



A Review on Emerging Strategies for Heavy Metal Remediation from Various Sources

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Abstract

The current review addressed a research gap by identifying the most effective different remediation techniques and reducing soil contamination by adapting less cost-effective heavy metal contamination reduction techniques. Around 20 million hectares of terrestrial have been polluted by heavy metals that are above the geo-baseline or regulatory limitations. These metals include Arsenic, Chromium, Lead, Cadmium, Mercury, Cobalt, Nickel, Zinc, and Selenium. Land reclamation benefits both the natural world and the economy. For environmental and health reasons, we should prohibit agricultural practices Nitrogen-based fertilizers, chemical pesticides depraved management practices include poorly managed animal feeding operations, overgrazing, plowing, fertilizer, and improper, excessive, or badly timed use of pesticides that degrade local air quality. Many people feel that lead is the most hazardous metal there is. Production, use, and disposal of gasoline, fertilizers, paints, and explosives contribute to lead contamination, which is damaging to creatures besides the environment. Heavy metal contamination of soil endangers wellbeing of all living creatures. An overview of the global problem of heavy metal poisoning of soil, the rate at which metals accumulate at toxic levels in plants, and the various types of soil contamination controls. Some in-situ and ex-situ remedy strategies for heavy metal contamination removal comprise external capping, encapsulation, landfilling, soil flushing and washing, electrokinetic extraction, stabilization, solidification, vitrification, phytoremediation, and bioremediation. The main objective is to preferred elimination/abstraction of impurities over the immobilization of hazardous containments, and among numerous methods in-situ soil remediation is more cost-effective than ex-situ handling. Reducing heavy metal exposure in people and plants is made easier with the help of the many strategies presented in this article.

Keywords: Heavy metals, Sources, In-situ remediation, Ex-situ remediation,

Introduction

Elements having atomic masses more than 20 and specific gravities greater than 5 are known as "heavy metals." This class of elements includes cadmium, mercury, copper, arsenic, lead, chromium, nickel, nickel, and zinc (Zn) With a growing human population and the resulting shifts in the natural ecosystem, heavy metal pollution has become a major problem that must be addressed immediately (Sarwar *et al.*, 2017). Heavy metals, and occasionally metalloids, are extremely hazardous to all forms of life, but in biology, the expression "heavy" points to a specific class of alloys (Rascio and Navari-Izzo, 2011). Because of their toxicity, life span, and bioaccumulation in various environmental matrices (including live organisms and soil), heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), zinc (Zn), nickel

(Ni) are ubiquitous contaminants (Baccaro *et al.*, 2021). Metal and metalloid contamination have contaminated five million locations, or 500 million acres (Liu *et al.*, 2018). Now, mining operations all over the world create vast quantities of heavy metals (Shahid *et al.*, 2015). Soil contamination from heavy metals can be managed, cleaned, and repaired using any number of in-situ and ex-situ remediation techniques. Various methods of cleanup include phytoremediation, solidification, vitrification, soil flushing, and surface capping (Khalid *et al.*, 2017). When added to a farming setting, heavy metals are catastrophic for all life. As a result, plants benefit from exposure to even trace amounts of heavy metals like iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn), and this impact is then passed up the food chain (Imran *et al.*, 2016). For agriculture to thrive, civilization to advance, the economy to grow, and people's health to

be protected, soil quality and safety requirements must be respected (Gao *et al.*, 2016). The objective of this study was to explore the existing methods for cleaning up heavy metals in soil, including their theoretical underpinnings, technical procedures, application, benefits, drawbacks, and implementation status. Because contamination is a new issue, the novelty of this review to focus on a variety of strategies, including in-situ and ex-situ techniques for heavy metal contamination remediation, and this review study objectively discusses and analyses the diverse options for preparing heavy metal-free soil through soil remediation technologies.

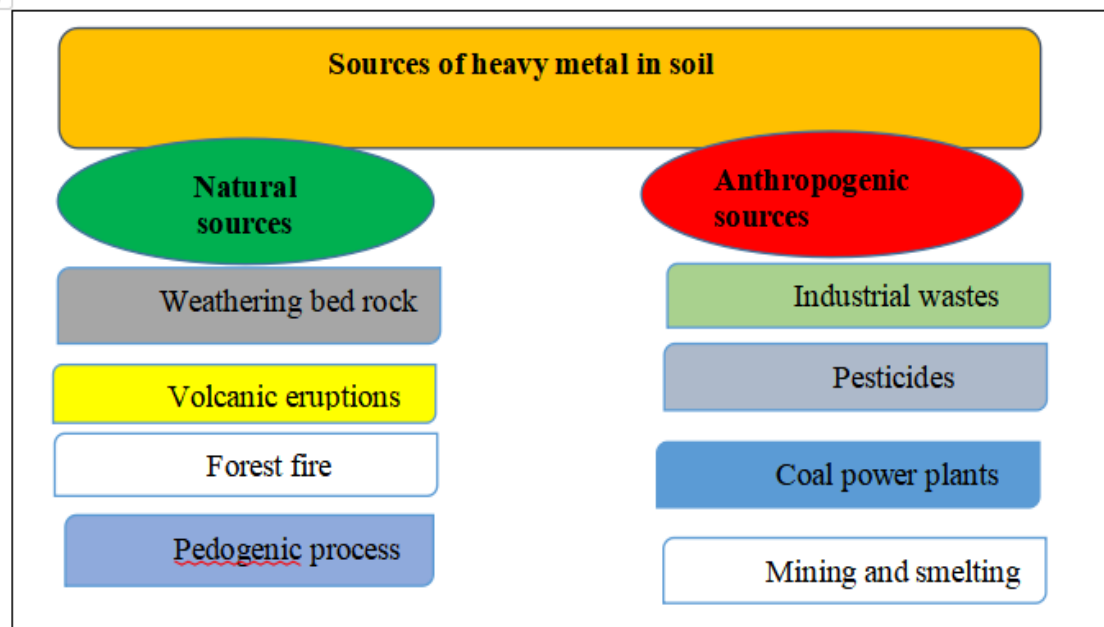
Sources of heavy metal in soil

Elevated heavy metals in the soil at hazardous levels are derived from heavy metals occurring unsurprisingly in Earth top lid and being emitted into the soil by diverse human activities. Pb, Cr, As, Zn, Cd, Cu, as well as Hg are the top eight most prevalent heavy metals found in polluted soil.

Diagram 1

Description: Soil contamination with heavy metal compounds may also be caused through natural processes and anthropogenic processes.

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Natural sources

Rock erosion distributes harmful metals into the soil (Shakoor *et al.*, 2015). Soil type and parent material can affect the heavy metal concentrations in each soil (Cheng *et al.*, 2014). Volcanic eruptions, mineral depletion, wildfires, pedogenic activities, soil the upstream substances, as well as evaporation are just some of the natural sources commonly cited for heavy metal pollution in soils (He *et al.*, 2013). Low levels of Cr along with Mn were connected to environmental influences like that soil type and original material (Li *et al.*, 2013). Once a year, filthy groundwater beneath the surface of the Earth releases heavy metal (loids) that spread pollution across the atmosphere, water, and soil. Soil high in metals likely originated from rocks that are themselves rich in these elements (Pourrut *et al.*, 2011).

Anthropogenic sources

Fertilization, the use of agricultural chemicals, air

accumulation, sewage watering, mining, sludge usage, metal ore melting, industrial wastes, fossil fuel combustion, refining, and refinishing all that promotes heavy metals in soils (Qingjie *et al.*, 2008). Garbage dumps, septic tanks, slime applications, automobile emissions, mining, refining, urbanization, gardening, and industry are some of the several reasons of heavy metals in the soil (Wang *et al.*, 2010). High concentrations of lead, zinc, cadmium, and arsenic were found in the soil of a nearby farm, all the result of industrial waste from a local smelter (Shahid *et al.*, 2013). Human activities including volcanic activity, airborne soil particulate matter, ocean-saline aerosols, wildfires, biogenic resources, along with rock eroding all contributing to the elevated heavy metal concentrations in the surrounding nature (Wuana *et al.*, 2011).

Table 1. Anthropogenic sources of different heavy metals

Heavy Metal	Anthropogenic Sources	Reference
As	Insecticides, disinfectant, fireworks, metallurgy, livestock additives, wood preservatives, electric manufacturing (geothermal/coal), a semiconductor, pottery, mining and metallurgy, coal-fired power plants, herbicides, eruptions.	(Hallaji et al., 2015)
Cd	Dyes, Ni–Cd battery packs, coal combustion, copper coating (anti-corrosive), geogenic to the springs, brilliant rocks, smelting, fossil fuel combustion, ingenious rocks, application of phosphoric fertilizers.	(Atari et al., 2018)
Ni	Containers of glass/ceramic materials, catalytic converter, machine component elements, volcanic eruption, Ni–Cd power cells, land fill up, along with the gas exchanges at sea, wildfires, eroding of land or geological raw material, industrial emissions.	(Rogival et al., 2007)
Pb	Dyes, welding, sanitary equipment, pottery, battery-powered, petroleum, crystal, and lead mining, batteries, extraction and smelting of metal-containing minerals, incineration of stained-glass.	(Sangeetha et al., 2021)

Beneficial aspects of the heavy metals

Heavy metals play important biochemical and physiological roles in plants and animals. Beneficial heavy metals have a significant role in the creation of protein, nucleic acids, photosynthetic pigment, as well as structural and functional integrity of cell membranes at low concentrations (Oves et al., 2016). The etheric HMs such as cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn) is playing a positive role in plant growing along with development (Arif et al., 2016). At optimal concentrations, essential heavy metals play a beneficial role on crop growth, development, and increased productivity (Singh et al., 2016). Because of concentration gradients and selective uptake of certain metals, the plant absorbs significant heavy metals like iron, zinc, copper, as well as manganese in soil (Pichhoda and Nikhil, 2015). Heavy metals are necessary in a variable level by living beings. Creatures demand minerals in form of iron, cobalt, copper, manganese, molybdenum, and zinc (Lane et al., 2009).

Harmful effect of heavy metals

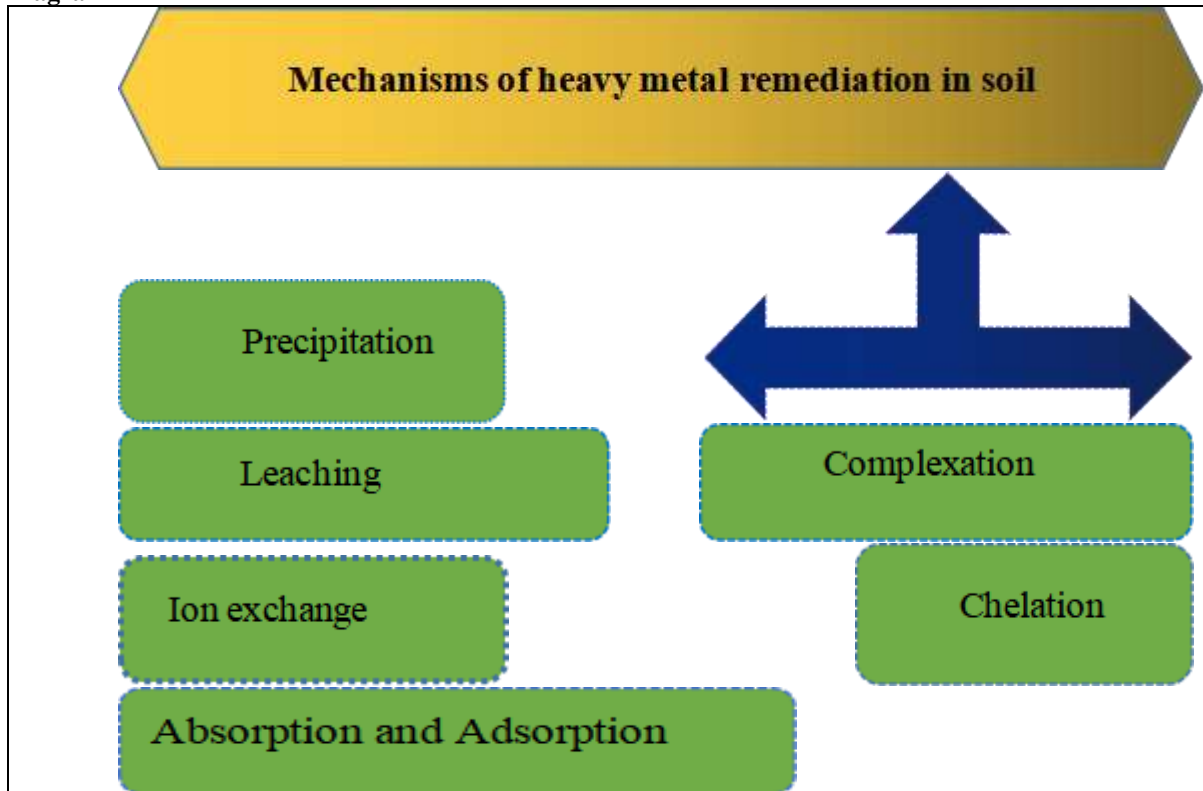
Ingesting heavy metals can have devastating impacts on bodily function. An organism's development, metabolism, and reproductive potential can all be stunted by exposure to toxic substances. How exactly they affect the animals' health and systems is a mystery (Ali et al., 2019). Asbestos, cadmium, chromium, mercury, and lead are all examples of heavy metals which are exceedingly hazardous to human. Pollution has seen a dramatic increase because of rapid industrialization, urbanization, and the use of synthetic agrochemicals. Human health, agricultural output, soil fertility, biological activity, and food quality are all negatively affected by heavy metals in the soil (Pan et al., 2016). Heavy metals in soil absorbed by the humans through skin, lungs, or digestive tract (Boularbah et al., 2006). Humans are at risk from heavy metals in soil if they swallow, inhale, or come into direct touch with the contaminants (Ali et al., 2019). Studies have connected cadmium's toxicity to many organ failures, including the kidneys, heart, and brain (Bernard,

2008). It has been shown that lead is harmful to multiple tissues and organs (Tchounwou et al., 2012). Cancer, birth defects, organ failure, and organ damage have all been linked to exposure to heavy metals like nickel, arsenic, lead, cadmium, and chromium (Tong et al., 2018). Metal contamination has been classified as a major concern in the field of public health due to the grave threat it poses to human health. Lead and cadmium are two examples of heavy metals that can pollute soil and be absorbed by plants and animals, resulting in a wide range of health problems (Riaz et al., 2021; Alam et al., 2003). Heavy metals are a cause for concern because they are present throughout the food chain and have been related to a wide variety of health problems in both animals and humans. It only takes an extraordinarily little amount of these drugs to cause harm (Sarwar et al., 2010). Heavy metal pollution harms more than simply vegetation to not only people but it is also harming animals (Roy and McDonald, 2015). Heavy metals disrupt several plant cellular and physiological processes, such as photosynthesis, stomatal opening, and cell death (Xu et al., 2009). Stressed plants produce more reactive oxygen species (ROS), which can damage membranes, break down macromolecules, and even kill organelles (Ekmekçi et al., 2008). Soil pollution with heavy metal (loid) particles can infect plants via their roots (Pierart et al., 2015). Heavy metal (loid) taken up by plants grown in polluted soil if the bioavailability of the pollutant is high enough. Potentially disastrous effects on public health (Xiong et al., 2014).

Strategies to remediate heavy metals.

Surface capping, electrokinetic extraction, vitrification, soil flushing, solidification, and phytoremediation are some of the in-situ as well as ex-situ remediation processes that were established over time to hold, cleaning up, or fix heavy metal-contaminated land. We can classify these methods as either control (which includes capping and encapsulation) or transformation (which includes stabilization and immobilization) or transportation (such as extraction or removal).

Diagram 2



Description: Heavy metal remediation include various mechanism to reduce contamination in soil. These mechanisms involve various process including chelation, precipitation, complexation, leaching, ion exchange, absorption and adsorption.

Physical treatment and remediation

Chemical reaction-free approaches for removing contaminants from soil are part of a physical treatment for land remedy. By moving the pollution into other media, like water as well as air, and gathering it in intense form, a separation procedure decreases the volume of the pollutant. The new polluted media may necessitate additional treatment. Exact amount as well as the concentration of heavy metals must be known. This additional remedy eliminates or concentrates the contaminant for elimination or recovery/recycling. As a result, physical repair typically requires enactment of further processing to tackle heavy metal problems (Kolawole *et al.*, 2018)

Soil isolation

Soil isolation is the separation of heavy metallic ions from polluted soil. Isolation practices used to hold heavy metals along with other pollutants from exiting the spot by confining them to a small area. Soil isolation method is applied to stop augmented heavy metal contamination of soil. when different clean-up approaches do not exactly nor efficiently feasible. Polluted sites are sometimes temporarily separated during site evaluation and cleanup to prevent relocation. (Prakash *et al.*, 2021).

Soil replacement

To reduce pollution concentrations and increase soil capacity, the replacement practice is applied to repair polluted land by entirely or partially substituting

contaminated soil with the clean land. Soil replacement lowers the total number of metal ions into the soil, which usually improves land function. Metallic ions are frequently detached from reclaimed soil before they are settled in another place. Soil substitution can similarly be conducted by soil excavating and by introduction of a fresh soil. Soil digging is to dig deep in a trench in contaminated zone and dispersing heavy metals into the pit to achieve metal thinning. Importing new soil entails combining pure soil along with the metal-contaminated soil (Gomes *et al.*, 2012).

Electrokinetic remediation

Electrokinetic treatment for heavy metal removal is a novel besides low-cost physical practice. The electrokinetic treatment process operates by introducing a suitable electric field gradient over the two sides of an electrolytic vessel containing being soaked in contaminated land. Heavy metallic ion removal via electro-phoresies or electro-migration (Yao *et al.*, 2012). Clean-up of soil metallic toxins like copper, lead, or cadmium, and possess precise levels of the cationic metallic toxins that will migrate to the cationic elevated pH condition. Adding faint acids like acetic acid to cathode tank can reduce the pH of land across cathode zones, consequently eliminating metals (Selvi *et al.*, 2021).

Chemical remediation of soil

The soil is being treated using chemical methods to reduce contamination. Chemical remedies generate

satisfactory results, but output of by-products is a considerable disadvantage (Toan *et al.*, 2021b). In chemical remediation immobilization, soil cleaning, encapsulation, chemical fixation, verification technology, and chemical leaching are some of the approaches applied for elimination of contaminants from the soil, but it is costly and hazardous to human (Qayyum *et al.*, 2020).

Immobilization techniques

More heavy metal content adjusts through immobilization strategy by the insoluble fixation of chemical substances along with reagents, it results in a decline in heavy metal mobility in the entire environment and in the ecosystem, involving vegetation, aquatic, along with land. Numerous immobilization approaches for heavy metals have been discovered to reduce its intensity in contaminated land. Soil immobilization entails adding ingredients or reagents into contaminated soil to impede poisonous metal dissolution as well as movement, hence preventing dangerous metals from transferring to other media. (Derakhshan *et al.*, 2018)

Washing of the soil

A different technique for eliminating heavy metal from contaminated soil is to wash it through extractants coupled with chemicals which filter the metal ions. In latest ages, one of the highly efficient techniques for contaminated soil treatment has been the use of appropriate reagents for heavy metallic ion leaching (Wang *et al.*, 2019). Chelating agents (EDDS, EDTA), acids, surfactants, as well as humus components are amongst the leaching agents. Land is being washed by extracting a contaminated soil and subsequently mixing with the reagent and Metallic ions in soil travels to reagent solution through ion exchange, precipitation, and beyond adsorption therefore heavy metals detached from the solution. (Tran *et al.*, 2022).

Chemical stabilization

Heavy metals mobility, bioavailability, and toxicity are governed by their species instead of their abundance in the environment (Qi *et al.*, 2015). Chemical stabilization is associated with the addition of chemical ingredients or reagents in soil to inactivate heavy metals through complexation, adsorption processes, precipitation, limiting heavy metal mobility, along with absorption. (Zhao *et al.*, 2022). Chemical stabilization cannot eliminate contaminants from the soil, although it may reduce the frequency that heavy metals carried to the plants along with their mobility along with the solubility.

In-situ remediation methods for heavy metal-contaminated soils

As opposed to conventional remediation methods, in-situ remediation doesn't include moving the contaminated soil to a new location, hence reducing the amount of dirt that must be moved and the number of individuals who are exposed to the hazardous materials in the soil. Factors including meteorological, ground permeable, contamination complexity, and potential for the deep discharge of chemicals must all be

considered a single field evaluation (Olexsey and Parker, 2006).

Surface capping

Order to maintain dirt and dust from collecting on a surface, it is sometimes "capped," or covered with a waterproof coating. This method of confinement cannot be called "remediation" because no attempt is made to "remediate" the soil by eliminating or reducing the heavy metal pollutants (Liu and colleagues, 2018). To prevent any potential soil contaminants from seeping into the groundwater below, the surface cap forms an impermeable barrier between the soil and the surface water. The land can be utilized for anything legitimate, such as a park or a sports field, after that time has expired (Karaca *et al.*, 2014).

Phyto-stabilization

Phyto-stability is an alternative strategy for cleaning up metal contamination (or phyto-immobilization). Exudate complexation/precipitation, rhizosphere reduction, root absorption, and root adsorption all contribute to Phyto-stability. Phyto stabilization works best with plants that have a high metal tolerance, high root biomass production, and little metal leaching from the roots to the leaves. Sibth (*Agrostis tenuis*), Red Fescue (*Festuca rubra* L.), wiregrass (*Gentiana pennelliana*), thatching grass (*Hyparrhenia hirta*), Syrian bean-caper (*Zygophyllum fabago*), and hippo grass (*Vossia cuspidate*) are used for stabilizing soil that has been heavily metalized (Galal *et al.*, 2017). Phyto-stabilization is a tried-and-true technology that can be used to reforest metal-rich areas and reduce the flexibility of Pb, As, Cd, Cr, Cu, and Zn in polluted lands. This is only a stopgap measure if you are trying to clean up a contaminated area, especially one where the indigenous flora has been eradicated by metal poisoning (Chaney and Baklanov, 2017).

Phytoremediation

Soils having a fine texture and high matter content, spread out over a slightly disturbed region, are ideal for phytoremediation (Chaney and Baklanov, 2017). Plant (species, growth stage), soil (pH, buffering capacity, texture, clay minerals, organic matter content, fertility, along with cation exchange capacity) characteristics, contaminant (e.g., metal species, content, and speciation), chemical amendments applied (e.g., kind, rate, and application method), weather (precipitation, temperature), and topography (e.g., slope) all performs a role in effectiveness of phytoremediation that is removal of heavy metal contamination by plants (Vamerali *et al.*, 2010).

Bioremediation

Bioremediation is a method of repairing soil that uses bacteria rather than plants to bring it back to health. One common application is cleaning up areas contaminated by organic compounds (Marks *et al.*, 1994). Biosorption (on the surface of the cell), extracellular biochemical precipitation (by S2 from sulfur-dropping bacteria), besides volatilization (by causing dimethylselenide, trimethylarsine, and Hg

vapour) are all mechanisms by which microorganisms take metals from the environment (Garbisu and Alkorta, 2003). Metals in soil can be dissolved with the help of biosurfactants produced by several bacteria including *Bacillus subtilis* and *Torulopsis bombicola* (Açkel, 2011). Lactic acid bacteria have been identified as potent tools for the decontamination of heavy metals, cyanotoxins and mycotoxins (Halttunen *et al.*, 2008). Isolates of *Klebsiella pneumoniae* (AUSL2S) and *Pseudomonas putida* strains (USL4W and USL5W) proved that isolates retained powerful bio-removal capability for an extreme tolerance to Pb, Hg, Cd, Cu, Ni and Zn (Orji *et al.*, 2021). There is a wide variety of rhizosphere bacteria, and they all play an important role in allowing plants to flourish in polluted soils and boosting their resistance to heavy metals (Mishra *et al.*, 2017). A theoretically plausible approach for Hg removal is the use of in-situ soil bioremediation, in which methyl mercury is first converted to Hg (II) and then to Hg (I) by microbial assisted volatilization (Dash and Das, 2015). Heavy metals in soil can be removed using microorganisms like bacteria, algae, yeasts, and fungi (Yadav *et al.*, 2017). *Glomus mosseae*, *Glomus geosporum*, and *Glomus etunicatum* are mycorrhizal fungi exist in the *Plantago lanceolata* L, which were reported in order to strengthen the arsenic accumulation and decline it in soil (Orłowska *et al.*, 2012). Bacteria can decrease soil pH, modify redox conditions in the soil, produce plant development promoting along with metal chelating chemicals among them siderophores, organic acids, and bio-surfactant, all improve metal mobility and bioavailability in the soil (Ahemad, 2019).

Ex-situ remediation techniques

Ex-situ soil remediation indicates to the elimination of polluted soil from its initial site, its subsequent treatment at an off-site capacity, and its final dumping in an authorized area. The expenses of ex-situ treatment are higher than those of in-situ remediation because of the need to excavate the affected area, remove the soil, dispose of it, and then replant the area. It enhanced precision and speed, ex-situ treatment allows for better outcomes to be produced in a shorter amount of time.

Landfilling

Soil remediation using the "dig and haul" technique, which entails eliminating contaminated land from place besides disposing of it in a landfill, can be useful in some cases. With the top cap/liner system in place, surface runoff is redirected away from the fill, reducing the amount of precipitation that can seep into the fill. From original design to routine maintenance, landfills must adhere strictly to all regulations (Liu *et al.*, 2018). Garbage dumps are seen as an effective solution to the problem of where to put toxic waste (Marks *et al.*, 1994). Specifically, heavy metals concentrations are very adjustable, and dependent on the toxic waste get rid at landfill sites. Land filling is uncomplicated procedure which involves digging contaminated soil beyond the prepared position then tilling it regularly up to pollutants were destroyed by microorganisms, it is practices that

restricted to treating a minor fraction of the soil (Sivakumar *et al.*, 2014).

Biopiles

Biopiles are a mixture of land cultivation besides composting. Biopiles are creating improved environments for various microorganisms. Aqueous reactors are an ex-situ remedy for contaminated environment in which reactors are injected up at a certain location. It entails utilizing specially built technique to bioremediate a contaminated environment. Bio-piling is regarded as a realistic and cost-effective technology for treating polluted soils (Sayqal *et al.*, 2021). Engineered cells are used to treat surface pollutants by regulating physical loss-absorption of toxins due to leaching, which is followed by volatilization (Sivakumar *et al.*, 2014). It can be used to clean up very filthy environments, such as extremely cold locations. It can also remediate vast amounts of dirty soil in a small amount of space (Chemlal *et al.*, 2013). It is critical to sieve and aerate contaminated soil in order to keep the biopile functional (Delille *et al.*, 2008). Biopiling is regarded as a realistic and cost-effective method for treating contaminated soil (Paul *et al.*, 2021).

It can be applied to remediate extremely polluted environments such as very cold regions. It can also treat large volumes of polluted soil in limited space. It is process can be easily scaled up to a pilot system for achieving the same performance which was obtained during laboratory studies (Chemlal *et al.*, 2013). Sieving and aeration of contaminated soil are important to maintain the efficiency of biopile (Delille *et al.*, 2008)

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Soil washing

Physically and chemically removing heavy metals from soil is possible through a process called "soil washing," which entails washing polluted soil away from its original location using specially formulated solutions. When cleaning up polluted soil, it's important to get rid of the larger pieces of trash and debris first, like plastic, wood, and stones. To get rid of the magnets in the dirt, we employ magnets (Zhu *et al.*, 2015). The ideal detergent would be biodegradable, safe for humans and animals, and effective at raising the soluble and mobile forms of heavy metals without having a significant effect on the soil's structural integrity (Alghanmi *et al.*, 2015). Heavy metals in soil can be "washed" away with the use of mixtures coupled with extraction agent (Guo *et al.*, 2016).

Solidification

Screening soil to remove large particles (e.g., >5 cm) is the first step in stabilizing it outside of its natural environment. After the binding agent has penetrated the soil, it hardens to form a barrier that prevents impurities from leaving. This process is frequently described to as micro encapsulation (Changfeng *et al.*, 2019). The solidification stabilization method's remediation principle is primarily based on the chemical reaction among the solidifying agent besides the soil system, consequently that heavy metal impurities can be coagulated and alleviated through physical adsorption, chemical absorption, sedimentation, and ion exchange (Liu *et al.*, 2018). In solidification, the inclusion of the curing agent is creating an alkaline medium for heavy metals and avoids heavy metal to migrate (Kim *et al.*, 2017).

Conclusion

Soil pollution from heavy metals is prevalent and requires effective cleaning methods. Polluted places can be cleaned up quickly and effectively if only a few remediation strategies are available. Soil remediation procedures may use natural, biochemical, genetic, electrical, or heat processes, as surface capping, encapsulation, landfilling, coagulation, stabilization, vitrification, extraction, phytoextraction, flushing, and washing. Even though landfill sites and soil washing are examples of ex-situ techniques, most topsoil treatments can be conducted without first excavating and transporting the soil to a new area besides these techniques insitu techniques are more environment-friendly and cost-effective for the remediation of heavy metal contamination and removal of heavy metal at its own sites.

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