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Conventional and Contemporary Techniques for Removal of Heavy Metals from Soil

Vaishali Arora and Babita Khosla

Abstract

One of the most important components of the natural environment is soil. Soil is a non-renewable natural resources on which the whole human society is dependent for various goods and services. The intensive, and unsustainable anthropogenic practices along with the rapid growth of the human population have led to continuous expansion and concern for the degradation of soil. The agricultural soil is exposed to a plethora of contaminants, the most significant contaminant among them is heavy metals. The major sources of heavy metal contamination are associated with agriculture, industries, and mining. The increase of heavy metal contents in the soil system affects all organisms via biomagnification. In this chapter, we will review various conventional and contemporary physical or chemical and biological techniques for remediation of contaminated soil. The advanced solution for degraded soil is integrating innovative technologies that will provide profitable and sustainable land-use strategies.

Keywords: Metal toxicity, Soil Pollution, *In-situ*, *Ex-situ* remediation, Bioremediation

1. Introduction

Soil is the uppermost layer of Earth's crust, which is produced at the rate of a few centimeters per thousand years by the continuous transformation of solid crust material. According to FAO, the soil consists of mineral particles, organic matter, water, air, and living organisms [1]. It is one of the most essential, complex, and non-renewable natural resources. It provides humanity with a wide range of ecological, economical, and cultural services. These include provisional services: food, fiber, raw materials; regulating services: mitigation against flood, drought, carbon storage, support hydrological and nutrient cycle, recycling of wastes; cultural services: recreational, esthetic, heritage values, and cultural identity [2]. According to McBratney, 2017 soil provides around US\$ 11.4 trillion of ecosystem services [3].

Soil conditions underpin food security, habitat for various organisms, bio-economies, and above-ground biodiversity. It is the major variable in regulating the climate, hydrological, and nutrient cycles. However, anthropogenic activities including industrialization and urbanization have polluted the environment extremely and deteriorating the quality of life for all living organisms. There is enormous pressure on this finite, non-renewable natural resource. Further, inappropriate land-use management severely impacts the functions of soil, which is amplified by climate change. These stresses lead to degradation processes of soil like erosion, contamination, and degradation [4].

1.1 Soil pollution

In the era of the Anthropocene, the imprudent discharge of waste, and chemicals in the ecosystem has led to the increase of concentration of contaminants to critical levels. According to FAO. “Soil pollution” refers to the presence of a chemical or substance out of place and/or present at a higher than the normal concentration that has adverse effects on any non-targeted organism [1]. Although there is the contribution of contaminants through natural sources like, volcanic, seepage from parental rock, biogenic, and forest emissions, the widespread soil contamination and degradation are caused by anthropogenic activities. The rapid and injudicious industrialization, intensive agricultural practices, faulty mining practices and waste disposals are the major causes of heavy metal contamination of soil.

The pollutants introduced in soil by anthropogenic activities can arise from a plethora of sources. These might be discrete point sources or diffuse sources. The emission of heavy metals from point sources includes thermal power plants, coal mines, gold mines, smelting, electroplating, textiles, leather, and e-waste processing; and non-point sources include soil erosion, agricultural run-off, vehicular emissions, ash fallout, combustion of fuel, acid deposition, mining tailings, heavy metal mining and smelting, mismanaged radionuclides waste, and open freight storage (**Figure 1**).

One of the major concerns is the contamination of heavy metals in agricultural soil. It has increased tremendously in the soil system since the last decade. Although most of the heavy metals exist geologically, the emission of them in the ecosystem through anthropogenic sources like increased chemical discharge through the indiscriminate usage of pesticides and fertilizers into the agricultural soil has led to the accumulation of heavy metals concentration to dangerous levels. As soil holds the largest terrestrial pool for carbon, thus degrading soil will only worsen the phenomenon of climate change. The conditions of soil also underpin various Sustainable Development Goals (SDGs) set by the United Nations (**Figure 2**).

In view of these facts, strategies for remediation of contaminated soil must be implemented. Various remediation techniques have been developed to solve or minimize the influences of contamination. These technologies include physical, chemical, and biological methods.

1.2 Heavy metals

Heavy metals and metalloids are generally referred to as a group of elements that have densities $>5 \text{ g cm}^{-3}$. These include lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni). They are naturally occurring elements, whose natural concentration in the soil ecosystem is primarily dependent on parent rock material [5]. Some heavy metals, like Zn, Cu, Fe, Ni, Mn, Mo, and Cr are essential for the functioning of structural and biochemical processes in living organisms and are required in trace concentrations, hence called micronutrients. They can cause harmful effects to plants if absorbed in higher concentrations. While non-essential heavy metals, including Pb, Hg, As have unknown biological functions but are used for various processes in modern industrial applications. The non-essential heavy metals are toxic to plants even at low concentrations [6]. However, the emission rate of pollutants through anthropogenic sources has increased the concentration of heavy metals in soil to hazardous amounts.

Heavy metals speciation plays an important role in their long-lasting presence in the environment, as mobile forms are easily leachable thus making them to spread ubiquitously in different media, and the bioavailable heavy metals are easily

Figure 1.
Various anthropogenic sources of soil pollution.

Figure 2.
The negative impacts of soil pollution on SDGs.

absorbed by living organisms. They are non-biodegradable and non-thermodegradable so their accumulation in living organisms can cause biomagnification of heavy metals, that is they can affect organisms throughout all levels of the food chain. Particularly humans, as they are at the top of the food chain. The physicochemical properties of soil, like pH, cation exchange capacity and soil texture, also play a key role in the accumulation and availability of heavy metals [7]. Once heavy metals are exposed to humans, via inhalation, ingestion, or absorbed through the skin, they can accumulate in vital organs such as the kidney, brain, liver where they can be a threat to the health of humans [8]. Heavy metal contamination in agricultural soils may cause disturbance in the structure of soil, interfere with plant growth, and be harmful for human health via entering the food chain [9], posing health problems for all living organisms [10]. Furthermore, degradation of agricultural soil will impact crop yield and will put the most vulnerable people at higher risk of economic loss and malnutrition [4].

Soil Pollution by heavy metals is now a global concern. Europe has been found with 2.8 million sites that are potentially contaminated with heavy metal soil pollution, in China 19% of agricultural soil contain harmful pollutants exceeding the standards of environmental quality [11]. In India, heavy metal pollution in soil cover is approximately 80% by anthropogenic origin in the states of Maharashtra, Gujarat, and Telangana [12]. Therefore, the studies on agricultural soils which are contaminated with heavy metals are of much concern, especially due to two reasons. Firstly, ingestion is the main source of heavy metal exposure to humans and the agricultural food chain is the primary source of various food products for humans [8]. Secondly, densely accumulated heavy metals in agricultural soil can percolate through pore spaces and enter groundwater systems, consequently deteriorating the groundwater quality [13].

2. Remediation techniques

The comprehensive objective of any soil remediation approach is to create a final solution that is protective of human health and the environment. The remediation strategies should incorporate reduction of metal bioavailability and the reduction should be demonstrated for a long term, only if the reduction of heavy metal is equated to reduced risk [14].

A successful process of remediation includes the following steps: 1) Technology pre-screening and treatability study scoping; 2) Remedial investigation of the contaminated site; 3) Feasibility study of pre-screened remediation technology; 4) Determination of best remediation method; 5) Design and implementation of remediation practices; 6) Evaluation and monitoring of remediation process; 7) Depletion in concentration and/or removal of toxic metal [15].

Various remediation techniques applied to soil can be employed via *ex-situ* or *in-situ* methodologies. Although the *ex-situ* methodology of soil remediation is less expensive, fast, and easier to apply, it generates a significant amount of waste product that must be treated before storing or releasing it in the landfill sites. While *in-situ* remediation methodology involves low land disturbance, applicable to a broad range of inorganic pollutants, lesser in cost, and reduced risk of spreading contamination. Broadly various remediation techniques known for improving the quality of contaminated soil are studied under three categories of their application:

- Physical Remediation Techniques
- Chemical Remediation techniques
- Biological Remediation Techniques

2.1 Physical remediation techniques

The remediation techniques that are applied through physical amendments to the soil are incorporated under this category. The physical techniques of remediation include the capping of contaminated sediments, washing, and excavation of soil.

2.1.1 Capping

It is a non-intrusive and cost-effective method for remediating contaminated sediment. The technique is utilized to decrease the solubility, mobility and transfer

rate of heavy metals in the sediment [16]. It is usually applied in sub-aqueous conditions. Sandy material and apatite are usually tiered in specific proportions, which are placed on the contaminated sediment like a cap. The cap is usually composed of a, (i) stabilizing base layer which supports the added weight of cap; (ii) an isolation base layer, it isolates the contaminants from the sediment; (iii) a filter layer for hydraulic protection for the base layer; (iv) an armor layer, it inhibits erosion for the protection of filter and base layer. Capping can be performed in two ways, Passively (inactive) or Reactively (active). The former methodology includes a cap composed of clean and neutral material which provides a physical barrier between the environment and contaminated sediment. However, passive methods have been observed to cause leaks of toxic metals. The latter methodology includes the cap with reactive material which can reduce the mobility, toxicity, and bioavailability of contaminants in sediments. This technique is not appropriate for shallow water or marshes or water bodies with large water flows as the capping material can be washed away [17]. Below is a graphical representation of the capping methodology (Figure 3) [18].

2.1.2 Washing of soil

Sediment washing is a simpler technique that is performed *ex-situ*. In this technique, a solution is utilized to wash the contaminated sediment for the transfer of pollutants from sediment to an aqueous solution. This is achieved by mixing the soil with an aqueous solution of alkalis, acids, and surfactants [14]. Washing includes (i) excavation of highly contaminated sediment from the bulk soil; (ii) washing of sediment is processed with the help of aqueous mixtures; (iii) the solubilized contaminants are removed from aqueous solution through various chemical processes. For performing this method more efficiently additives are added to the aqueous solution, depending upon the physicochemical nature of contaminated sediment. These additives should have high treatment efficiency and environmental compatibility. Common additives used are inorganic acids (sulfuric acid, nitric acid), organic acid (oxalic acid, ascorbic acids), and surfactants (sophorolipids

Figure 3.
Capping technique for isolating contaminated sediment [18].

and rhamnolipids) [16]. EDTA has been reported as the additive for the removal of heavy metals, due to its versatile chelating nature, however, the toxic effect of EDTA on the environment and its low biodegradability has reduced its application widely [19]. After washing, the sediment is considered contaminant depleted instead of contaminant free. Therefore, to make this technique successful, the number of contaminants treated should be quantified to be equivalent to the site-specific action limit. This technique is suitable for the contaminants which are weakly associated with sediments, and in coarse-grained sediments [14].

2.1.3 Excavation of soil

This technique includes physical removal of majorly contaminated soil from the bulk soil. There are several ways to perform this technique. It can be divided into three methodologies (i) substitution of polluted sediment by removing the soil and putting it in another soil. This method is more suitable for land contaminated in small areas; (ii) the deep excavation of contaminated sediment for natural degradation of heavy metals; (iii) importing new soil and mixed with contaminated soil for dilution of heavy metals. This technique is expensive and is efficiently applicable only on land with small areas of contamination [20].

2.2 Chemical remediation techniques

This technique includes the utilization of chemical reagents, reactions, and principles for the removal of contaminants. Major methodologies used under this technique are solidification, immobilization, vitrification, and electro kinetics.

2.2.1 Immobilization

This methodology is used to stabilize heavy metals, can be applied *ex-situ* and *in-situ*. It often uses organic and inorganic reagents for the reduction of heavy metals mobility, toxicity, and bioavailability in the soil. The primary objective of this technique is to alter the bioavailable phases of metals into more geo-chemically stable phases, with the immobilization of chemicals. It is achieved through combined mechanisms of adsorption, complexation, and precipitation. The stabilizing effect of amendments is dependent upon the physical, chemical, and biological characteristics of sediment, heavy metal type, remediation time, remediation method, and evaluation method. The most common inorganic reagents used for immobilization are silico-calcium reagents, phosphates, iron-containing materials, aluminum salts, and mineral-based amendments. Organic reagents for immobilization of heavy metals include manure, biochar, biosolids, bark, wood chips, sawdust, sewage sludge, and turf. A complex formulation of inorganic and organic amendments can also be applied to the contaminated sediments for more efficient stabilization [21].

2.2.2 Solidification

It is a technique applied by mixing contaminated sediments with materials that impart physical stability to encapsulate contaminants in a solid product. Solidification is the physical encapsulation of contaminants in a solid matrix, which are formed by cement, bitumen, asphalt, fly ash and thermoplastic binders. During *In-Situ* remediation, a binding agent is added to contaminated sediment which is followed by an auger spin mixing to transform the soil into a solid matrix [15]. The stabilization of heavy metals includes chemical reactions which reduce their mobility in the environment. The entrapped toxic metals are not leachable as

the solid block is impermeable to water. A mixture of various salts can be used for the solidification or stabilization of contaminants in soil *ex-situ* or *in-situ*. Several economically effective and environmentally friendly waste resources have been reported for their application in contaminated sediment. These waste resources can also improve the quality of polluted soil, such as lime-based agents, calcined oyster shells, eggshells, waste mussel shells, and calcined cockle shells [20]. However, the process does not extract the pollutant. So, over the long term, if the integrity of solid matrix is deteriorated due to natural weathering or any uncontrolled physical disaster the contaminants which are trapped can mobilize into the environment. Therefore, this methodology is applied as a last option for remediation of soil. This technology is dependent on the concentration of contaminants present in the sediment, amount of water, and ambient temperature. These factors affect the binding reaction of contaminants to the solid material, it inhibits the binding and decreases the stability of the solid matrix [14].

2.2.3 Vitrification

This methodology of remediation is a type of stabilization/solidification technique. It requires high thermal energy in contaminated soil, at least 1400°C - 2000°C, for the removal of organic or volatile substances. It is achieved by mixing the contaminated sediments with glass-forming precursors, heating the mixture till its liquid solution is formed. The steam produced by introducing high thermal energy and the products of pyrolysis are collected from exhaust gas [21]. On the cooling of this solution, an amorphous homogenous glass is obtained. The contaminants can be stabilized by two ways of interactions with solid glass matrix, that is chemical bonding and encapsulation. For *in-situ* remediation, electrodes can be inserted directly into the contaminated sediments. This technique is efficient but expensive and complex to perform [20].

2.2.4 Electrokinetic remediation

In this technique, the electric field is applied to the wet contaminated sediments for the movement of ionized metals towards the cathode or anode. The pollutants are migrated towards electrodes through electro-migration (charged chemical movements), electro-osmotic flow (fluid movements), electrophoresis (charged particle movements), and electrolysis (chemical reaction due to electric field) procedures [21]. On the completion of the remediation process, the contaminant concentrated electrodes can be treated through several techniques for treating the heavy metals. This technique performs more efficiently in fine-grained clayey soil, where heavy metals are present as soluble ions, because of high electric conductivity and strong electric field [16]. To enhance the efficiency of this technique application of chelating agents can be performed, such as EDTA, nitrilinoacetic acid, succinic acid, citric acid. A schematic representation of this technique has been represented in (Figure 4).

2.3 Biological remediation

Biological remediation or bioremediation is a technique of transforming the heavy metals present in the contaminated soil, into a less toxic element. This technique uses biological phenomena that are intrinsic to plants and microorganisms, for the destruction, removal, or immobilization of hazardous contaminants from the polluted environment. Bioremediation is an eco-friendly and economically effective technique for heavy metal removal compared with the conventional chemical and physical methods, which are usually expensive and ineffective especially for sediments contaminated

Figure 4. *A schematic representation of in-situ electrokinetic installation; B schematic representation of detailed electrokinetic remediation technique [22].*

with low metal concentrations, in addition to producing significant amounts of toxic sludge [20]. The main objective of the bioremediation technique is to stimulate a favorable condition for microflora or plants at the contaminated site by providing suitable growth conditions. So, they can grow at their full potential and produce enzymes as secondary metabolites for immobilizing the toxic metals. During the bioremediation process of the contaminant, chemical bonds are broken, and energy is released, which is further utilized by the microorganisms for their growth. Various investigations show that the total transformation percentage of various heavy metals by microbes are Cr (27%), Co (20%), Cd (31%), Pb (22%) [23]. Bioremediation technology is aided with several methodologies, such as bioventing, bioleaching, and land farming, bioreactor, composting, and bioaugmentation, rhizo-filtration, and biostimulation. Therefore diverse metabolic activity inherent to microbes can be exploited for degradation, removal, or transformation of heavy metals in contaminated soil [24]. Mostly bioremediation can be performed by utilizing microorganisms (algae, fungi, and bacteria), and plants (phytoremediation), or with the combinations of both.

2.3.1 Phytoremediation

This technique involves the use of various native, imported, or genetically modified plant species for the reduction, and removal of contaminants from soil,

sludge, wastewater, sediments, and groundwater. This technique is best applicable when the contaminants are present around the rhizosphere and in a wide area of land. The basic principle in phytoremediation involves the disintegration through secondary metabolites or absorption by roots, and storing them in leaves of plants, of contaminants present in soil [20]. Hyperaccumulation and hyper tolerance are very important characteristic for a plant for their utilization in phytoremediation. Phytoremediation technique includes phytoextraction, Phytodegradation, Phytostabilization, Phytovolatilization, and Phytodegradation [19].

Phytoextraction/Photoabsorption/Phytosequestration/Phytoaccumulation refers to a biochemical process where the assimilation of heavy metal contaminants from the sediment or water is processed through roots and translocated to any harvestable part of the plant, based on the mechanism of hyperaccumulation (**Figure 5**). Hyperaccumulators can concentrate 100 to 1000 times higher than those found in non-hyperaccumulators without suffering any apparent phytotoxic effect. This method includes three steps (i) cultivation of suitable plant species in the contaminated land; (ii) harvesting of biomass concentrated with metal; (iii) post-harvest treatment for obtaining economic value [25]. The most used hyperaccumulators are from the family *Fabaceae*, *Brassicaceae*, *Lamiaceae*, *Cryophyllaceae*, *Violaceae*, *Asteraceae*, *Cyperaceae*, and *Poaceae* [24].

Phytodegradation is the cleanup method for a contaminated environment with the use of plant roots. It could be performed in three forms of rhizofiltration (plant roots), blastofiltration (seedlings), caulofiltration (excised plant shoots) [19].

Figure 5.
Schematic representation of several strategies involved in phytoremediation technique [26].

Phytostimulation enhances the conditions of the rhizosphere for the efficient growth of microbes. It is performed for the removal of organic pollutants in the sediment.

Phytostabilization aims to the reduction of mobility and bioavailability of heavy metals in the environment by stabilizing the contaminants in the rhizosphere of plant species. It is performed by reducing the accessibility and mobility of heavy metals through precipitation, root sorption, metal valence reduction, and complexation. The efficiency of this technique can be enhanced by changing the pH and organic matter content in the sediment [25].

Phytodegradation is a technique utilized for degrading organic matter into non-hazardous chemicals through secondary metabolites or enzymes secreted by plants. Enzymes like nitroreductase and dehalogenases are used by plants for the degradation of organic matter. These enzymes are used only in optimal conditions (temperature, pH). This process can be performed more efficiently with the introduction of microorganisms in the contaminated soil, this technique is called Rhizodegradation [26].

Rhizofiltration is the process in which plants absorb and precipitate organic and inorganic contaminants through roots from contaminated wastewater, groundwater, and surface water. Major characteristic features of plants are hypoxia tolerant, and large absorption surface area for a suitable application of this technique. Terrestrial plants are more efficient for this purpose than aquatic plants [27].

2.3.2 Microbial remediation

Microorganisms can absorb or adsorb the heavy metals present in the soil to transform its chemical nature and reduce its mobility, bioavailability, and solubility. This remediation technique by microbes can be carried out in two ways, through mobilization or immobilization. These processes are accomplished by mechanisms, like bio-precipitation, biosorption, bioaccumulation, bio-assimilation, bioleaching, biodegradation, and biotransformation (**Figure 6**). Commonly microbial species used for remediation methodology are *Bacillus*, *Arthrobacter*, *Pseudomonas*, *Enterobacter*, *Aspergillus*, *Penicillium*, *Rhizopus*, *Rhodotorula*, *Candida utilis* [23].

Biosorption is a mechanism where microbes either absorb or adsorb the inorganic contaminants on the cell surface or into the cell. While adsorption is performed on the surface of the cell, absorption involves an entire volume of material. Several mechanisms involved in biosorption are precipitation, the formation of stable complexes with organic ligands, and redox reaction. The process of adsorption involves forming a complex of the heavy metals and functional groups on the cell surface, from where they can be absorbed into the cell. Adsorption is executed by binding heavy metals to the cell surface through electrostatic interaction, complexation, and ion exchange. According to Jin et al. [28], microbes perform adsorption predominantly in comparison to absorption.

Bioleaching is the mobilization of heavy metals from contaminated soil through biological dissolution, complexation, or bio-oxidation by microbial activity. The best-known microbes for bioleaching are *Thiobacillus* and *Leptospirillum ferrooxidans*. Various mechanisms of microbial metabolism produce several secretions, like low molecular organic acids. These organic acids have shown to effectively dissolve heavy metals and soil particles containing toxic heavy metals [28].

Bioaccumulation includes the agglomeration of contaminants into the microbe where it is concentrated, where metal is sequestered.

Bio-assimilation of heavy metals includes the active transport of microbial cell's siderophore for the chelation of toxic metals. Siderophores are biomolecules that are produced when microbes are present in iron-deficient media/environment. These

Figure 6.
Schematic representation of various mechanisms involved in microbial remediation of heavy metal contaminated soil [3].

Methodology	Remediation Technique	Applicability	Advantages	Limitations
Physical Remediation	Surface Capping	<i>In Situ</i> , in areas with excessive heavy metal pollution	Applicability is unchallenging, low operating cost, high security	Limited to small land areas, and applicable at specific geographic locations, deprivation of land
	Landfilling	<i>Ex Situ</i> , applicable to areas with high metal pollution	Immediate restoration, high security	High capital cost, supplementary land is required for storing of the unproductive sediment
	Encapsulation	<i>In Situ</i> , applicable to areas with high heavy metal pollution	Isolation of heavy metal from contaminated sediment is effective, installation can be done quickly	Limited to small scale and shallow land areas, costly,
	Soil Washing	<i>Ex Situ</i> , applicable to soil with moderate to high heavy metal pollution	Efficiency is high, immediate remediation can be observed, cost-effective, removal of heavy metals are absolute	Effectiveness varies with the variation in physicochemical nature of soil, drastic soil disturbance has been observed
	Excavation of Soil	<i>Ex Situ</i> , applicable to areas with high heavy metal contamination	Removal of heavy metal is effective, Less time is required for completion of process	Production of harmful waste products which can have negative impact on soil, costly

Methodology	Remediation Technique	Applicability	Advantages	Limitations
Chemical Remediation	Stabilization	<i>In Situ</i> , applicable to areas with high heavy metal contamination	Affordable, easy to applicability, instantaneous effect on contaminated soil, covers a broad-spectrum of inorganic pollutants	Specific to different metals, temporary effectiveness, constant monitoring is required, remnants of contaminants will still be present in the soil
	Solidification	<i>In Situ</i> and <i>Ex Situ</i> , applicable to areas with high heavy metal contamination	Implementation is quick, high efficacy	High capital cost, treated land loses important ecological functions
	Vitrification	<i>In Situ</i> and <i>Ex Situ</i> , applicable to areas with high heavy metal contamination	High efficiency, easy to install, applicable to various contaminants	High capital cost due to energy requirement, limited to a small scale areas, treated land loses its environmental function
	Electrokinetics	<i>Ex Situ</i> , fine soil, applicable to soil with moderate to high heavy metal pollution	Application is easy, economically effective, deterioration of soil functions are minimum	Time-consuming, low efficiency, best for fine-textured soil with low permeability, pH of soil has to be controlled
Bioremediation	Phytoremediation	<i>In Situ</i> , applicable to soil with low to moderate heavy metal pollution	More public acceptance, economically effective, easy to apply	Limited to shallow land, time-consuming, restricted to specific metals, effectiveness depends on the growth conditions, and bioavailability of heavy metals.
	Contaminant transformation with the help of microbes	<i>In Situ</i> , applicable to soil with low to moderate-heavy metal pollution	Easy to implement, economical, disturbance to soil is low, remediation is less time consuming	Depends on microbes, soil, metal type, and plant, low efficacy

Table 1.
Mechanisms, advantages and disadvantages of the available remediation techniques for heavy metal contaminated soil [19].

biomolecules are specifically iron (Fe III) chelators which are finally transported into microbes by various uptake proteins. Many reports have suggested that if siderophores are bonded with other metals, they can still be recognized by uptake protein for its transportation into the microbial cell [16, 24].

Bioprecipitation is a method that uses the mechanism of immobilization for the reduction of mobility and bioavailability of heavy metals in soil. It involves converting soluble heavy metals into insoluble hydroxides, carbonates, sulfides, and phosphates.

Biotransformation changes the chemical nature of heavy metals, altering their toxicity, mobility, and bioavailability. This methodology includes methylation, reduction, dealkylation, and oxidation of heavy metals for altering their soluble form into an insoluble form [16].

The applicability of these individual techniques in any specific soil remediation project is determined primarily by contamination site geography, characteristics of contaminants, the goal of remediation, cost-effectiveness, financial budget, readiness in implementing the technique, the time provided, and public acceptability (**Table 1**). Integration of more than one technique has been experimentally proved to be more efficient, such as application of chemical remediation in highly heavy metal contaminated sediment, which can be followed by phytoremediation for further removal of remaining contaminants [15].

3. Conclusion

Over-exploitation of natural resources, land mismanagement, industrialization, and urbanization has led to the discharge of heavy metal through anthropogenic activities. The contamination of soil by heavy metals is of great concern because of its potential impact on human, animal, and plant health. Therefore, effectual technologies of remediation are necessary. Although the traditional physical and chemical methods for cleanup of sediment contaminated with high concentrations of heavy metal are low in cost, but simultaneously can modify soil properties and native microflora and can also produce secondary pollutants in the soil. By comparison, bioremediation is a better alternative to solve this issue. It is environmentally friendly, cost-effective, does not impact the natural microflora of soil, and the use of nature-based products enhances the attainment of UN Sustainable Goals. However, various aspects of bioremediation make the method moderately debilitated, such as longer time is required for transforming the heavy metals. Integration of various techniques can help in achieving a more efficient result for remediating the contaminated soil. Furthermore, the screening of various native plants for remediation of polluted soil with toxic heavy metals as well as advancement in the application of biotechnological approaches has offered various modified plants for phytoremediation.

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