).

EFFECTS OF HEAVY METAL TOXICITY ON PLANTS

Heavy metals are accessible for plant absorption and are present as soluble components in soil solutions or are quickly dissolved by root exudates (Blaylock & Huang, 2000). Although plants require heavy metals for development and maintenance, excessive quantities can be poisonous. Plants' capacity to gather critical metals also allows them to acquire non-essential metals (Djingova & Kuleff, 2000). Since metals cannot be broken down, when their concentrations inside the plant reach ideal levels, they hurt the plant both directly and indirectly. Some of the direct harmful consequences of the high metal concentrations include cytoplasmic enzyme inhibition and oxidative stress-induced cell structural destruction (Jadia & Fulekar, 2008; Assche & Clijsters, 1990). The replacement of critical nutrients at plant cation exchange sites is an example of an indirect harmful impact. Taiz & Zeiger (2002) found that certain heavy metals, such as As, Cd, Hg, Pb, or Se, are not required for plant development since they serve no recognized physiological role. Others, such as Co, Cu, Fe, Mn, Mo, Ni, and Zn, are required for proper plant development and metabolism. However, when the concentration of these metals surpasses acceptable levels, they can easily cause poisoning (Rascio & Izzo, 2011). While waste composts are mostly used to enhance soils used for the production of vegetables, using compost to boost agricultural productivity without considering the potential negative consequences might be an issue. Given that the edible portion of most vegetable species is the plant, the potential of heavy metal transmission from soil to humans should be a problem (Jordao et al., 2006).

The effect of heavy metal toxicity on plant development varies depending on the heavy metal involved in the process. Table 4 highlights the harmful effects of different metals on plant development, biochemistry, and physiology. Metals such as Pb, Cd, and Hg, which have no helpful role in plant growth, have been shown to have negative effects even at extremely low concentrations in the growing media. Kibra (2008) discovered that the rice plants grown in soil polluted with 1 mg Hg/kg grew significantly shorter. With this Hg content in the soil, tiller and panicle development were similarly reduced. When Cd in the soil solution was as low as 5.5 mg/L, shoot and root development in wheat plants was reduced (Ahmad et al., 2012). Most reductions in the growth parameters of plants cultivated in contaminated soils can be related to decreased photosynthetic activities, inhibited plant mineral nutrition, and reduced enzyme activity (Kabata-Pendias, 2000).

The heavy metal uptake by plants and its subsequent accumulation in the food chains poses a great risk to animals and the human health. In this case, the mobile heavy metals cause serious pollution problems, and because of their easy absorption by plants, they enter the food chains or contaminate the groundwater (Sprynskyy et al., 2007). Some factors influencing the plants' uptake of heavy metals are metal species and plant species. As documented by several earlier scientists, vegetables, especially the leafy vegetables grown in soil contaminated with heavy metals, accumulate high amounts of metals through their leaves. Heavy metals at excessive levels harm plant growth; they can cause oxidative stress in plants and hence, damage cell structure by replacing defective elements with toxic heavy metals and inhibiting photosynthetic reactions in plant cells (Bakshi et al., 2018).

Furthermore, heavy metals affect seed germination and reduce the possibility of harvest production. Heavy metals cause a detrimental effect on plant growth compared to other environmental stresses. Enzymatic activities like (amylase, protease, and ribonuclease) have been delayed due to Ni toxicity, affecting plant germination and growth (Bakshi et al., 2018).

Table 4. Heavy metal toxicity effects on plants

Heavy metal	**Plant**	**Toxicity effect on plant**	**Reference**
Cadmium (Cd)	Wheat (Triticum sp.)	Reduced seed germination; lower plant nutritional content; decreased shoot and root length.	Ahmad et al., (2012) Jiang et al., (2001)
	Garlic (Allium sativum)	Reduced shoot growth; Cd accumulation.	Wang et al., (2021)
	Maize (*Zea mays*)	Reduced shoot growth; inhibition of root growth.	Bakshi et al., *(*2018)
	Aeluropus littoralis	Imbalances the macro and micronutrients by augmenting the macronutrients and reducing micronutrients. Several abnormalities occur in many plant sections, including roots, shoots, leaves, and fruit, as well as an increase in the dry-to-fresh mass ratio (DM / FM) in all organs.	Singh et al. (2006)
Arsenic (As)	Rice (*Oryza sativa*)	Reduced seed germination; reduced seedling height; decreased leaf area and dry matter production.	Abedin et al., (2002)
	Tomato (*Lycopersicon esculentum*)	Reduced fruit yield; decrease in fresh leaf weight. Stunted growth; chlorosis; wilting.	Barrachina et al., (1995)
	Canola (*Brassica napus*)	Arsenic can inhibit photosynthesis, which is how plants produce food leading to reduced plant growth and yield.	Cox et al. (1996)
Cobalt (Co)	Tomato (*Lycopersicon esculentum*)	Reduction in plant nutrient content.	Jayakumar et al., (2011)
	Mung bean (*Vignaradiata*)	Reduced antioxidant enzyme activity; reduction in plant sugar, starch, amino acid, and protein content.	Jayakumar et al., (2008a)
	Radish (*Raphanussativus*)	Shoot length, root length, and total leaf area are decreased; chlorophyll content is reduced; plant nutrient content and antioxidant enzyme activity are reduced. Decrease in plant sugar, amino acid, and protein content.	Jayakumar et al., (2008b)
Copper (Cu)	Bean (*Phaseolus vulgaris*)	Accumulation of Cu in plant roots; root malformation and reduction.	Cook et al. (1998)
	Black bindweed (*Polygonum convolvulus*)	Plant mortality; reduced biomass and seed production.	Kjær et al. (1999)
	Rhodes grass (*Chloris gayana*)	Root growth reduction.	Sheldon & Menzies, (2005)

Mercury (Hg)	Rice (*Oryza sativa*)	Plant height reduction; reduced tiller and panicle development; yield loss; bioaccumulation in seedling shoot and root.	Du et al. (2004)
	Tomato (*Lycopersicon esculentum*)	Reduced germination percentage; decreased plant height; reduced flowering and fruit weight; chlorosis.	Shekar et al., (2011)
Lead (Pb)	Maize (Zea mays)	Slowing down seed germination gradually. Root, shoot, and leaf growth are all decreased, as are fresh and dry biomass.	Singh & Kalamdhad (2011)
	Soybean (*Glycine max*)	Lead toxicity causes a histological alteration in the leaves, resulting in a narrow leaf blade and a reduction in the diameter of the xylem arteries.	Jamal et al. (2002)
	Oat (*Avena sativa*)	Suppression of enzyme activity, which has an impact on CO2 fixation.	Moustakas et al., (1994)
Zinc (Zn)	Cluster bean (Cyamopsis tetragonoloba)	Germination % decreased; plant height and biomass decreased; chlorophyll, carotenoid, sugar, starch, and amino acid content reduced.	Manivasagaperumal et al., (2011)
	Pea (Pisum sativum)	Reduced chlorophyll concentration; altered chloroplast structure; decreased photosystem II activity; reduced plant growth.	Doncheva et al., (2001)
	Rye grass (Lolium perenne)	Zn accumulation in plant leaves leads to reduced development, a decrease in plant nutritional content; decreased photosynthetic energy conversion efficiency.	Bonnet et al., (2000)

Ni can result in plant height reduction, root length reduction, chlorophyll content decrease, photosynthetic pigments reduction, and accumulation of Na^+, K^+, and Ca^{2+} in the plant (Bakshi et al., 2018). Heavy metal toxicity leads to plant chlorosis, poor plant growth, and depression. However, it is also associated with reduced nutrient uptakes, plant metabolism disturbance, and reduced ability to repair molecular nitrogen in leguminous plants (Singh & Kalamdhad, 2011).

It is crucial to remember that certain plants can withstand high levels of heavy metals in their environment. Baker (1981) reported that these plants could tolerate these metals through three mechanisms: I exclusion: restriction of metal transport and maintenance of a constant metal concentration in the shoot over a wide range of soil concentrations; (ii) inclusion: metal concentrations in the shoot reflecting those in the soil solution via a linear relationship; and (iii) bioaccumulation: metal accumulation in the shoot and roots of plants at both low and high soil concentrations.

BIOREMEDIATION

Bioremediation is a process that uses living organisms such as bacteria, fungi, and plants to degrade or eliminate pollutants in the environment. It is an effective and eco-friendly method of removing soil, water, and air contaminants. Bioremediation can clean up many pollutants, including oil spills, heavy metals, pesticides, and organic solvents.

Plants were being used to remediate heavy metal-polluted soils. Phytoremediation is a type of bioremediation in which plants remediate contaminated soils. It is appropriate when the contaminants are widespread and located within the plant's root zone (Garbisu & Alkorta, 2003). Several strategies can be used to address heavy metal-polluted soil phytoremediation. Among these are phytoextraction, phytostabilization, and phytovolatilization.

Phytoremediation

Phytoremediation is an *in-situ* remediation method that employs plants and related bacteria, soil amendments, and agronomic techniques to remove or render environmental toxins harmless. It is also known as green remediation, Botan remediation, agro remediation, or vegetative remediation. Phytoremediation is an emerging technology that uses plants and associated soil microorganisms to reduce environmental pollutants' concentration or toxic effects, aiming to cultivate heavy metal-tolerant plants that absorb heavy metals into plant tissues during metabolic processes (Ali et al., 2013). Phytoremediation processes have included phytoextraction or phytoaccumulation, phytostabilization, phytovolatilization, and phytodegradation (Ashraf et al., 2019). In contrast to several other methods, phytoextraction ensures the permanent removal of metals from contaminated sites. Phytoextraction has been defined as the process by which the heavy metals that cause soil contamination are transported through the roots to the green parts of the plant and are accumulated there. A field experiment on remediation of contaminated soil by planting commercial chrysanthemums was conducted in farmland contaminated with heavy metals Cd and Zn as a result of stream sediment application: phytoremediation for three consecutive years reduced the Cd and Zn contents of the soil by 78.1% and 28.4%, respectively (Luo et al., 2020).

For this reason, researchers have developed the concept of hyperaccumulation plants capable of accumulating heavy metals (loid) in their stem tissues and showing no obvious signs of toxicity. After two years of phytoremediation by ryegrass, the cadmium concentration in the soil decreased by 24.9%, indicating that ryegrass can absorb heavy metals from the soil and has good metal tolerance (Ji et al., 2016; Rehman et al., 2017). When grown in soils with Cd levels below 100 mg/kg, Balsam fir plants did not show significant damage or reduced shoot biomass. They exhibited high Cd tolerance, efficient photosynthesis coordination, and rapid reactive oxygen species scavenging (Liu et al., 2019).

Phytoextraction.

Based on the principle of hyperaccumulation, phytoextraction includes the absorption and transport of metal contaminants in the soil through plant roots onto aboveground components of the plants (Jutsz & Gnida, 2015). Phytoremediation is an in-situ remediation method that employs plants and related bacteria, soil amendments, and agronomic techniques to remove, contain, or render environmental toxins harmless, making them ideal for phytoremediation (Jabeen et al. 2009 and Rascio et al. 2011). These plants typically flourish in places with long-term metal pollution in the soil and generate copious biomass that is easily collected. Van der Ent et al. (2013) defined hyperaccumulator plants based on the metal concentrations in dried leaves (Cd 100, Co, Cu, Cr 300, Pb, Ni 1000; Zn 3000, and Mn (g/g). Based on these criteria, around 500 species have been identified as metal hyperaccumulators. *Brassicaceae, Caryophylaceae, Violaceae, Fabaceae, Euphorbiaceae, Lamiaceae, Asteraceae, Cyperaceae, Poaceae, Cunouniaceae*, and *Flacourtiaceae* are the most common (Muszynska & Fajerska, 2015), as shown in Table 2. The following characteristics distinguish these plants: (1) a substantially better capacity to absorb heavy metals from the soil; (2) improved photoshoot metal ion transfer; and (3) a lot stronger ability to detoxify and sequester exceptionally large levels of heavy metals in the shoots (Muszynska and

Fajerska, 2015 and Rascio et al. 2011) (4) a capacity to develop quickly; and (5) a dense root system (Jabeen et al., 2009).

Because of the plant's propensity to absorb heavy metals from the environment, there has recently been much interest in utilizing sunflower (Helianthus annuus) for the phytoremediation of organic pollutants and heavy metals. The location of heavy metal buildup varies from plant to plant. Some authors showed that heavy metal buildup occurs mostly in sunflower roots with limited transport from the roots to the above-ground bulk (Marchiol et al., 2007), while others reported effective transfer from the roots to the above-ground mass (Adesodun et al., 2010). Angelova et al. (2016) discovered that the distribution of heavy metals in sunflower organs is selective for each metal, with 59% Pb accumulating in the leaves. As little as 1% accumulates in the seeds. Similar findings were observed for Zn and Cd, which accumulated in sunflower leaves at 47% and 79%, respectively. Hyperaccumulator plants, such as those in the Brassica genus (Brassica napus, Brassica juncea, and Brassica rapa), grow quickly and have a large biomass (Ebbs et al., 1997). Micranthemum umbrosum (J.F. Gmel.) S.F. Blake, an attractive hyperaccumulator plant, was able to extract a larger proportion of As (79.3-89.5% from 0 to 1.0. g/mL) than Cd (60-73.1% 0.3 to 30.0. g/mL Cd) (Islam et al., 2013). Islam et al. (2013) discovered Micranthemum umbrosum's efficacy as an efficient Cd accumulator and a hyper-accumulator of As toxicity. Despite the benefits of phytoextraction, its efficacy can be impeded if the heavy metal concentrations are very high, the plant produces little biomasses, or the plant's growth rate is sluggish, preventing metal absorption. In such cases, the phytoextraction process can be aided by the use of chelators like citric acid and EDTA, which increase the mobility of heavy soil metals (Freitas et al. 2013 and Paz-Ferreiro et al. 2014), or organic supplements like chicken manure, which has been shown to increase the growth of the species Rorippa globose while decreasing soil-extractable Cd and concentrations of Cd (Paz-Ferreiro et al. 2014 and Wei et al. 2011). The pace at which the hyperaccumulating plants can repair a contaminated site is determined by the kind of soil present and the degree of metal pollution. As a result, more research should be done to uncover fast-growing hyperaccumulating plants capable of collecting large amounts of biomass while being resistant to various metals.

Phytostabilization

Plants are used in Phyto stabilization to immobilize metals, lowering their bioavailability through erosion and leaching. It is typically utilized when phytoextraction is either unwanted or impossible (McGrath & Zhao, 2003). According to Marques et al. (2009), this type of phytoremediation is best used when the soil is so extensively contaminated that utilizing plants for metal extraction would take too long and hence be insufficient. Jadia and Fulekar (2008) on the other hand, discovered that when heavy metal concentrations in the soil are high, plant growth (used for phytostabilization) is negatively affected.

Phytovolatilization

Plants take up contaminants from the soil in this type of phytoremediation; these pollutants are converted into volatile forms and then transpire into the atmosphere (Thakur, 2016). Phytovolatilization is generally utilized to remediate Hg-polluted soils. The poisonous form of mercury (mercuric ion) is converted into a less dangerous form (elemental Hg). The difficulty with this process is that the new product created, elemental Hg, may be redeposited into lakes and rivers after being recycled by precipitation; this, in turn, repeats the process of anaerobic bacteria producing methyl-Hg (Thakur, 2016).

CONCLUSIONS AND RECOMMENDATIONS

Plants growing on heavy metal-polluted soils show a reduction in growth due to changes in their physiological and biochemical activities. This is especially true when the heavy metal involved does not play any beneficial role towards the growth and development of plants. Heavy metals can increase soil acidity, negatively impacting soil health and plant growth. Heavy metals can reduce soil fertility by interfering with microbial activity, nutrient cycling, and plant growth. It can also be toxic to soil biotas, such as bacteria, fungi, and earthworms, reducing biodiversity and ecosystem function. Bioremediation can be effectively used for the treatment of heavy metal-polluted soils. It is most appropriate when the remediated site is used for crop production because it is a non-disruptive soil remediation method. Using plants for bioremediation (phytoremediation) is a more common approach. Plants employ different mechanisms in the remediation of heavy metal-polluted soils. Phytoextraction is the most common method of phytoremediation. It ensures the complete removal of the pollutant. The successful use of plants depends on the species of plants involved and to some extent on the concentration of the heavy metal in the soil.

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