



## A review on the responses of ornamental plants in the phytoremediation of disturbed sites

Namrata Jadaun\*, Sonali Pandey

Department of Botany, JECRC University, Jaipur, Rajasthan, India

### Abstract

Environmental pollution of various contaminants, such as aromatic hydrocarbons, petroleum products, explosives and cyanides, chlorinated solvents, heavy metals (Cr, Cd, Mn, Fe, Zn, Pb) increases day by day due to uncontrolled anthropogenic activities, among them heavy metals are the most important non-biodegradable source of pollution, highly poisonous even present in less amount, put adverse effects on the physical and mental health of human beings. Many physical and chemical methods are already used for the remediation of heavy metals but they are very costly and less effective. Phytoremediation is the mechanism by which developing plants can remove pollutants, processes such as Phytostabilization, phytoextraction, phytovolatilization, and rhizofiltration include heavy metal phytoremediation. In comparison to other plant varieties such as edible crops and medicinal plants, ornamental plants appear to be a more realistic option because they offer a variety of advantages, including the removal of heavy metal pollution, environmental beautification, by-product generation to convince local people and government, lack of involvement in the food chain and other direct human consumption. The introduction of various amendments, fertilizers, soil modifications, chemical chelators, microorganisms and genetic approaches, etc. accelerate phytoremediation. In this review a compilation of data is produced to study the status and the effects of heavy metals on human health. Current research on the phytoremediation of contaminated soils with ornamental plants evaluated the phytoremediation capacity of plants against heavy metals and identification and screening of ornamental plants with high accumulation ability and tolerance towards contaminants.

**Keywords:** pollution, phytoremediation, ornamental plants, disturbed sites, income generation

### Introduction

A huge number of chemical substances are released in the air, water, and soil through various anthropogenic activities (urbanization, industrialization, and mining) that harm the environment in various ways, among them heavy metals are the most important source of contaminants (Tangahu *et al.*, 2011) [58]. Heavy metals are classified into essential and nonessential heavy metals. Essential heavy metals e.g., copper (Cu), nickel (Ni), manganese (Mn), iron (Fe), and zinc (Zn) are required for performing many biological and physiological activities of plants (Cempel and Nickel, 2006) [11]. Lead (Pb), chromium (Cr), mercury (Hg), cadmium (Cd), and arsenic (As) are non-essential heavy metals that are poisonous even present in less amount, not biologically degradable, may enter into the food chain by edible plant parts, accumulate in animals through biomagnification (Sarwar *et al.*, 2010) [48] and cause many diseases in animals. Metals having a density greater than 5g/cm<sup>3</sup> were considered toxic for certain types of organisms (Saxena and Shekhawat 2013) [51]. Heavy metal produces reactive oxygen species (ROS) in cells of the living being that may cause damage of DNA and protein and finally death of the cell (Stanley *et al.*, 2018) [54]. Presence of heavy metals in

the soil results in decreased soil fertility, microbial activity, and yields (Mc Grath *et al.*, 1995) [38]. Because of the increased risk of chronic diseases caused by heavy metals, especially in the relationship between fish and crop consumption by humans, authorities must improve precision inland plans (Leung *et al.* 2017) [30]. There are many physical and chemical methods used for remediation of heavy metals e.g., excavation and landfills but they are very costly and have low efficiency. These problems lead to the development of phytoremediation as an effective and affordable strategy to remove heavy metals from contaminated soil (Chaney *et al.*, 2000) [12]. Phytoremediation is a process by which green living plants are used to clean up contaminants from the environment. Phytoremediation is a cost-effective, eco-friendly, sustainable technology for site restoration and relatively easy approach for developing countries. The majority of these plant species belong to the following taxonomic orders: Poales, Malpighiales, Fabales, Rosales, Brassicales Caryophyllales, Solanales, and Asterales are some of the most common plant families (Bremer *et al.*, 2009) [7].

### A.1. Effects of heavy metals on human health

Table 1

S. No.	Heavy metals	Effects	References
1.	Hg	Deafness, digestive problems, kidney damage, mental retardation, adverse neurodevelopmental impacts.	Mahurpawar, 2015, Gupta and Kumar, 2017
2.	Pb	Mental retardation, Kidney diseases and nervous system disorders.	Gupta and Kumar, 2017, Mahurpawar, 2015
3.	As	Skin diseases, cancers, respiratory diseases gastrointestinal problems.	Gupta and Kumar, 2017, Mahurpawar, 2015
4.	Cu	Liver damage, Wilson disease, insomnia	Gupta and Kumar, 2017, Mahurpawar, 2015
5.	Cd	Degeneration of bones, kidney Damage, carcinogenic.	Gupta and Kumar, 2017, Mahurpawar, 2015

6.	Cr	Cytoplasmic DNA and protein damage, carcinogenic, dermal diseases, gastrointestinal hemorrhage	Gupta and Kumar, 2017, Mahurpawar, 2015
7.	Ni	Bronchitis, sickness cardiovascular damage	Lone <i>et al.</i> , 2008
8.	Al	Forgetfulness, anemia, depression, inability to concentrate	Crisponi <i>et al.</i> , 2013

### Phytoremediation process and strategies

Strategies and mechanisms used for phytoremediation depend on soil property and the type of contaminants. The plant accumulates and absorbs water and minerals from the soil through the root surface area for their growth along with non-essential contaminants also absorbed (Alkorta *et al.*, 2004) [1]. Here we focus on some widely used strategies for phytoremediation.

### Phytoextraction

Phytoextraction is the process through which plants absorb pollutants from soil and water and store them in their aboveground parts (Salt *et al.*, 1995) [50]. A hyperaccumulator Plant species is capable of accumulating metals in a very high concentration than a non-hyperaccumulator plant (Erakhruman, 2007) [19], although non-hyperaccumulator plants accumulate lower concentrations of heavy metals this is compensated by their high biomass production (Vamerali *et al.*, 2010) [59]. The Hyperaccumulator plants also hold the potential of 'Phytomining'. *Chrysanthemum* showed good bioaccumulation of lead (Ramírez *et al.*, 2020) [44]. *Celosia cristata pyramidalis* identified as a Pb-accumulator (Cui *et al.*, 2013) [16]. *Catharanthus roseus* is a good accumulator of lead (Pb) and nickel (Ni) (Subhashini and Swami 2013) [56].

### Rhizofiltration

By this process, contaminants are absorbed and accumulate in the roots of the plants. The plants are first grown in clean water (hydroponically) to develop a large root system after this for acclimating the plant's clean water is replaced by contaminated water and the plant is then transplanted to contaminated areas, where it is collected once the roots have gotten saturated (Wuana and Okieimen, 2011) [63].

### Phytovolatilization

Phytovolatilisation is a phytoremediation process in which plants absorb contaminants from the soil, convert them to less hazardous volatile forms, and then release them into the atmosphere by transpiration. Phytovolatilization can eliminate three elements from the soil environment: arsenic (As), selenium (Se), and mercury (Hg), (Greger *et al.*, 2005) [23]. Hg (mercury) is a liquid metal at room temperature after absorption by the plant it is converted into a less harmful volatile state, which is then released into the atmosphere (Bizily *et al.*, 2000) [4].

### Phytostabilisation

Phytostabilisation is the process of using certain plant species to immobilise contaminants in the soil through adsorption and accumulation in plant tissues, adsorption or precipitation onto the roots, preventing pollutants from migrating through the soil and reducing metals entering in the Food chain (Marques *et al.*, 2009) [37]. In *Calendula calypso* roots accumulated a greater portion of Cd than the shoot and leaves, it was determined that *Calendula calypso* can be successfully grown for phytostabilisation of Cd contaminated soils. Five ornamental plants have been reported by Zeng *et al.*, (2018) [64], as Cd phytostabilized,

namely *Osmanthus fragrans*, *Cinnamomum camphora*, *Ligustrum vicaryi*, *Euonymus japonicus* and *Loropetalum chinense*.

### Selection and preference for an ornamental plant in heavy metals phytoremediation

The selection of appropriate plant species is the key to successful phytoremediation. To fulfil the specification of phytoremediation, plants should be tolerant to heavy metals and have abilities to absorb them through roots even they present in low concentration, have a dense rooting system, able to produce a large amount of biomass, have a good adaptation to the current environment, be repulsive to herbivores so that the risk of biomagnifications of heavy metals into the food chain is reduced (Seth 2012) [53].

### Morphological characters of ornamental plants used in phytoremediation

Based on their morphological characteristics, ornamental plants with a greater potential for phytoremediation may be preliminarily assessed. According to studies, estimating the aggregation abilities of various organs of remediation plants can help with remediation efficiency (Pinto *et al.* 2014) [43]. Root, stem, and leaf morphologies play a key role in the process of phytoremediation (Wei *et al.*, 2005) [60]. Heavy metal is concentrated in the roots of the majority of ornamental plants. Root length, density, and surface area are essential characteristics that can directly affect contaminant absorption or degradation, and root exudates can influence rhizosphere microorganism growth and reproduction (Cheng *et al.*, 2016) [15]. The leaf area index affects biomass growth by manipulating photosynthesis, and the leaf is also a significant site for volatilization and excretion, which is one way for toxic materials to be detoxified (Sun *et al.* 2011) [55]. Ornamental plants need to be established stem tissue, tolerance and accumulation of pollutants are related to both the height and diameter of the stem (Cay 2016) [10].

In ornamental plants, the heavy metal content does not always fulfil the criteria of a hyperaccumulator, but their high biomass means that more heavy metals may be accumulated than hyperaccumulators (Marques *et al.*, 2013) [36].

### The physiology behind uptake and translocation of heavy metals in plants

The processes involved in heavy metal accumulation in plants include heavy metal mobilisation, root absorption, xylem loading, root-to-shoot transit, cellular compartmentation, and sequestration. Heavy metals enter roots largely via two routes: apoplastic (passive diffusion) and symplastic (active transport). Metal ion carriers mediate the common uptake of heavy metals through the symplastic pathway, which is an energy-dependent process (Peer *et al.*, 2005) [45]. Heavy metal ion uptake from the soil requires these specialised transporters (channel proteins) or H<sup>+</sup> coupled carrier proteins, which are present in the plasma membrane of root cells. By mediating influx–efflux, they can transport specific metals through cellular membranes

and mediate metal transfer from roots to shoots (DalCorso *et al.*, 2019) [18].

### Rewards of Ornamental plants as phytoremediator

Ornamental plants are cultivated for the show of aesthetic characteristics including flowers, leaves, smell, Overall texture of foliage, fruits, stems, and bark. They are grown for decorative purposes in pots, gardens, and landscape design projects for landscape beautification, ecotourism, and cut flowers (Nakbanpote *et al.*, 2016) [40]. Exposure to plants and flowers restoration of our health, recovery from stress, offers a feeling of tranquillity, influences people's mental state and physiological and psychological relaxation, promotes eco-tourism (Liu *et al.*, 2017) [33]. Ornamental plants not only grow for beautification but also remediate the contaminated environment with income generation. *Tagetes patula* is an ornamental plant that can be applied for both purposes that is remediation and income generation in Thailand (Nakbanpote *et al.* 2016) [40]. Ornamental plants are classified into terrestrial and aquatic plants, for flowers and foliage terrestrial plants are essential.

### Some terrestrial ornamental plants tested for heavy metals accumulation

*Calendula officinalis* displayed high Cd tolerance and a greater capacity to accumulate Cd. The accumulation of Cd

in the roots was higher than in the shoots (Liu *et al.*, 2008) [32]. *Quamoclit pennata*, *Antirrhinum majus*, *Celosia cristata pyramidalis* have been treated with Pb (NO<sub>3</sub>)<sub>2</sub>, BCF and TF were <1 of these plants, only *Celosia cristata pyramidalis* was recommended as Pd accumulator (Cui *et al.*, 2013) [16]. Marigold (*Calendula calypso*) is a multipurpose ornamental plant, can be grown well on Cd-contaminated soils for phytostabilization (Farooq *et al.*, 2020) [20]. In vitro experiments were performed using three cultivars of *Chrysanthemum* (Asteraceae) for 12 weeks with lead concentrations of 0, 300, 600, 900, and 1500 mg/kg. The findings indicate that the three cultivars had strong phytoextraction potential at moderate pollution levels, as they showed good lead bioaccumulation with only negligible effects on biomass production and root elongation (Ramrez *et al.*, 2020) [44].

*Impatiens* (*Impatiens walleriana*) and French marigold (*Tagetes patula*) will serve as hyperaccumulator plants to remove cadmium (Cd) from polluted sites, and this activity increases with the application of Chelator like EDTA (Wei *et al.*, 2012) [61]

### Ornamental plants as heavy metal phytoremediator

Table 2

Plants Species	Heavy metal	References
<i>Genipa americana</i>	Cr	Santana <i>et al.</i> , 2012
<i>Melastoma malabathirum</i>	As, Pb	Selamat <i>et al.</i> , 2014
<i>Mirabilis jalapa</i>	Cd	Yu and Zhou, 2009
<i>Calendula officinalis</i> , <i>Althaea rosea</i>	Cd	Liu <i>et al.</i> , 2008
<i>Celosia cristata</i>	Pb	Cui <i>et al.</i> , 2013
<i>Iris lacteal var. chinensis</i>	Pb	Han <i>et al.</i> , 2008
<i>Willow</i>	Cd	Robinson <i>et al.</i> , 2000
<i>Nerium oleader</i>	Pd	Triguems <i>et al.</i> , 2012
<i>Quamoclit pinnata</i> , <i>Antirrhinum majus</i>	Cd	Cui <i>et al.</i> , 2013
<i>Tagetes patula</i>	Cd	Chaturvedi <i>et al.</i> , 2014
<i>Amaranthus hypochondriacus</i>	Cd	Li <i>et al.</i> , 2013
<i>Calendula alata</i>	Cs, Pb	Borgei <i>et al.</i> , 2011
<i>Helianthus annuus</i> , <i>Tagetes patula</i> , <i>Celosia cristata</i>	Ca, Cr, Mn, Fe, Cu, Zn, Pb	Chatterji <i>et al.</i> , 2012
<i>Helianthus annuus</i>	Zn, Cd, Cu	Nehnevajova <i>et al.</i> , 2012
<i>Helianthus annuus</i>	Hg	Cassina <i>et al.</i> , 2012
<i>Helianthus annuus</i> , <i>Salvia splendens</i> , <i>Tagetes erecta</i>	Cd	Bosiacki, 2008
<i>Tagetes patula</i> , <i>Impatiens walleriana</i>	Cd	Wei <i>et al.</i> , 2012
<i>Mirabilis jalapa</i> , <i>Impatiens balsamin</i> , <i>Tagetes erecta</i>	Cr	Miao and Yan, 2013
<i>Tagetes erecta</i> , <i>Chrysanthemum indicum</i> , <i>Gladiolus grandiflorus</i>	Cd	Lal <i>et al.</i> , 2008
<i>Tagetes patula</i>	Cd, Cu, Pb, and benzo[a] pyrene (B[a]P)	Sun <i>et al.</i> , 2011
<i>Tagetes patula</i>	Fe	Chaturvedi <i>et al.</i> , 2014
<i>Tagetes erecta</i>	Cu	Castillo <i>et al.</i> , 2011
<i>Tagetes erecta</i>	Cd	Liu <i>et al.</i> , 2011
<i>Calendula calypso</i>	Cd	Farooq <i>et al.</i> , 2020
<i>Chrysanthemum</i>	Pd	Ramrez <i>et al.</i> , 2020
<i>Tagetes patula</i> , <i>Impatiens walleriana</i>	Cd	Wei <i>et al.</i> , 2012
<i>Salvia sclarea</i>	Cd, Zn and Pb	Angelova, 2013

### Phytoremediation enhancers

Various amendments are required for plant growth, such as organic manures, chemical chelator, and plant hormones and have positive effects on plant growth (Nakbanpote *et al.* 2016) [40]. Chemical chelators such as ethylene glycol-bis (2-aminoethyl) tetraacetic acid (EGTA) and ethylenediaminetetraacetic acid (EDTA) may be used to improve metal bioavailability (Wei *et al.*, 2012) [61]. EDTA and citric acid are the most famous amino polycarboxylic acids widely used in phytoremediation (Lesage *et al.*, 2005).

Application of Ethylene gluatarotriacetic acid (EGTA), Ethylenediaminetetraacetic acid (EDTA), and sodium dodecyl sulphate (SDS) increase the dry biomass of the *Calendula officinalis* and *Althaea rosea*, and also promote the Cd accumulation in shoots and roots while EDTA was toxic to plant (Liu *et al.*, 2008) [32]. The processes associated with metal stress, phytohormones, particularly cytokinins (CKs), can also play an important role. Application of cytokinin (CKs) increases transpiration rate due to stomatal opening also increase in pollutant uptake by plants from soil

(Cassina *et al.*, 2012) <sup>[8]</sup>. *Helianthus annuus* was treated with swine manure, potassium chloride (KCl) and salicylic acid (SA), KCl increased Cd (Cadmium) and Zn (Zinc) accumulations (Xiu-Zhen *et al.*, 2012). <sup>[65]</sup> Application of cytokinin and ammonium thiosulfate increased Hg (mercury) uptake and translocation in *Helianthus annuus* (Cassina *et al.*, 2012) <sup>[8]</sup>. The phytoremediation activity of *Consolida ambigua* and *Calendula officinalis* L. ornamental plants in the nickel polluted soil enhanced by *Kocuria rhizophila* bacterium (Anum *et al.*, 2019) <sup>[2]</sup>. Degrading bacteria can convert polycyclic aromatic hydrocarbons, into simpler materials. NPK (Nitrogen, Phosphorus, and Potassium) fertilizer increased dry biomass in *Amaranthus hypochondriacus*, resulting in a large increment of Cd accumulation. (Li *et al.*, 2013) <sup>[31]</sup>. Plant growth-promoting bacteria (PGPB) are capable of colonizing the root by various mechanisms to promote plant growth by fixing atmospheric nitrogen, using ACC as the sole source of nitrogen, generating siderophores and antipathogenic substances, producing plant growth regulators (phytohormones). Tea saponin (TS) was extracted from tea *camellia* seed using microwave-assisted extraction. The ability of TS was compared to that of ethylenediaminetetracetic acid (EDTA), a common chemical agent used to increase cadmium (Cd) uptake by *Amaranthus caudatus*, an ornamental plant is grown in a pot. Cd uptake increased in plants as we increase tea saponin (Cay, 2016) <sup>[10]</sup>. Integrated therapies *viz.* elemental sulphur vermi-compost and microbial co-inoculation for the enhanced phytoremediation of Cd and Pb-contaminated soils are more effective. By genetically altering the structure of hyper-accumulator plants, biomass production and metal extraction from soils can be enhanced (Gisbert *et al.*, 2003) <sup>[21]</sup>. An Arabidopsis CAX1 mutant (CAXcd) expressing *Petunia hybrida* plant with 2.5 times more Cd accumulation than controls (Wu *et al.*, 2011) <sup>[62]</sup>

### Limitations

Many growing seasons are required to clean up a contaminated site by using phytoremediation technology. Compound volatilization can turn a groundwater pollution issue into an air pollution issue (Sakakibara *et al.* 2010) <sup>[47]</sup>. Phytoextraction and plant-assisted bioremediation are particularly relevant if soil contamination is contained within 3 feet of the surface and groundwater is contained within 10 feet of the surface (Ruskin *et al.*, 1994) <sup>[45]</sup>. Metal-enriched biomass must be safely disposed of after processing, which is a technical problem that is still partly unresolved Composting, compacting, pyrolysis, and biogas processing are among the techniques being researched (Ghosh and Singh, 2005) <sup>[22]</sup>.

### Conclusion and future approach

Plants could live in highly contaminated environments and withstand high levels of toxic compounds in their tissues. Many plants of the representative families *viz* Poaceae, Rosaceae, Solanaceae, Asteraceae, Caryophyllaceae, and Betaceae are used in phytoremediation to degrade, assimilate, metabolize, and detoxify metal and organic chemical pollution. Relevant requirements for the selection of phytoremediator plants, contains the provision of economic benefits, management of harvesting, and utilization of their by-products. Most of the ornamental plants are non-edible so the possibility of toxic metals

entering the food chain is minimized and reduces its chances of Biomagnification in the food chain. Growing ornamentals not only add color to the landscape but also helps to remove harmful toxins from both terrestrial and aquatic habitats. Ornamental plants have the added benefit of improving the aesthetics of the area under cultivation along with the addition of cleaning up the environment. The beauty of ornamental plants influences people's mental health and psychology exposed to plant setting the people have more positive emotions more productivity lesser stress hence interaction with ornamental plants can change human altitude behavior and psychological responses. The planting of ornamental plants on disturbed and polluted sites can create additional revenue, offers more job opportunities and self-employment to an individual. The sales and tourism revenue can encourage local people to remediate their polluted land and water bodies. About 295,383 flowering plants are distributed all over the world and very few reports are available with the ornamental plant species sustaining phytoremediation capabilities. The *In-situ* and *Ex-situ* application of ornamental plants and their selection depends upon site soil, water characteristics, and feasible ecosystem. The self-engineering and self-design of the disturbed and polluted site need to be explored and require the proper selection of plant species and the future research and knowledge required to select the best technique and the plant for the remediation of sites on large scale. In conclusion, instead of modification in plant species through biotechnology or plant breeding processes, we should focus on screening of phytoremediator ornamental plant species growing and adapting to the local environment. In practice, a single solution is neither feasible nor necessary to clean up heavy metal-polluted soil effectively. For highly effective and comprehensive phytoremediation in the future, a combination of different approaches, such as genetic engineering, plant fertilizers and microbe-assisted, and chelate-assisted approaches, is needed.

### References

1. Alkorta I, Hernández-Allica J, Becerril JM, Amezcaga I, Albizu I, Garbisu C. Recent findings on the phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as zinc, cadmium, lead, and arsenic. *Reviews in Environmental Science and Biotechnology*,2004;3(1):71-90.
2. Anum S, Khan SM, Chaudhary HJ, Ahmad Z, and Afza, R. Phytoremediation of nickel polluted ecosystem through selected ornamental plant species in the presence of bacterium *Kocuria rhizophila*. *Bioremediation Journal*,2019;23(3):215-226.
3. Angelova VR. Proceedings of the XV Balkan Mineral Processing Congress. Sozopol, Bulgaria, 2013, 1045.
4. Bizily SP, Rugh CL, Meagher RB. Phytodetoxification of hazardous organomercurials by genetically engineered plants. *Nature Biotechnology*,2000;18:213-217. doi:10.1038/72678
5. Borghei M, Arjmandi R, Moogouei R. Potential of *Calendula alata* for phytoremediation of stable cesium and lead from solutions. *Environmental monitoring and assessment*,2011;181(1):63-68.
6. Bosiacski M. Accumulation of cadmium in selected species of ornamental plants. *Acta Scientiarum Polonorum, Hortorum Cultus*,2008;7(2):21-31.

7. Bremer B, Bremer K, Chase MW, Fay MF, Reveal JL, Soltis DE *et al.* An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Botanical Journal of the Linnean Society*,2009;161:105-121.
8. Cassina L, Tassi E, Pedron F, Petruzzelli G, Ambrosini P, and Barbaferi M “Using a plant hormone and a thioligand to improve phytoremediation of Hg-contaminated soil from a petrochemical plant. *Journal of hazardous materials*,2012;231:36-42.
9. Castillo OS, Dasgupta-Schubert N, Alvarado CJ, Zaragoza EM, and Villegas HJ. The effect of the symbiosis between *Tagetes erecta* L.(marigold) and *Glomus intraradices* in the uptake of Copper (II) and its implications for phytoremediation. *New biotechnology*,2011;29(1):156-164.
10. Cay S. Enhancement of cadmium uptake by *Amaranthus caudatus*, an ornamental plant, using tea saponin. *Environmental monitoring and assessment*,2016;188(6):320.
11. Cempel M, Nikel G. Nickel: a review of its sources and environmental toxicology. *Polish Journal of Environmental Studies*,2006;15(3):375-382.
12. Chaney RL, Brown SL, Li YM. Progress in Risk Assessment for Soil Metals, and In-situ Remediation and Phytoextraction of metals from Hazardous contaminated soil, *Phytoremediation: State of Science*,2000;1(2):232-240.
13. Chaturvedi N, Ahmed MJ, Dhal NK. Effects of iron ore tailings on growth and physiological activities of *Tagetes patula* L., *Journal of soils and sediments*,2014;14(4):721-730.
14. Chatterjee S, Singh L, Chattopadhyay B, Datta S, Mukhopadhyay SK. A study on the waste metal remediation using floriculture at East Calcutta Wetlands, a Ramsar site in India. *Environmental monitoring and assessment*,2012;184(8):5139-5150.
15. Cheng L, Wang Y, Cai Z, Liu J, Yu B, Zhou Q. Phytoremediation of petroleum hydrocarbon-contaminated saline-alkali soil by wild ornamental Iridaceae species. *International Journal of Phytoremediation*,2016;19(3):300-308.
16. Cui S, Zhang T, Zhao S, Li P, Zhou Q, Zhang Q *et al.* Evaluation of three ornamental plants for phytoremediation of Pb-contaminated soil. *International journal of phytoremediation*,2013;15(4):299-306.
17. Crisponi G, Fanni D, Gerosa C, Nemolato S, Nurchi VM, Crespo-Alonso M, Lachowicz JI, Faa G. The meaning of aluminium exposure on human health and aluminium-related diseases. *Biomol Concepts*,2013;4(1):77-87, doi: 10.1515/bmc-2012-0045. PMID: 25436567.
18. DalCorso G, Fasani E, Manara A, Visioli G, Furini A. Heavy metal pollutions: state of the art and innovation in phytoremediation. *International Journal of Molecular Science*,2019;20:3412. doi: 10.3390/ijms20143412
19. Erakhrumen AA, Agbontalor A. Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. *Educational Research and Review*,2007;2(7):151-156.
20. Farooq A, Nadeem M, Abbas G, Shabbir A, Khalid MS, Javeed HMR *et al.* Cadmium Partitioning, Physiological and Oxidative Stress Responses in Marigold (*Calendula calypso*) Grown on Contaminated Soil: Implications for Phytoremediation. *Bulletin of Environmental Contamination and Toxicology*, 2020. <https://doi.org/10.1007/s00128-020-02934-6>
21. Gisbert C, Ros R, De Haro A. A plant genetically modified that accumulates Pb is especially promising for phytoremediation. *Biochemical and Biophysical Research Communications*,2003;303:440-445. [https://doi.org/10.1016/S0006-291X\(03\)00349-8](https://doi.org/10.1016/S0006-291X(03)00349-8)
22. Gosh M and Singh SP. A Review on Phytoremediation of Heavy Metals and Utilization of It's by Products. *Asian Journal on Energy and Environment*,2005;6(4):214-231.
23. Greger M, Wang Y, Neuschütz C. Absence of Hg transpiration by shoot after Hg uptake by roots of six terrestrial plant species. *Environ Pollut*,2005;134:201-208.
24. Gupta P, Kumar V. Value added phytoremediation of metal stressed soils using phosphate solubilizing microbial consortium. *World Journal of Microbiology and Biotechnology*,2017;33(1):1-15.
25. Han YL, Huang SZ, Gu JG, Qiu S, Chen JM. Tolerance and accumulation of lead by species of *Iris* L. *Ecotoxicology*,2008;17(8):853-859.
26. Huang H, Gupta DK, Tian S, Yang XE, Li T. Lead tolerance and physiological adaptation mechanism in roots of accumulating and non-accumulating ecotypes of *Sedum alfredii*. *Environmental Science and Pollution Research*,2012;19:1640-1651, doi:10.1007/s11356-011-0675-1
27. Koptsik GN. Problems and Prospects Concerning the Phytoremediation of Heavy Metal Polluted Soils: A Review. *Eurasian Soil Sci*,2014;47:923-939.
28. Lal K, Minhas PS, Chaturvedi RK, Yadav RK. Extraction of cadmium and tolerance of three annual cut flowers on Cd-contaminated soils. *Bioresource technology*,2008;99(5):1006-1011.
29. Lesage E, Meers E, Vervaeke P, Lamsal S, Hopgood M, Tack FMG *et al.* Enhanced phytoextraction: II. Effect of EDTA and citric acid on heavy metal uptake by *Helianthus annuus* from a calcareous soil. *International Journal of phytoremediation*,2005;7(2):143-152.
30. Leung HM, Duzgoren-Aydin NS, Au CK, Krupanidhi S, Fung KY, Cheung KC *et al.* “Monitoring and assessment of heavy metal contamination in a constructed wetland in Shaoguan (Guangdong Province, China): bioaccumulation of Pb, Zn, Cu and Cd in aquatic and terrestrial components. *Environmental science and pollution research*,2017;24(10):9079-9088.
31. Li N, Li Z, Fu Q, Zhuang P, Guo B, Li H. Agricultural technologies for enhancing the phytoremediation of cadmium-contaminated soil by *Amaranthus hypochondriacus* L. *Water, Air, and Soil Pollution*,2013;224(9):1-8.
32. Liu JN, Zhou QX, Sun T, Ma LQ, Wang S. Identification and chemical enhancement of two ornamental plants for phytoremediation. *Bulletin of environmental contamination and toxicology*,2008;80(3):260-265.
33. Liu J, Xin X, Zhou Q. Phytoremediation of contaminated soils using ornamental

- plants. *Environmental Reviews*,2017;26(1):43-54. <https://doi.org/10.1139/er-2017-0022>
34. Lone MI, He ZL, Stoffella PJ, Yang XE. Phytoremediation of heavy metal polluted soils and water: progresses and perspectives. *Journal of Zhejiang University Science B*,2008;9(3):210-220.
  35. Mahurpawar M. Effects of heavy metals on human health. *International Journal of Research-Granthaalayah*, 2015. *ISSN-23500530*, 2394-3629.
  36. Marques AP, Moreira H, Franco AR, Rangel AO, Castro PM. Inoculating *Helianthus annuus* (sunflower) grown in zinc and cadmium contaminated soils with plant growth promoting bacteria—Effects on phytoremediation strategies. *Chemosphere*,2013;92(1):74-83.
  37. Marques AP, Rangel AO, Castro PM. Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. *Critical Reviews in Environmental Science and Technology*,2009;39(8):622-654.
  38. McGrath SP, Chaudri AM, Giller KE. Long-term effects of metals in sewage sludge on soil microorganism and plants. *J Ind Microbiol*,1995;14(2):94-104.
  39. Miao Q, Yan J. Comparison of three ornamental plants for phytoextraction potential of chromium removal from tannery sludge. *Journal of Material Cycles and Waste Management*,2013;15(1):98-105.
  40. Nakbanpote W, Meesungnoen O, Prasad MNV. Potential of ornamental plants for phytoremediation of heavy metals and income generation. In *Bioremediation and bioeconomy*, Elsevier, 2016, 179-217.
  41. Nehnevajova E, Lyubenova L, Herzig R, Schröder P, Schwitzguébel JP, Schmülling T. Metal accumulation and response of antioxidant enzymes in seedlings and adult sunflower mutants with improved metal removal traits on a metal-contaminated soil. *Environmental and experimental botany*,2012;76:39-48.
  42. Peer WA, Baxter IR, Richards EL, Freeman JL, Murphy AS. Phytoremediation and hyperaccumulator plants. in *Molecular Biology of Metal Homeostasis and Detoxification*, eds M. J. Tamas and E. Martinoia (Berlin: Springer), 2005, 299-340, doi: 10.1007/4735\_100
  43. Pinto E, Aguiar AA, Ferreira IM. Influence of soil chemistry and plant physiology in the phytoremediation of Cu, Mn, and Zn. *Critical Reviews in Plant Sciences*,2014;33(5):351-373.
  44. Ramírez A, García G, Werner O, Ros RM. In vitro lead tolerance and accumulation in three *Chrysanthemum* cultivars for phytoremediation purposes with ornamental plants. *International journal of phytoremediation*,2020;22(11):1110-1121.
  45. Raskin I, Kumar PBAN, Dushenkov S and Salt D. Bioconcentration of heavy metals by plants. *Current Opinion Biotechnology*,1994;5:285-290.
  46. Robinson BH, Mills TM, Petit D, Fung LE, Green SR, Clothier BE. Natural and induced cadmium-accumulation in poplar and willow: Implications for phytoremediation. *Plant and Soil*,2000;227(1):301-306.
  47. Sakakibara M, Watanabe A, Inoue M, Sano S, Inoue M, and Kaise T. Phytoextraction and phytovolatilization of arsenic from As-contaminated soils by *Pteris vittate* In: *Proceedings of the annual international conference on soils, sediments, water and energy*,2010:12:26
  48. Sarwar N, Malhi SS, Zia MH, Naeem A, Bibi S, Farid G. Role of mineral nutrition in minimizing cadmium accumulation by plants. *Journal of the Science of Food and Agriculture*,2010;90(6):925-937. Doi: 10.1002/jsfa.3916.
  49. Santana KB, de Almeida AAF, Souza VL, Mangabeira PA, Silva DDC, Gomes FP and Loguercio, LL. Physiological analyses of *Genipa americana L.* reveals a tree with ability as phytostabilizer and rhizofilterer of chromium ions for phytoremediation of polluted watersheds. *Environmental and experimental botany*,2012;80:35-42.
  50. Salt DE, Baylock M, Kumar NPBA, Dushenkov V, Ensley BD, Chet I. Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. *Nature Biotechnology*,1995;13:468-474. doi:10.1038/nbt0595-468
  51. Saxena I, Shekhawat GS. Nitric oxide (NO) in alleviation of heavy metal induced phytotoxicity and its role in protein nitration. *Nitric Oxide*,2013;32:13-20.
  52. Selamat SN, Abdullah SRS, Idris M. Phytoremediation of lead (Pb) and arsenic (As) by *Melastoma malabathricum L.* from contaminated soil in separate exposure. *International journal of phytoremediation*,2014;16(7-8):694-703.
  53. Seth CS. A review on mechanism on Plant tolerance and role of transgenic plants in environment clean-up. *The Botanical Review*,2012;78:32-62. Doi:10.1007/s12229-011-9092-x
  54. Stanley IRO, Grace OI, Ebere PA, Abraham OA, Ibe KE. Toxicity and Bioremediation of Heavy Metals Contaminated Ecosystem from Tannery Wastewater: A Review. *Journal of Toxicology*, 2018. <http://doi.org/10.1155/2018/2568038>.
  55. Sun Y, Zhou Q, Xu Y, Wang L, Liang X. Phytoremediation for co-contaminated soils of benzo [a] pyrene (B [a] P) and heavy metals using ornamental plant *Tagetes patula*. *Journal of Hazardous Materials*,2011;186(2-3):2075-2082.
  56. Subhashini V, Swamy, AVVS. Phytoremediation of Pb and Ni Contaminated Soils Using *Catharanthus roseus* (L.). *Universal Journal of Environmental Research & Technology*,2013;3(4):465-472.
  57. Sun Y, Zhou Q. Uptake and translocation of benzo[a]pyrene (B [a] P) in two ornamental plants and dissipation in soil. *Ecotox. Environ. Safe*,2016;124:74-81.
  58. Tangahu BV, Abdullah SRS, Basri H, Anuar N, Mukhlisin M. A Review on Heavy Metals (As, Pd, and Hg) uptake by plants through phytoremediation. *International Journal of Chemical Engineering*, 2011. <https://doi.org/10.1155/2011/939161>.
  59. Vamerali T, Bandiera M, Mosca G. Field crops for phytoremediation of metal-contaminated land. A review. *Environmental Chemistry Letters*,2010;8(1):1-17.
  60. Wei SH, Zhou QX, Wang X. Cadmium-hyperaccumulator *Solanum nigrum L.* and its accumulating characteristics. *Journal of Environmental Sciences-China*,2005;26(3):167-171.
  61. Wei JL, Lai HY, Chen ZS. Chelator effects on bioconcentration and translocation of cadmium by

- hyperaccumulators, *Tagetes patula* and *Impatiens walleriana*. *Ecotoxicology and environmental safety*,2012;84:173-178.
62. Wu Q, Shigaki T, Williams KA, Han J, Kim CK, Hirschi KD, Park S. Expression of *Arabidopsis* Ca<sup>2+</sup>/H<sup>+</sup> antiporter CAX1 variant in *Petunia* enhances Cadmium tolerance and accumulation. *Journal of plant physiology*,2011;168(2):167-173.
63. Wuana RA, Okieimen FE. Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Notices*, 2011, 402647. <https://doi.org/10.5402/2011/402647>
64. Zeng X, Hu Q, He L, Liu Z, Gao S, Yu Z. Occurrence, distribution and ecological risks of organophosphate esters and synthetic musks in sediments from the Hun River. *Ecotoxicology and environmental safety*,2018;160:178-183.
65. Xiu-Zhen HAO, Dong-Mei ZHOU, Dan-Dan LI, Jiang P. Growth, cadmium and zinc accumulation of ornamental sunflower (*Helianthus annuus* L.) in contaminated soil with different amendments. *Pedosphere*,2012;22(5):631-639.
66. Yu Z, Zhou Q. Growth responses and cadmium accumulation of *Mirabilis jalapa* L. under interaction between cadmium and phosphorus. *Journal of Hazardous Materials*,2009;167(1-3):38-43.