Environment

# How to Remediate Heavy Metal Contamination in Soil?

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**The issue of heavy metal soil pollution has risen to the forefront. In addition to harming the pedosphere as a whole, soil pollution also has an impact on other significant sectors, such as air and water pollution. The two primary categories of pollution sources are natural sources and man-made sources. Mainly Hg, Cd, Pb, Cr, As, Zn, Cu, Ni, and other heavy metals are involved. The safety of agricultural products and the proper growth of people are of utmost importance. Thus, the origins of soil heavy metal pollution, the state of soil remediation research, and the development of soil heavy metal pollution remediation technology are all covered in this review. The technologies currently employed in soil heavy metal pollution remediation primarily include physical remediation, chemical restoration, bioremediation, agroecological restoration, and joint restoration. These methods are described, along with the conditions under which they can be used, application examples, and an analysis of their benefits and drawbacks. The most popular restoration technique is bioremediation.**

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THE earth's surface is covered in a complex biogeochemical material called soil. It is a dynamic ecosystem created by a confluence of climatic, topographical, biological, temporal, parent material, and human activity variables. The ability of soil to offer the fertility needed for plant growth is by far its most important quality (1). In addition to being interrelated and constrained with the atmosphere, water, and other organisms, soil is an essential component of the earth's ecosystem and is strongly linked to human production and survival (2, 3). It is crucial for preserving natural harmony and safeguarding the ecosystem. Recent years have seen a rise in soil environmental pollution issues as a result of high levels of heavy metal contamination in the soil brought on by human beings' reckless pursuit of economic gain and improper industrial and agricultural production practices. Hg, Cd, Pb, Cr, As, Zn, Cu, Ni, and other heavy metal elements are the principal culprits behind soil pollution (4-6). Latent, hidden, lengthy time to degrade, severe environmental effects, and challenging to repair are all difficulties for soil pollution related issues. The characteristics of soil heavy metal contamination include a large pollution area, and its harm is on par with that of air and water pollution.

The seriousness of the soil contamination has made it difficult for human civilization and the economy to flourish sustainably (7). People from all walks of life are now interested in researching what kind of effective and scientific remediation technology is employed to treat soil contaminated by heavy metals. In order to limit the contamination of heavy metals and the danger of harm to the environment and human health, heavy metal pollution in soil must be remedied (8). This could be done by using physical, chemical, or biological means to remove heavy metals from the soil or fix them in the soil. So, starting with the origin of soil's heavy metal pollution, to provide economical, scientific, and effective soil remediation as well as sustainable development, the successful experience and techniques of soil remediation at home and abroad as well as the present research technological advances are briefly described.

## Examining the Origins of Soil Heavy Metal Pollution

The two primary types of causes of soil heavy metal pollution are natural sources and man-made sources. The human-caused pollution is the major cause of the buildup of heavy metals in the soil (9). The weathering of parent materials, as well as the movement of wind and hydraulic power, are the primary causes of the soil heavy metals in nature (10). As reported industrial sources, agricultural sources, transportation sources and urban life sources can be used to categorize the various activity patterns.

Soil contamination research was on the road in the 1960s and 1970s, and the issue of "bone pain disease" brought on by cadmium-contaminated soil attracted significant attention. Soil remediation technologies and extensive remediation experience have been studied extensively in both the United States and Europe.

## Technological Advancements in Soil Heavy Metal Pollution Remediation

The negative effects of heavy metal pollution in soil are widespread. The issues of soil pollution and food safety have drawn considerable attention as a result of the development of society, people's pursuit of a high quality of life, and the heightened awareness of environmental protection (11). To remediate contaminated soil, governments at all levels and related professionals employ physical, chemical, biological, agroecological, and joint restoration techniques in order to ensure human safety while fostering sustainable social development (12).

### Physical Remediation

Engineering techniques like soil turning, soil removal, solidification, and landfilling as well as high-temperature pyrolysis technology and vitrification technology are the main restoration methods. Adding fertilizer can be used to make up for the nutrients lost during deep plowing while also reducing the number of contaminants present on the soil's surface (13). The contaminated soil's top layer is evenly mixed. For less polluted soil, turning soil and foreign soil are suitable. Landfilling is the practice of burying the contaminated untreated soil as solid waste to isolate contaminants. Solidification is the process of mixing the contaminated soil with cement, silicate, fly ash, and other curing agents according to a particular proportion. Landfilling and solidification compromise soil structure and are only appropriate for locally polluted soil that is extremely contaminated (14-16). The majority of volatile heavy metals including Hg, As, and Se are treated using high-temperature pyrolysis technology. Despite the fact that it is used to alleviate soil pollution during the treatment process, hazardous gases and mercury waste gas will be produced at high efficiency but high cost. If handled improperly, it will result in secondary pollution, degrade the air quality, and endanger human health (17). While the waste is being treated, structural water and soil organic matter will both be eliminated. In order to fix heavy metals in the soil, vitrification technology involves heating contaminated soil to high temperatures and high pressures, then cooling it and forming a hard vitreous substance.

Physical remediation is straightforward and time-consuming, but it requires extensive engineering, is expensive, and has a narrow range of applications. This technique could harm the soil's structure and result in secondary contamination, making it unsuitable for general use.

### Chemical Remediation

To change the properties of the soil, such as pH and Eh, and repair or remove heavy metals in the soil by chemical processes, chemical remediation primarily leverages the properties of modifiers to react with heavy metals in the soil. Chemical cleanup mostly uses two methods. The first is to alter the properties of heavy metals using specific chemical compounds or chelating agents in accordance with the characteristics of soil self-purification, such as by adding silicate, lime, and other passivation agents (18). The second is to restrict heavy metals in the soil to fix their chemical characteristics while allowing plant growth to receive a regular supply of nutrients (19). The precise technique leaching method, chemical passivation repair method, and electric repair method are the primary ones.

#### *Chemical Rinsing*

In the chemical leaching process, biochemical solvents are used to dissolve or migrate contaminants in the soil, dissolve and transfer heavy metals from the solid to the liquid phase of the soil, remove the liquid from the soil, and then separate and treat it to fulfill the goal of eliminating heavy metals from soil (20). It can be separated into in-situ leaching and ex-situ leaching depending on the treatment site. By adding a leaching agent to the soil and collecting, treating, and reusing the leaching solution, heavy metal-contaminated soil can be fully remedied (21). Ectopic chemical leaching is the process of excavating and sifting polluted soil. After that, heavy metal contaminants are removed from the extremely big particles by washing them in clean water or eluent. Finally, the heavy metal pollutant-containing waste liquid or leaching solution is treated, and the cleaned, treated soil is backfilled or put to other uses (22).

#### *Chemical Passivation*

Chemical passivation remediation involves introducing a passivating agent into the soil that is either organic (farm manure, crop straw, and other fertilizers), inorganic (phosphates like lime, phosphate rock powder, minerals like zeolite, bentonite, and inorganic silicon fertilizer, etc.), or organic sludge (23). Reducing the mobility and biological activity of heavy metals by altering their physical and chemical characteristics, causing them to induce adsorption, precipitation, ion exchange, and redox processes (24). Study has revealed that in soil by intercepting and adsorbing metal ions into the newly formed polymer under normal water conditions, the nanoscale material Ca/CaO considerably lowers the concentrations of As, Cd, Cr, and Pb on the soil surface; the addition of amorphous SiO2 to the soil can lower Cd (25). Both green waste and chicken manure-derived activated carbon may efficiently fix Cd, Cu, and Pb in soil and lower bioavailability while also promoting plant development (26). The effect of chicken manure-derived activated carbon is more notable.

### *Electrodynamic Remediation*

The goal of electrodynamic remediation is to get more of the soil's heavy metal ions to the electrode through the use of an electric field. This technique can change the direction in which pollutants flow, and it has a greater impact on low-permeability clay and silt (27).

## Bioremediation

Bioremediation technology is regarded as the most practical remediation method out there, compared to conventional physical and chemical cleanup methods. Three perspectives can be used to study it: those of plants, animals, and microbes.

### *Plant-Based Remediation*

Heavy metals and other pollutants can be fixed and transformed using phytoremediation techniques, in addition to being absorbed and removed. Plant fixation, plant volatilization, and plant extraction are the three basic methods (28).

Through plant roots or exudates, heavy metals can be made to modify their characteristics, lowering their toxicity and migration (29). Accordingly, heavy metal lead can be coupled with the phosphate secreted by plant roots to create insoluble lead phosphate, which is fixed in plant roots resulting in the reduction of lead's activities (30).

Plant volatilization is a remediation technique that is constrained by the nature of the pollutants and is ineffective for those that are difficult to volatilize. It also releases the gas that has been volatilized into the atmosphere, which has an effect on the environment. For instance, tobacco may change divalent mercury into gaseous mercury (31). For one-year, Indian mustard can remove 48% of the selenium from the soil (32). The growth of A. chinensis might lower the soil's Cu concentration (33). It was discovered that when birch weeping was planted on Zn-contaminated soil, each section of the weeping accumulated more Zn than the other parts (34).

### *Animal Remediation*

Through the absorption, transformation, and destruction of fauna in the soil, animal remediation method removes or reduces heavy metals and other contaminants from the soil (35). More than 60% of the biomass of soil animals comes from earthworms. Accordingly, the earthworm-based removal of pollutants is generally thorough, the effect is good, and secondary pollution is difficult to create (36). The content of heavy metals in soil can be decreased by two methods, diffusion and ingestion, and it has an enrichment effect on heavy metals.

### *Microbiological Remediation*

The technique of employing bacteria, fungi, algae, and other microorganisms in soil to lower the toxicity of heavy metal contaminants in polluted soil through adsorption, precipitation, oxidation, and reduction is known as microbial remediation technology. It is vital to inoculate microorganisms with specific degrading capabilities since there may not always be comparable bacteria that can degrade contaminants in damaged soil (37).

The primary technique for microbial remediation is microbial adsorption technology, which can be broadly categorized into three categories: extracellular adsorption, intracellular accumulation, and cell surface adsorption. Some strains that have the ability to secrete extracellular polymers mixed with nearby heavy metal ions or with heavy metal ions are primarily what is meant by extracellular adsorption (38). To fix cadmium ions, K. aerogenes creates cadmium sulfides with Cd2+, whereas Citrobacter sp. reduces its toxicity by building phosphate-insoluble complexes with Cd2+ in the environment (39, 40). In order to "fix" the heavy metal inside the cell, intracellular metallothionein, complexin, and polypeptides join forces with heavy metal ions to form a precipitate. Metal and cell wall are the foundations of the cell surface adsorption. On the basis of physical reactions between functional groups, it is carried out.

## Agroecological Remediation

Agronomic and ecological factors are the key components of agroecological restoration. Agroecological restoration involves modifying unsuitable farming practices and management frameworks in accordance with the farming environment (41). Examples include planting ornamental plants that do not get into the food chain and using organic fertilizers to fix heavy metals in the soil or lessen heavy metals. The activity of heavy metals can be effectively reduced in agricultural production by using nitrate nitrogen fertilizer. For heavily polluted soils, the heavy metals can be continuously removed from the polluted area by planting hyperaccumulators. For lightly polluted soils, tolerant plants can be planted; reduce the buildup of heavy metals in plant edible organs. By modifying the conditions of the environment where soil pollutants are found, such as water, nutrients, temperature, humidity, and pH, ecological restoration attempts to lower the bioavailability of pollutants (42).

## Joint Remediation

Even while using just one remediation technique to address soil pollution can have some effects, the advantages are not ideal. One remedial technique's limitations prevent further development. As a result, the most researched area of current research is the employment of combined remediation technology including physicochemical and biological combinations as well as biological and physicochemical combinations.

To remediate the heavy metal element copper in the contaminated soil, the approach of interplanting plus leaching can be utilized for the composite contamination of Zn, Cd, and Pb. Earthworms are currently the subject of the most investigation in studies on the cooperative restoration of animals and plants. Earthworms can both increase soil fertility and encourage plant root growth (43). Hexavalent chromium was removed from contaminated soil using a combination of bacteria, sludge, and straw (44), and the findings indicated that 1% straw plus 1% Compound bacteria and 30% sludge together reduce soil chromium by 96.6%, and this combination can provide the greatest effect.

## Conclusion and Perspectives

Heavy metal poisoning of the soil environment has become a global issue as society and the economy have grown. The issue of soil pollution has received a lot of attention, both domestically and internationally. Enhancing and deepening the process. Soil pollution is the product of numerous forces acting collectively. Even if a single restoration technique can produce a certain restoration result, the result is not very excellent due to the application's limitations. As a result, the real therapy procedure should begin with the following elements: (i) Promote environmental awareness and ease citizens' concerns while pursuing rapid economic development, paying attention to the protection of natural resources, changing the farming system, and using pesticides, fertilizers, and sewage irrigation sensibly. (ii) The contamination of soil with heavy metals comes from a variety of sources. Prevention, source-based management, and strict monitoring of the composition and release of various pollution sources should all be the cornerstones of soil protection so that they can be released once they meet the standards. (iii) The greatest economic and ecological way to recover soil heavy metal pollution at the moment is through phytoremediation and integrated restoration technology. Practical applications should make use of these two restoration types. Single phytoremediation is still not perfect, though. Future study should concentrate on the use of physical chemistry, animals, microbes, agronomic practices, and other remediation strategies in conjunction with phytoremediation to carry out collaborative soil remediation. (iv) To prevent injury to other ecosystems throughout the restoration process, carefully link the relationships between soil and the atmosphere, hydrosphere, biosphere, etc. at the same time as soil repair.■

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