

## Review Article

# Vermiremediation and Phytoremediation: Eco Approaches for Soil Stabilization

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## Abstract

The contamination of soil by anthropogenic activities has raised many concerns in scientific community. There is an urgent need of reliable and nature friendly techniques for addressing these concerns. Vermiremediation and phytoremediation are two such dependable techniques. Vermiremediation involves earthworms to convert solid organic materials and wastes into vermicompost which acts as a soil conditioner and nutrient-rich manure. The contaminants in organic wastes which could pollute the soil can be significantly reduced using earthworms. The vermicompost generated from earthworms increases soil fertility (physical, chemical, biological). In vermicompost nutrients such as nitrogen, potassium, phosphorus, sodium, magnesium and calcium are in plant available forms. Vermicompost is increasingly considered in agriculture and horticulture as a promising alternative to chemical fertilizers. Phytoremediation involves plants and soil microbes to minimize the amount of contaminants (such as heavy metals) in the environment. Plants have capacity to uptake contaminants from the soil and execute their detoxification by various mechanisms (phytoaccumulation, phytostabilization, phytofiltration, phytodegradation, phytovolatilization). Plants store these contaminants in their tissues from where these can be harvested or dumped in safe sites. This study is aimed to document the various techniques and their role, with commercial examples, benefits, and drawbacks etc of phytoremediation and also effects of vermicompost on the soil fertility, physicochemical and biological properties of soil.

**Keywords:** Earthworms; Heavy metals; Microbes; Nutrients; Organic fertilizer; Vermicompost

## Introduction

Excessive use of chemical fertilizers deteriorates the soil properties (physical and chemical) and also contaminates the surrounding environment [1]. According to Chaoui et al [2], excessive leaching of nutrients and salinity-induced plant stress can be caused by the excessive use of inorganic fertilizers. The joint application of organic and chemical fertilizers maintains the Soil Quality Index (SQI) [3]. The excessive use of chemical fertilizers without organic fertilizers can deteriorate the soil properties [1]. The physico-chemical characteristics of agricultural soils can be modified directly by the application of vermicompost which acts as a soil conditioner and nutrient-rich manure [4]. Vermicomposting involves joint interaction between earthworms and microorganisms to generate a homogeneous, stable and nutrient rich product called as vermicompost [5-8]. The final vermicompost is nutritionally improved as compared to traditional compost [9-11]. Vermicomposting process increases the rate of mineralization of organic substrates and enhances higher degree of humification [12]. Soil fertility can be enhanced by the application of vermicompost through physically (aeration, porosity, water retention, bulk density), chemically (pH, electrical conductivity, organic matter content) and biologically (microbial biomass, enzymes, micro and macro nutrients) [13-15]. Vermicompost is increasingly considered in agriculture and horticulture as a promising alternative to chemical fertilizers. Vermicompost is rich source of macro and micro nutrients

such as nitrogen, potassium, phosphorus, sodium, magnesium and calcium [11,16] and can play a major role in soil nutrient management. The use of vermicompost can enhance the physicochemical properties of soil, which can increase the plant growth [17]. Phytoremediation involves plants and soil microorganisms to minimize the toxic effects of pollutants in the environment [18,19]. This technique is used to remove toxic metals and other organic pollutants. According to Mench et al. [20] plants amend soil fertility with application of organic materials. The present review article is aimed to document the effects of vermicompost on the soil fertility, plant growth, physicochemical and biological properties of soil and various techniques of phytoremediation and their role in soil stabilization.

## Vermicomposting

The process of vermicomposting involves earthworms to convert organic materials into vermicompost which acts as a soil conditioner and nutrient-rich manure. Vermicomposting technology is cost-effective and eco-friendly technique that plays an important role in minimizing environmental pollution. The final vermicompost can be applied for agricultural purposes which provide maximum microbial activity to the soil [21]. Through vermicomposting, many researchers have successfully converted various types of industrial wastes into nutrient rich manure [22-24].

**Table 1:** Nutrient content of vermicompost and traditional compost.

Nutrient content	Vermicompost	Traditional compost
pH	8.92±0.09	8.40±0.10
EC (mS/cm)	2.82±0.03	3.22±0.02
TKN (%)	2.40±1.20	1.03±0.24
TOC (%)	37.12±0.11	45.40±1.01
C:N ratio	15.46±0.57	44.30±1.62
TAP (%)	1.49±0.81	0.92±0.30
TK (%)	1.90±2.08	4.01±1.20
TNa (%)	1.41±0.38	0.71±0.20
Zn <sup>a</sup>	11.54±0.37	9.85±0.37
Cu <sup>a</sup>	9.03±0.20	8.04±0.23
Fe <sup>a</sup>	590.04±1.52	620.04±1.60
Mn <sup>a</sup>	38.01±0.88	13.02±1.77

Weight in mg/Kg. Source: Bhat et al., [10].

### Nutrient content in vermicompost

Vermicompost produced from organic sources can play a major role in soil fertility and also in organic farming. The final vermicompost has higher macro and micro nutrients as compared to traditional compost [10]. Vermicompost is granular, with large surface area due to mineralization and degradation by earthworms [7,25]. The nutrient content in vermicompost (prepared from cattle dung) and traditional compost is shown in Table 1.

### Effect of vermicompost on soil quality, physico-chemical and biological properties

Vermicompost increases the soil microbial population and acts as a rich source of nutrients. It increases the availability of nutrients (potassium and nitrogen) through improving phosphorus solubilization and nitrogen fixation [17]. Application of vermicompost can directly enhance the physiochemical and biological properties of soil. Vermicompost increases soil porosity, aeration, water holding capacity and infiltration [13]. According to Kale and Karmegam [26] earthworms in the soil add mucus secretion which enhances the soil stability. The combination of earthworms and microbes decreases the particle and bulk densities of soil which increases the porosity and aggregate formation of the soil [1]. Soil treated with vermicompost increases the available (N, K, P) and total (Ca, Cu, Fe, Mg, Mn, Na, Zn) macro and micro-nutrients in the soil [1]. Leaching problem of nutrients in soil can be reduced by the application of vermicompost. Bhattacharjee et al. [27] observed that the nutrient leaching from the soil is greatly reduced by the application of vermicompost which changes the physico-chemical characteristics of the soil. Vermicompost can also be used in acid and alkaline soils, due to its near neutral to alkaline nature of pH. According to *Manivannan et al.* [1] pH between 6-7 ranges increases the availability of nutrient content to the plants. Many researchers have observed that the soil pH increases in acidic soils and reduces in alkaline soils with the application of vermicompost [28,29]. In vermicomposting process, Electrical Conductivity (EC) of final vermicompost depends on initial raw material used [30]. Addition of vermicompost lowers the EC of soil due to increase in the exchangeable Ca<sup>2+</sup> concentration, which allows higher leaching of exchanged Na<sup>+</sup> and lowers the soil EC [31]. Vermicompost improves soil porosity and infiltration

rate, which enhances salt leaching leading to decrease in EC of soil [32]. Vermicompost with EC value lower than 4.0 ds m<sup>-1</sup> are ideal for organic soil amendments [33]. Application of vermicompost in soil increases the organic matter and biomass of soil microbes [1]. According to Atiyeh et al. [34] dehydrogenase enzyme activity was higher in vermicompost as compared to commercial medium. Application of organic fertilizers (vermicompost, neem cake, farmyard manure and ash) and biofertilizers to soil increases the enzyme activities (dehydrogenase, acid phosphatase and  $\beta$ -glucosidase [35]. Vermicompost increases the surface area for microbial activities and retention of nutrients [36,37]. Application of vermicompost increases the biomass of soil microbes, which increases the plant growth and fruit yield [38]. The scientific research on the plant growth by the application of vermicompost are still sparse.

### Effect of vermicompost on productivity and growth of plants

Many researchers studied the effect of vermicompost on productivity and growth of plants [39-42]. Vermicompost contains high levels of soil enzymes and plant growth hormones and also retains nutrients in soils for longer duration without affecting the environment [17,36]. Vermicompost can be used as a soil additive and plant container media for overall growth and development of plants [43]. According to Roy et al. [44] vermicompost increases the root and shoot weight and plant height as compared to traditional compost. Earthworms in the soil may impact the physico-chemical characteristics of the soil and other organisms (nematodes, collembolans) living within the soil [45]. Application of vermicompost accelerates the growth of crops and plants. Vermicompost contains enzymes and hormones that stimulate plant growth and makes it pathogen free [46]. Plant growth promoting substances and plant growth hormones (auxin, cytokinins, humic substances) produced by microbes have been reported from vermicompost by many researchers [47,48]. The final vermicompost is considered an excellent material of homogenous nature as it has reduced level of contaminants and holds more nutrients over a longer time without affecting the environment [49]. Many researchers [50-53] have reported that the vermicompost produced from animal dung, sewage and paper industry sludge contains higher amounts of humic substances, which have important role in growth and productivity of plants. So vermicomposting and vermiculture technology is economically sound, environmentally safe technology for organic waste degradation and can create employment opportunities for all weaker sections of the society. India, were a large amount of organic waste is available could produce million tons of vermicompost and will reduce the use of toxic chemical fertilizers. Hidalgo et al. [54] observed that the addition of vermicompost to a greenhouse potting medium (mixture of sand, pine bark and peat) showed a significant increase in water holding capacity and total porosity. Ferreras et al. [55] reported that addition of 20 ton ha<sup>-1</sup> of vermicompost in two consecutive years to an agricultural soil significantly improved soil porosity and fertility. Marinari et al. [56] reported that the elongated soil Macropores number increased significantly in corn field after a single vermicompost application equal to 200 kg ha<sup>-1</sup> of N. Gopinath et al. [57] observed increase in total organic carbon and soil pH and decrease in bulk density of soil after application at a rate equal to 60 kg ha<sup>-1</sup> of N of vermicompost in two consecutive growing seasons. Vermicompost is increasingly considered in agriculture and horticulture as a promising alternative

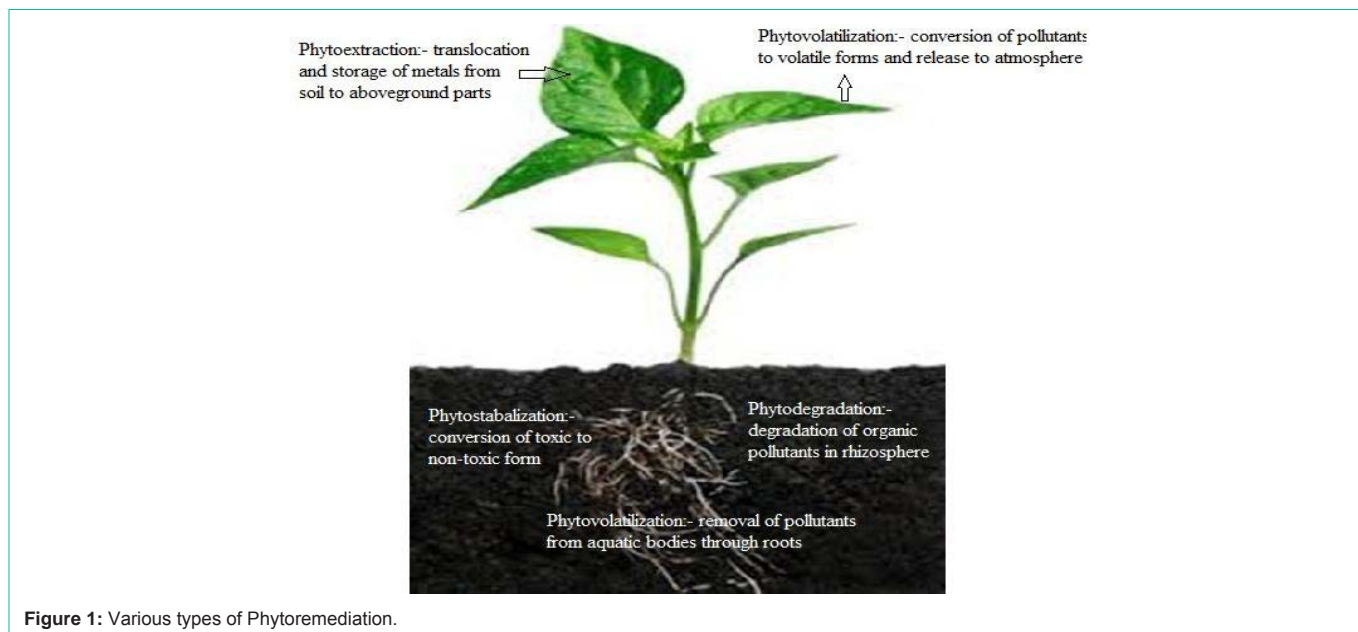
**Table 2:** Various studies conducted on metal accumulation and phytoremediation potential of plants.

S. No.	Plant species	Metals accumulated	References
1	<i>Acorus calamus</i> , <i>Cyperus malaccensis</i> , <i>Eleocharis valleculosa</i> , <i>Equisetum ramosist</i> , <i>Juncus effuses</i> , <i>Leersia hexandra</i> , <i>Neyraudia reynaudiana</i> , <i>Phragmites australis</i> , <i>Phalaris arundinacea</i> , <i>Polypogon fugax</i> , <i>Typha latifolia</i> , and <i>Typha angustifolia</i>	Cd, Cu, Pb and Zn	Deng et al., [64]
2	<i>Brassica napus</i> and <i>Raphanus sativus</i>	Cd, Cr, Cu, Ni, Pb and Zn	Marchiol et al., [107]
3	<i>Paspalum notatum</i> , <i>Pennisetum glaucum</i> × <i>P. purpureum</i> , <i>Stenotaphrum secundatum</i> and <i>Vetiveria zizanioides</i>	Pb and Cd	Xia, [108]
4	<i>Achnatherum chingii</i> , <i>Adiantum capillus-veneris</i> L., <i>Arundinella yunnanensis</i> , <i>Artemisia lancangensis</i> , <i>Carpinus wangii</i> , <i>Fargesia dura</i> , <i>Juncus effuses</i> , <i>Lithocarpus dealbatus</i> , <i>Llex plyneura</i> , <i>Pinus yunnanensis</i> Tranch, <i>Populus yunnanensis</i> , <i>Polystichum disjunctum</i> , <i>Rhododendron decorum</i> , <i>Rhododendron annae</i> , <i>Rhododendron decorum</i> , <i>Rhododendron annae</i> , <i>Salix cathayana</i> , <i>Sambucus chinensis</i> , and <i>Trifidium repensl</i>	Cd, Cu, Pb and Zn	Yanqun et al., [63]
5	<i>Carthamus tinctorius</i> L., <i>Cannabis sativa</i> L., <i>Malva verticillata</i> L., <i>Mellilotus alba</i> L., and <i>Trifolium pratense</i> L.,	As, Cd, Pb, and Zn	Tlustoš et al., [109]
6	<i>Bidens alba</i> var. <i>radiata</i> , <i>Cyperus esculentus</i> L., <i>Gentiana pennelliana</i> Fern., <i>Plantago major</i> L., <i>Phyla nodiflora</i> L., <i>Rubus fruticosus</i> L., <i>Sesbania herbacea</i> and <i>Stenotaphrum secundatum</i>	Cu, Pb and Zn	Yoon et al., [65]
7	<i>Aeschynomene indica</i> L., <i>Alternanthera philoxeroides</i> (Mart.) Griseb, <i>Aster subulatus</i> Michx, <i>Cyperus iria</i> L., <i>Cyperus difformis</i> L., <i>Digitaria sanguinalis</i> (L.) Scop, <i>Eleusine indica</i> (L.) Gaertn, <i>Echinochloa crus-galli</i> (L.) Beauv, <i>Echinochloa caudata</i> Roshev, <i>Echinochloa oryzicola</i> (Ard.) Fritsch, <i>Eclipta prostrata</i> L., <i>Fimbristylis miliacea</i> (L.) Vahl, <i>Isachne globosa</i> (Thunb.) Kuntze, <i>Monochoria vaginalis</i> (Burm. f.) Presl, <i>Oryza sativa</i> L., <i>Phragmites communis</i> Trin., <i>Polygonum lapathifolium</i> L., <i>Polygonum hydropiper</i> L. and <i>Zizania latifolia</i> (Griseb.) Stapf	Cd, Pb and Zn	Liu et al., [110]
8	<i>Dianthus chinensis</i> , <i>Rumex crispus</i> , <i>Rumex K-1</i> , <i>Rumex acetosa</i> DSL, <i>Rumex acetosa</i> JQW, <i>Sedum alfredii</i> , <i>Vertiveria zizanioides</i> and <i>Viola baoshanensis</i>	Cd, Pb and Zn	Zhuang et al., [111]
9	<i>Artemisia lactiflora</i> Wall, <i>Aster subulatus</i> Michx, <i>Bauhinia variegata</i> , <i>Buddleia officinalis</i> Maxim, <i>Colocasia esculenta</i> , <i>Coryza canadensis</i> (L.) Cronq., <i>Debregeasia orientalis</i> , <i>Polygonum chinense</i> , <i>Polygonum rude</i> , <i>Pteris ensiformis</i> , <i>Pteridium</i> var. <i>Pteris fauriei</i> Hieron, <i>Osyris wightiana</i> , <i>Ricinus communis</i> L., <i>Rumex hastatus</i> , <i>Smilax china</i> L. and <i>Tephrosia candida</i>	Cu, Pb and Zn	Xiaohai et al., [67]
10	<i>Lobelia chinensis</i> and <i>Solanum nigrum</i>	Cd, Cu, Pb and Zn	Peng et al., [112]
11	<i>Helianthus annuus</i> and <i>Tithonia diversifolia</i>	Pb and Zn	Adesodun et al., [68]
12	<i>Amaranthus viridis</i> L., <i>Brachiaria reptans</i> (L.) Gard. & Hubb., <i>Cannabis sativa</i> L., <i>Cenchrus pennisetiformis</i> Hochst. and Steud. ex Steud., <i>Chenopodium album</i> L., <i>Cynodon dactylon</i> (L.) Pers., <i>Cyprus rotundus</i> L., <i>Dactyloctenium aegyptium</i> (L.) P. Beauv., <i>Elusine indica</i> (L.) Gaerth., <i>Ipomoea hederacea</i> Jacq., <i>Malvastrum coromandelianum</i> (Linn.) Garcke., <i>Parthenium hysterophorus</i> L., <i>Portulaca oleracea</i> L., <i>Ricinus communis</i> L., <i>Solanum nigrum</i> L., and <i>Xanthium strumarium</i> L.	Cr, Cu, Co, Ni, Pb and Zn	Malik et al., [113]
13	<i>Beta vulgaris</i> var. <i>canditva</i> L., <i>Brassica oleracea</i> var. <i>capitata</i> L., <i>Cucurbita pepo</i> L. convar. <i>giromontiana</i> Greb., <i>Cichorium intybus</i> var. <i>foliosum</i> Hegi, <i>Hordeum vulgare</i> L., <i>Medicago sativa</i> L., <i>Pastinaca sativa</i> L., <i>Phaseolus vulgaris</i> L., and <i>Zea mays</i> L. convar. <i>saccharata</i> Koern.	Cd, Pb and Zn	Poniedziątek et al., [114]
14	<i>Brassica campestris</i> , <i>Croton bonplandianum</i> , <i>Datura stramonium</i> , <i>Dolichos lablab</i> , <i>Lycopersicum esculentum</i> , <i>Parthenium hysterophorus</i> , <i>Ricinus communi</i> , <i>Solanum nigrum</i> , <i>Solanum xanthocarpum</i> , <i>Triticum aestivum</i> and <i>Typha</i> spp (weed)	Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn	Singh et al., [115]
15	<i>Solanum nigrum</i> L.	Cd	Ji et al., [70]
16	<i>Argemone mexicana</i> , <i>Cassia italic</i> , <i>Calotropis procera</i> , <i>Citrullus colocynthis</i> , <i>Cyperus laevigatus</i> , <i>Phragmite australis</i> , and <i>Rhazya stricta</i>	Cd, Cr, Co, Cu, Fe, Pb, Ni and Zn	Badr et al., [116]
17	<i>Arrhenatherum album</i> , <i>Corrigiola telephifolia</i> , <i>Cynosorus echinatus</i> , <i>Digitalis thapsi</i> , <i>Holcus mollis</i> , <i>Jasione montana</i> , <i>Plantago lanceolata</i> , <i>Rumex acetosella</i> , <i>Thymus zygis</i> , and <i>Trisetum ovatum</i>	Cd, Cr, Cu, Ni, Pb and Zn	García-Salgado et al., [117]
18	<i>Alternanthera Philoxeroides</i> , <i>Eichhornia crassipes</i> (Mart.) and <i>Pistia stratiotes</i> L.	Cu, Fe, Mg, Mn and Zn	Hua et al., [71]
19	<i>Medicago sativa</i>	Fe, Al, Ni, Zn, Cr, Co, Cu and Pb	Al-Rashdi and Sulaiman, [118]
20	<i>Sargassum hemiphyllum</i> and <i>Sargassum henslowianum</i>	Cd, Cr, Cu, Pb and Zn	Yu et al., [119]
21	<i>Plantago major</i> L.	Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sr, V and Zn	Galal and Shehata, [72]
22	<i>Trifolium respinatum</i> L.	Ni	Rad and Ghasemi et al., [120]
23	<i>Trifolium alexandrinum</i>	Cr, Cu, Cd, Co and Pb	Bhatti et al., [74] 2016
24	<i>Pennisetum sinese</i> Roxb	As, Cd, Cr, Cu, Mn, Pb and Zn	Ma et al., [73]

to chemical fertilizers. Vermicompost not only produces yield with all nutrients but also at the same time increases the soil fertility and nutrient availability to the crops. Thus it is a double edged technology which plays a major role in sustainable development.

## Limitations of Vermicomposting

While vermicomposting offers substantial environmental benefits, it also is associated with a number of limitations as given below:



**Figure 1:** Various types of Phytoremediation.

1. Earthworms require neutral pH, mesophilic temperature and maintenance of 60-70% moisture level.
2. Vermicomposting unit is more expensive to set up than compost piles.
3. Earthworms should be protected from direct light. Shade is required for maintaining moisture temperature and faster rate of degradation.
4. Worms need to be separated from vermicompost and do require some attention and proper care (Protection from other predators).

## Heavy Metal Contamination of Soil

With the advent of industrialization life has certainly become easy and human living conditions have improved vastly. But it has also brought with it the menace of environmental pollution which has become a severe cause of concern and existential threat for life on earth. Among different forms of pollution, soil heavy metal contamination is most dangerous because it affects the sources of food and thus poses severe risk to life on earth.

Heavy metals are the metals having atomic mass greater than 20 and are transition metals, metalloids, actinides and lanthanides [58]. Heavy metals in biological processes are classified into two classes: Essential heavy metals and Non-essential heavy metals. Those heavy metals which are required by organisms for their physiological processes are essential metals such as Copper (Cu), Cobalt (Co), Iron (Fe) etc. Non-essential metals are not required by organisms or sometimes are toxic even in small amounts such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb) etc. [19]. The essential elements above maximum permissible limits can pose severe risks to organisms. The main concern regarding the heavy metals is their long term persistence in environment, such as 150 – 5000 years for Pb, 18 years for Cd etc. [59-61]. Considering such long persistence and toxic effects of heavy metals, their management and removal

from soil becomes mandatory. There are several physical and chemical techniques available for remediation of heavy metals such as electrophoresis, soil washing, vitrification, pneumatic fracturing, chemical reduction etc. [62]. But these techniques have “pump and treat” and “dig and dump” approach. Also these techniques have very high cost, require huge setup, disturb the native soil micro flora and even generate secondary pollutants. Therefore, there is an urgent need for a cost effective, eco friendly and sustainable technique which can solve the problem of heavy metal contamination of soil.

In recent times, “phytoremediation” has emerged as a very effective tool for decontamination of heavy metal polluted soils.

## Phytoremediation

Phytoremediation is a technique that involves growing heavy metal tolerant plants having metal accumulating potential to clean the contaminated site. These plants can absorb, accumulate and detoxify pollutants from the site through their metabolic processes. Many studies have been conducted throughout the world on accumulation and phytoremediation of heavy metals from soil [63-76,107-120] (Table 2).

Different types of phytoremediation processes (Figure 1) are discussed here.

### Phytostabilization

In this process plants block the mobility and bioavailability of heavy metals in soil by converting the toxic metals to less toxic forms, thus stabilizing these metals in soils [75]. In this way metals are locked up in soil and do not pollute the groundwater, food chain, wind etc. [76]. Significant amounts of heavy metals can be stored at root level, especially in polyannual plant species, which contributes to long term stabilization of heavy metals [77]. The concept of phytostabilization lies in the variation in toxicity of different metal species. For example, Cr (VI) is highly toxic and readily bioavailable in comparison to Cr (III) [78]. But by excreting special redox enzymes in rhizosphere

**Table 3:** List of hyperaccumulator species.

S.No.	Metals	Hyperaccumulator plant species
1	As	<i>Pteris vittata</i> L., <i>Piricum sativum</i> L., <i>Pteris biaurita</i> , <i>Pteris cretica</i> , <i>Pteris quadriaurita</i> and <i>Pteris ryukyuensis</i>
2	B	<i>Gypophila sphaerocephala</i> Fenzel
3	Cd	<i>Azolla pinnata</i> , <i>Eleocharis acicularis</i> , <i>Lemna minor</i> L., <i>Oryza sativa</i> L., <i>Rorippa globosa</i> , <i>Solanum photeinocarpum</i> , <i>Thlaspi caerulescens</i> , <i>Thlaspi caerulescens</i> J. & C. Presl. and <i>Vetiveria zizanioides</i> L.,
4	Cr	<i>Brassica juncea</i> L., <i>Pteris vittata</i> L. and <i>Vallisneria americana</i>
5	Co	<i>Berkheya coddii</i> Roessler and <i>Haumaniastrum robertii</i> (Robyns) P. A. DuVign. & Plancke
6	Cu	<i>Brassica juncea</i> (L.) Czern., <i>Eleocharis acicularis</i> , <i>Elsholtzia splendens</i> Nakai ex Maekawa, <i>Festuca rubra</i> L., <i>Lemna minor</i> L., and <i>Vallisneria americana</i> Michx.
7	Pb	<i>Alyssum wulfenienum</i> Bernh., <i>Arrhenatherum elatius</i> (L.) Beauv., <i>Chenopodium album</i> L., <i>Cepaefolium</i> (Wulfen) Rouy & Fouc, <i>Euphorbia cheiradenia</i> , <i>Festuca ovina</i> L., <i>Hemidesmus indicus</i> L., <i>Thlaspi rotundifolium</i> (L.) Gaudin ssp. <i>Thlaspi caerulescens</i> J. & C. Presl., and <i>Vetiveria zizanioides</i> L.
8	Mn	<i>Agrostis castellana</i> Boiss. & Reuter, <i>Phytolacca americana</i> L., and <i>Schima superb</i>
9	Hg	<i>Marrubium vulgare</i> L. and <i>Pistia stratiotes</i> L.
10	Ni	<i>Alyssum bertolonii</i> , <i>Alyssum caricum</i> , <i>Alyssum corsicum</i> , <i>Alyssum heldreichii</i> , <i>Alyssum markgrafii</i> , <i>Alyssum murale</i> , <i>Alyssum pterocarpum</i> , <i>Alyssum serpyllifolium</i> , <i>Alyssum lesbiacum</i> (Candargy) Rech. f., <i>Agropyron elongatum</i> (Host.)P. Beauv., <i>Berkheya coddii</i> , <i>Isatis pinnatiloba</i> , <i>Lemna minor</i> L. and <i>Thlaspi</i> spp.
11	Se	<i>Brassica rapa</i> L., <i>Brassica</i> spp (Wild type) and <i>Lemna minor</i> L.
12	U	<i>Chenopodium amaranticolor</i> H.J.Coste & Reyn and <i>Lolium perenne</i> L.
13	Zn	<i>Brassica juncea</i> L., <i>Cynodon dactylon</i> (L.) Pers., <i>Cardaminopsis</i> spp., <i>Eleocharis acicularis</i> , and <i>Thlaspi</i> spp.

Sources: Jabeen et al., [62]; Vamerali et al., [76]; Ali et al., [19].

plants efficiently converts Cr (VI) to Cr (III) thus reducing its mobility and toxicity [79]. But phytostabilization is not an ultimate solution because the heavy metals will remain in soil can get converted back to their toxic form with changing conditions.

## Phytodegradation (Phytotransformation)

In phytodegradation plants degrade the organic pollutants in soil by enzymatic activity in rhizosphere [80]. Plants release enzymes like dehalogenase, nitroreductase, peroxidase, laccase and nitrilase to degrade organic pollutants [62, 81].

## Phytovolatilization

It is a technique in which plants absorb pollutants from soil and converts them to their volatile form, which is released into the atmosphere. It is specifically used for organic contaminants and metals like Mercury (Hg). However it is a controversial technique since it removes metal from soil but releases it into atmosphere from where it can be redeposited into soil [19].

## Phytofiltration

Phytofiltration is a process where plants are used to remove pollutants especially heavy metals from aqueous environments such as surface waters, waste water, nutrient recycling systems [82,83]. The ideal plants for phytofiltration should have extensive root biomass and root surface area, which should be able to accumulate and tolerate high levels of pollutants and have minimum handling requirements [84]. Various researchers have documented the metal uptake capabilities of aquatic plants, such as Water hyacinth, Water lettuce and *Siligator alternenthera* [85-87].

## Phytoextraction

Among all the techniques of phytoremediation, phytoextraction is most efficient and useful technique for removal of heavy metals from soil [88]. Phytoextraction is the main technique of phytoremediation from commercial point of view also. This technique involves heavy

metal uptake from contaminated soils in huge amounts and their translocation to aboveground aerial parts of plants [58]. These aerial parts sometimes accumulate higher concentration of pollutants than the soil and thus are highly desirable. This contaminated aerial biomass can be used for incineration purposes, thus fulfilling the much needed energy requirements. The ashes and remains after incineration can be dumped, included in construction materials or subjected to metal extraction [89]. The most important characteristics required for phytoextraction of metals by plants are shoot metal content and shoot biomass [90]. In order to quantify the phytoextraction capability of a plant two factors are calculated:

**a) Bioconcentration Factor (BCF):** It is expressed as ratio of heavy metal content in harvestable plant tissues to soil [91]

$$BCF = \frac{\text{Charvested tissue}}{C_{\text{soil}}}$$

where Charvested tissue is the metal concentration in harvested tissue and  $C_{\text{soil}}$  is the metal concentration in soil.

**b) Translocation Factor (TF):** It is a ratio of heavy metal contents in shoots to roots [92]

$$TF = \frac{C_{\text{shoot}}}{C_{\text{root}}}$$

Where  $C_{\text{shoot}}$  and  $C_{\text{root}}$  are metal concentration in shoots and roots, respectively

Both BCF and TF are required to assess the phytoextraction potential of a plant. Plants having both BCF and TF greater than 1 are excellent for phytoextraction; plants having BCF >1 and TF <1 are suitable for phytostabilisation [65].

## Hyperaccumulators

Hyperaccumulators are the plants which have unusual capacity of accumulating and tolerating very high content of heavy metals. This concept was firstly given by Brooks et al [93]. To explain the plants which can accumulate >1000 mg/kg of Ni while growing in their natural habitat. In 1989, Bakers and Brooks gave criteria

for hyperaccumulation, according to which plants capable of accumulating  $>100$  mg/kg of Cd, 1000 mg/kg Ni, Cu, Co and Pb and 10,000 mg/kg of Zn and Mn in their shoots are hyperaccumulators. A second criterion which can be used to identify hyperaccumulators is based on BCF and TF. Plants having both BCF and TF values  $>1$  can be considered for hyperaccumulation [65]. This criterion is highly useful in areas having low heavy metal contents. Throughout the world 400-500 plant species belonging to families *Brassicaceae*, *Asteraceae*, *Caryophyllaceae*, *Fabaceae*, *Cyperaceae* etc. have been identified as hyperaccumulators [94]. Plants like *Thlaspi caerulescens*, *Alyssum bertolonii*, *Arabidopsis halleri* etc. are known hyperaccumulators of Cd, Co, Ni, Pb, Zn etc. Table 3 represents some of the most prominent hyperaccumulator plants. Usually the metal uptake in plants depends on metal bioavailability to plants. But hyperaccumulation of metals by plants is achieved by over expression of transport systems required for enhanced sequestration, tissue-specific expressions of proteins and high metal chelator concentration in soil [95].

The heavy metals once up taken by roots is either stored in roots or translocated to the shoots [62]. The heavy metal tolerance in plant tissues is governed by inter-related network of physiological and molecular mechanisms which includes processes such as metal exclusion, vacuolar compartmentalization, phytochelatin production, metallothioneins secretion for metal chelation etc [96].

Although the natural metal absorption by plants is always preferable, but it has some hurdles such as significant reduction of plant biomass while metal accumulation and inability of natural mechanism to absorb insoluble fraction of metals in soil. Therefore, to overcome these drawbacks different chelators such as EDTA, citric acid, EDDS etc. are used, which increases the metal solubility so that leaching of metals can occur [97]. But some of these metal chelators are non-biodegradable and can pollute the groundwater and soil.

## Use of Metal Accumulating Plants

The plants that are used for phytoremediation can be used for several purposes such as construction, incineration and Phytomining. Phytomining is a process of extracting metals from hyperaccumulator plants [19, 98]. In this process plant biomass which has accumulated heavy metals is first incinerated and the metals can be extracted from ashes which are considered as bio-ore. The incineration process can provide energy for vital functions.

## Advantages of Phytoremediation

The concept of phytoremediation was first given by Chaney [99] and today this technique has gained acceptance worldwide. It is a green and eco approach which overall improves the environment. No secondary pollutants are generated in phytoremediation as plants have highly efficient systems. This process is highly cost effective. For example, Salt et al [100]. suggested that in order to clean up one acre of soil (depth 50 cm) soil excavation USD 4,000,000 was required, whereas phytoremediation only required USD 60,000 – 1,000,000. Plants having high biomass and fast growth such as *Jatropha*, grasses, willow etc. can be further used for economic purposes such as construction, incineration etc. [101]. Therefore, phytoremediation is a durable and effective method for soil cleanup.

## Limitations of Phytoremediation

Although phytoremediation is a very sustainable and

advantageous technology for decontamination of soil, there are certain limitations to it also. First of all, this technology is highly dependent on environmental conditions [58]. Plants which are considered hyperaccumulators may only grow in certain environmental conditions and certain seasons only. In that case rigorous research is required to identify the plants which could accumulate metals in different types of conditions. Secondly, phytoremediation is a very slow process in comparison to other metal decontamination methods [19]. Thirdly, this technology is more suitable in case of high biomass producing plants and does not work very well with low biomass plants [102]. Another major setback is the root system of plants. Plants having extensive and spread root system (as in grasses) are more capable in extracting metals from soil. On the contrary plants having limited roots are not capable for metal uptake and accumulation [103, 104]. There is also a high risk of food chain contamination, if proper care is not taken [105].

## Future Prospects

Phytoremediation is a reliable and environment friendly technique for cleaning up of soil. Although recently most of the research on phytoremediation is focused on laboratory based experiments, but more emphasis should be given to plants growing in wild and natural conditions which may provide better understanding of metal accumulating plants [70]. Extensive research should be focused on improving the metal uptake capabilities of weeds and other plants growing in wild by application of various genetic and biotechnological tools [106]. Lastly research must be focused on utilizing the plant material used for phytoremediation in profitable process in order to make this technique a commercial success [19].

## Combined Application of Vermiremediation and Phytoremediation: Boost to Soil Management

Although both Vermiremediation and Phytoremediation are distinct and very effective techniques for soil management, but if used in combination these techniques can bring marvelous results. In various contaminated environments (e.g. municipal dumpsites, industrially polluted lands, agro-chemically contaminated soils etc.) where soil is already affected by various pollutants, phytoremediation provides a sustainable solution for extracting out the pollutants and cleaning up the environment [19,62,76]. On the other hand vermiremediation provides an instrumental solution for managing the waste which can further contaminate that environment. Vermiremediation also generates very useful products such as vermicast and vermiwash [2,24]. These products further supplement phytoremediation by providing non-polluting nutrient source for plants used in phytoremediation. It will enhance the growth rate of plants and thus their phytoremediation potential. Also the vermicast and vermiwash are very efficient alternatives for polluting agrochemicals used in agriculture. Thus while decontaminating the agricultural soil using plants, vermicast and vermiwash can be used to enhance and maintain the soil nutrient pool. Thus, phenomenal results can be achieved by using vermiremediation and phytoremediation in tandem.

## Conclusions

The rising levels of pollutants (especially heavy metals) in soils

pose severe risks to future generations. To fulfill the requirements of increasing human population many adverse and environmentally dangerous methods are being used in every field. Undoubtedly, these unsustainable methods have increased human capacity to extract more from nature, but this has also led to deterioration of nature. Therefore, there is urgent need for environment friendly techniques such as Vermiremediation and Phytoremediation. Vermiremediation is a very efficient technique of waste management and reduction. The use of earthworms significantly reduces the toxic substances from the waste and decontaminates them. It also provides us manures and vermish which are very good alternatives of chemical fertilizers. The vermicompost generated during the process is a highly nutritious product for plants which increases the fertility of soil and also enhances microbial biomass in soil. On the other hand, phytoremediation provides us a green solution for already contaminated soils. The use of hyperaccumulating plants to extract metals from contaminated soils is the best eco-friendly remedy available. The use of plants for metal accumulation from soils is a highly efficient and cost effective system in comparison to other methods of decontamination. The metals stored in these plants can further be extracted out by phytomining processes. The efficiency of these metal accumulating plants can be increased using various genetic tools also. Thus, these two techniques i.e. vermiremediation and phytoremediation are best tools for waste management, soil fertility enhancement and decontamination of already contaminated sites. Further research must be carried out to improve and explore these techniques, as they hold the key to sustainable development.

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