**Phytoremediation: potential tool for remediation of heavy metals: a review**

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**Abstract**
Phytoremediation is an ecofriendly, effiicient and cost effective technique where the plants are used as an agents to clean environment. The usage of plants helps to extract, sequester, and/or detoxify pollutants through biological processes. Duo to the various unbridled anthropogenic actions like Mining operations, industrial production and domestic and agricultural use of metal and metal containing compound have resulted in the enormous release of toxic heavy metals into the environment. Being toxic, these heavy metals have posed a huge threat to the biodiversity on the surface of earth. So Phytoremediation being the environmentally sound remediation technique could be used as a tool at contaminated sites for the eco-restoration purpose.

**Keywords:** Phytoremediation, heavy metals, anthropogenic, remediation, restoration

**Introduction**
Heavy metal contamination is one among the main environmental issues. These metals are heterogenous group of elements, non biodegradable and get accumulated in ecological food chain. Although they are essential for the normal growth and development of plants and but the excess release of heavy metals such as cadmium, copper, lead, zinc etc though natural and anthropogenic activities lead to toxicity symptoms.. These heavy metals interfere with physiological activities of plants such as photosynthesis, gaseous exchange and nutrient absorption and cause reduction in plant growth. Vast extensive research findings have also reported that heavy metals also interfere with the levels of antioxidants in plants, reduce the nutritive value of the produce. Thus it is quiet imperative to put the use of phytoremediation technique to clean up the contaminated environment not only for the better survival of all organisms on the earth but also for the reduction of the risks associated with heavy metals. It is an eco-friendly approach and has the sufficient potential to restore the heavy metal polluted soil in a cost effective way. (Ashraf *et al.*, 2019). Besides restoration of land Phtoyremedation also increases land use value. Phytoremediation could be a successful method to mitigate serious threats posed to human health and the ecosystem. For the sake of efficacy up gradation of the cost-effective and environmentally sound remediation technique of phytoremedation it is paramount to have a comprehensive vision of the mechanism underlying heavy metal accumulation and tolerance in plants. Thus in order to cherish contaminant free healthier environment for all the living organism,

initiatives need to be taken to make our metal polluted sites free from heavy metals by adopting Phytoremediation technique. It emphasizes usage of specially selected metal-accumulating plants possessing genetic potential to remove, degrade, metabolize, or immobilize a wide range of contaminants to remediate soil contaminated with heavy metals, organic pollutants and radionuclides (Ali *et al.*, 2013).

**Sources of heavy metals**

Serious environmental problem posed by Heavy metal pollution has spread throughout the world. Almost 53 elements are classified as heavy metals (As, Cd, Cr, Cu, Zn, Hg, Ni, Pb etc.) Their densities exceed 5 g $cm^{-3}$, and they are known as universal pollutants in industrial areas (Sarma, 2011). Heavy metals enter the environment from various different natural and anthropogenic sources (**Figure 1**). The most significant natural sources are weathering of minerals, erosion and volcanic activity while anthropogenic sources include mining, smelting, electroplating, use of pesticides and (phosphate) fertilizers as well as biosolids in agriculture, sludge dumping, industrial discharge, atmospheric deposition, etc. (Chehregani and Malayeri, 2007; Fulekar *et al.*, 2009; Sabiha-Javied *et al.*, 2009; Wuana and Okieimen, 2011). The heavy metals essentially become contaminants in the soil and water environment because of their excess generation by natural and man-made activities, transfer from mines to other locations where higher exposure to humans occurs, discharge of high concentration of metal waste through industries, and greater bioavailability (Dixit *et al.*, 2015).

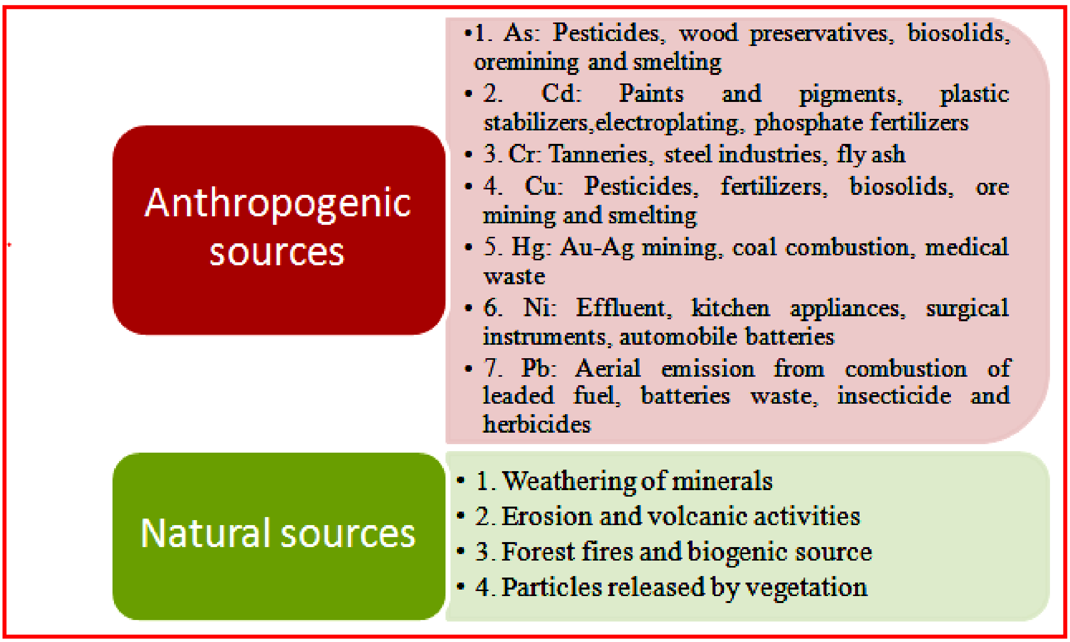


**Figure 1: Sources of heavy metals in the environment.**

**Effects of heavy metals**

Significant adverse effects of heavy metals on plants are the inhibition of growth rate, chlorosis, necrosis, leaf rolling, altered stomatal action, alterations in membrane functions, inhibition of photosynthesis, respiration, altered metabolism, (**Figure 2** ) and Reduction of several key enzymes activities (Dubey, 2011, Sharma and Dubey 2007 , Hossain, 2010.). In Plant cells excessive Reactive Oxygen Species [superoxide ($O2^{-}$), hydroxyl radical (OH·), singlet oxygen ($^{1}O2$), and hydrogen peroxide ($H_2O_2$)] production is triggered abiotic stress generated by Heavy Metals (Dubey, 2011; Hossain, 2010 and Anjum, 2012). Reactive Oxygen Species (ROS) causes peroxidation of lipid membrane, protein oxidation, enzyme inhibition, and damage to nucleic acids and subsequent cell death (Anjum, 2012, Gill *et al.*, 2011. Gill and Tuteja, 2010).

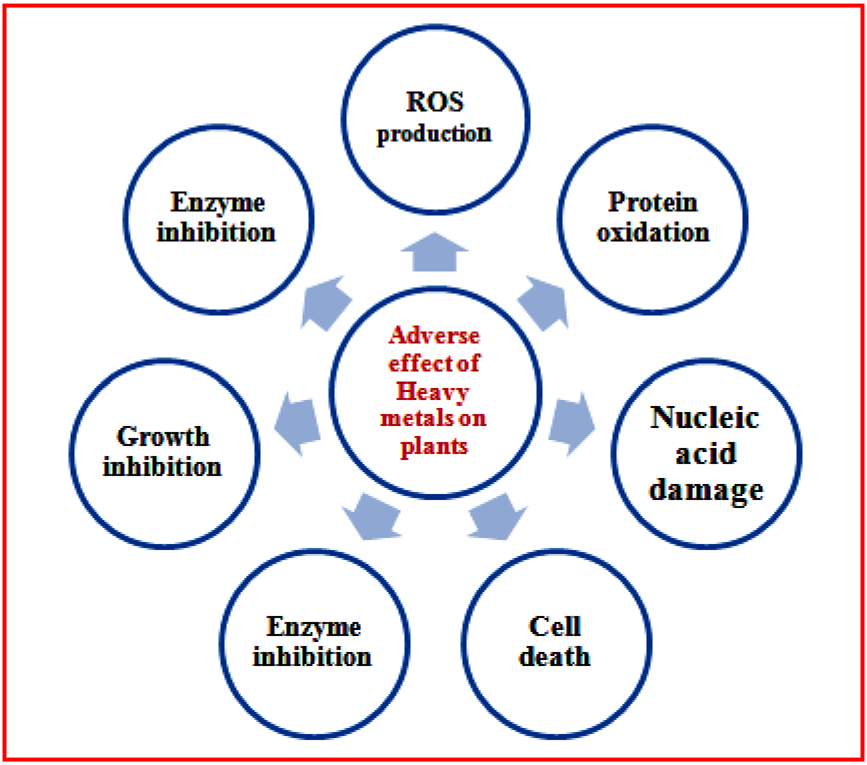


**Figure 2. Adverse effects of heavy metals on plants**

**Plants and phytoremediation**

Plants as a functional part of ecosystems and not only fulfill our basic needs like food, fooder, fuel, fibre, medicine but also provide free ecological services like purification of air by the production of oxygen. These plants are complex organisms having tremendous potential and thus have been used in phytoremediation technique. Phytoremediation-a green solution to the problem of heavy metal pollution involves the use of grasses, ferns and woody species to remediate, remove, immobilize, or transform environmental contaminants such as heavy metals, organic compound and other elements in natural resources (Dan, 1995). It is a novel, cost effective, efficient, environmentaly sound and eco-friendly remediation strategy (Kawahigashi, 2009; Saier and Trevors, 2010; Kalve *et al.*, 2011; Sarma, 2011; Singh and Prasad, 2011; Vithanage *et al.,* 2012). Metal accumulating plants have been found to have the ability to accumulate and tolerate high concentrations of heavy metals in their tissues. However, it has been found that the capability to hoard heavy metals varies suggestively between species, as diverse mechanisms of ion uptake are effective based on their genetic, morphological, physiological and anatomical features. Vast extensive research findings have reported that certain species not only survive in toxic stressful environment, but also can facilitate in the remediation of those environments. Approximately more than 400 plant species have been classified as hyper accumulators of heavy metals, such as grasses, Sunflower, Corn, Hemp, Flax, Alfalfa, Tobacco, Barley, Tomato, Spinach, Willow, Indian mustard, Water hyacinth, Hybrid Poplar Trees, Blue-green Algae, Arrowroot, Sudan Grass, Rye Grass, Duck Weed, Bermuda Grass, Alpine Bluegrass, Yellow or White Water Lillies, Poplar tree, Brake fern, Carrot, Periwinkle, Switch Grass, White reddish The root exudates of these plants play an important role in phytoremediation as it activate the surrounded microorganisms. The metal-rich plant material can be swathed, collected, and removed from the site using established agricultural practices, without the extensive excavation and loss of topsoil associated with traditional remediation practices.

**Table 1. List of selected plants reported for phytoremediation of heavy metals.**

| Heavy metal | Plant species | Reference |
|---|---|---|
| Cd, Cu, Pb, Zn | Salix spp. *(Salix viminalis, Salix fragilis)* | Pulford & Watson, 2003, Ruttens, *et al* 2011 |
| Cd | Castor *(Ricinus communis* | Huang, *et al.,* 2011 |
| Cd, Pb, Zn | Corn *(Zea mays)* | Meers, *et al* 2010 |
| Cd, Cu, Pb, Zn | Populus spp. *(Populus deltoides, Populus nigra, Populus trichocarpa)* | Ruttens, *et al* 2011 |
| Cd, Cu, Ni, Pb | Jatropha *(Jatropha curcas L.)* | Abhilash, *et al* 2009, Jamil, *et al* .2009 |
| Hg | *Populus deltoids* | Che *et al* 2003 |
| Se | *Brassica juncea, Astragalus bisulcatus* | Bitther, *et al* 2012 |
| Zn | *Populus canescens* | Bittsanszkya *et al* 2005 |

**Mechanisms for metal detoxification by plants**

Plants have evolved with the several defense mechanisms against heavy metals like morphological physical barriers - thick cuticle, biologically active tissues like trichomes and cell walls, as well as mycorrhizal symbiosis that can act as biophysical barriers when plants are under heavy metal stress (Emamverdian *et al.,* 2015). When the metal ions overshadow these natural obstacles and enter the plant tissue system several cellular defense mechanisms are initiated by the plant so as to prevent and reduce the harmful effects of the heavy metal (Silva and Matos, 2016). Enzymatic antioxidants such as superoxide dismutase, catalase and glutathione reductase, and non-enzymatic antioxidants such as ascorbate, glutathione, alkaloids, tocopherols, etc. (Singh *et al*., 2016, Rastgoo *et al.,* 2011) are generated by plants so as to attenuate the obnoxious effects of free radicals (Sharma, *et al.,* 2012). Besides these antioxidant production , a variety of other mechanisms have been also evolved in plants systems to minimize the lethal effects of metals viz. production of the enzyme phytochelatin synthase that readily binds to heavy metals at lethal levels (Jan and Parray, 2016; Solanki and Dhankhar 2011, Gupta *et al.,* 2013) production of metallothioneins ( Du *et al.,* 2012) and production of proline that acts as a compatible and metabolic osmolyte, a component of cell walls, free radical scavenger, antioxidant and macromolecule stabilizer (Ehsanpour *et al.,* 2012). Enzyme Phytochelatin synthase which act as defensive mechanism of plants against variety of abiotic environmental stresses such as salinity, drought, herbicide and heavy metals (Emamverdian *et al.,* 2015) leads to the formation of Phytochelatins (PCs) which are short-chain thiol-rich repetitions of peptides of low-molecular weight synthesized from sulfur-rich .They are used as biomarkers for the early detection of heavy metal stress in plants (Saba *et al.,* 2013). Plant metallothioneins production is induced by the presence of metals which are cysteine-rich, low-molecular-weight and metal-binding proteins, synthesized due to mRNA translation (Verkleij, *et al.,* 2003). Metallothioneins and have much affinity for a wide range of metals such as Cu, Zn, Cd and As (Guo, *et al.,* 2013). Apart from detoxification of heavy metals, plant Metallothioneins MTs also play a role in maintenance of the redox level (Emamverdian *et al.,* 2015, Macovei, *et al.,* 2010) , repair of plasma membrane (Emamverdian *et al.,* 2015, Mishra, and Dubey, 2006) cell proliferation and its growth, repair of damaged DNA and scavenge ROS (Grennan, 2011). Metallothineins and phytochetains being metal-detoxifying chelators can confer resistance to the plant by enhancing uptake, transport and accumulation of various heavy metals (Ruis and Daniell, 2009) Mutualistic symbiotic association of Arbuscular mycorrhizal also occurs with roots of most vascular plant species under different climatic conditions in which they improve the mineral nutrition position of plants and augment their tolerance towards abiotic stresses and pollutants while benefiting from the photosynthetic assimilations supplied by the plants (Emamverdian *et al.,* 2015).

**Phytoremediation technique**

Phytoremediation of heavy includes a number of different processes such as phytoextraction, phytofiltration, phytostabilization, phytovolatilization and phytodegradation (Alkorta, *et al.,* 2004).

**Phytoextraction**

Phytoextraction (Also known as phytoaccumulation, phytoabsorption or phytosequestration) is the uptake of contaminants by the plants from contaminated sites along with other nutrients and water required for their growth. Phytoextraction is based on the mechanism of hyperaccumulation (Jutsz and Gnida, 2015). Translocation of metals to shoots is desirable and important biochemical process in an effective phytoextraction process. The absorbed contaminants are not destroyed but get accumulated in shoots, leaves and other plant (Rashid *et al.,* 2014) above the ground at concentrations from 100 to 1000 times higher than those found higher in non-hyperaccumulating species without suffering any noticeable phytotoxic effect (Jabeen *et al.,* 2009, Rascio and Navari, 2011).

Hyperaccumulators plants are usually found growing in areas with long lasting metal contamination in soil over time and produce abundant biomass that can be easily harvested. Hyperaccumulators are characterized by some of the unique features like:

a. Proliferative growth ability and profused root system
b. Greater capacity to take up heavy metals from the soil
c. Enhanced root-to-shoot translocation of metal ions
d. Greater ability to detoxify and sequester extremely large amounts of metal ions in the shoots (Pourrut *et al.,* 2011; Rascio and Navari 2011).

About 500 taxa have been identified as hyperacumulators of some metals and the popular ones are representatives of the following families: Brassicaceae, Caryophylaceae Violaceae, Fabaceae, Euphorbaceae,lamiaceae, Asteraceae, Cyperaceae, Poaceae, Cunouniaceae and Flacourtiaceae (Muszynska and Hanus-Fajerska, 2015) as indicated in **Table 2**. Hyper accumulator plant species are used on many contaminated sites due to their tolerance of relatively extreme levels of pollution. Phytoextraction has been used more often for extracting heavy metals than for organic contaminants. Metal compounds that have been successfully phytoextracted include zinc, copper, and nickel. A living plant may continue to absorb contaminants until it is harvested. . After harvest, a lower level of the contaminant will remain in the soil, so the growth/harvest cycle must usually be repeated through several crops to achieve a significant clean-up. The process can be repeated to affect further decontamination. There are two forms of phytoextraction:

a. Natural hyper-accumulation, where plants take up the contaminants in soil unassisted.
b. Induced (assisted) hyper-accumulation, in which a conditioning fluid containing a chelator or another agent is added to soil to increase metal solubility or mobilisation so that the plants can absorb them more easily.

**Table 2: Some hyperaccumulator plants used in phytoextraction of heavy metals**

| Family | Species | Heavy Metals | References |
|---|---|---|---|
| Asteraceae | *Berkheya coddii* | Ni | Slatter, 2013 |
| Asteraceae | *Helianthus annuus* | Pb, Cd, Zn | Angelova, *et al.,* 2016;Fulekar, 2017 |
| Brassicaceae | *Alyssum bertolonii* | Ni | Mengoni *et al.,* 2012 |
| Brassicaceae | *Alyssum murale* | Ni | Broadhurst and Chaney,2016 |
| Brassicaceae | *Arabidopsis halleri* | Zn, Cd | Zhang, *et al.,* 2017 |
| Brassicaceae | *Arabidopsis halleri* | Cd Cd | Claire and Nathalie, 2012 |
| Caryophyllaceae | *Minuartia verna* | Zn, Cd, Pb | Bothe, 2011 |
| Crassulaceae | *Sedum alfredii* | Pb | Chibuike & Obiora, 2014 ; Chen, *et al.,* 2013 |
| Euphorbiaceae | *Euphorbia cheiradenia* | Cu, Fe, Pb, Zn | Nematian and Kazemeini, 2013 |
| Fabaceae | *Astragalus racemosus* | Se | Alford, *et al.,* 2012 |
| Fabaceae | *Medicago sativa* | Pb | Chibuike and Obiora, 2014 |
| Poaceae | *Spartina argentinensis* | Cr | Nalla, *et al.,* 2012 |
| Pteridaceae | *Pteris vittata* | As | Rathinasabapathi, 2011, Datta *et al.,* 2017 |
| Pteridaceae | *Pteris vittata* | Hg | Su, *et al.,* 2008 |
| Violaceae | *Viola boashanensis* | Pb, Zn, Cd | Zhuang , *et al.,* 2005 |

Various research experiments conducted for assessment of the bio-accumulative capacity in aquatic and terrestrial plants determined high accumulative potential of aquatic plants species for the remediation cause. Aquatic macrophytes are found to have great potential for accumulating heavy metals up to 1,00,000 times greater than the quantity of the associated water. The aquatic plants species, such as *Pistia stratiotes* (Zayed *et al.,* 1998), *Spirodela polyrrhiza* (Zayed *et al.,* 1998), *Myriophyllum aquaticum* (Harguinteguy *et al.,* 2013), *Ludwigina palustris* (Anawar *et al.,* 2008) and *Mentha aquatic*a (Zurayk *et al.,* 2002), have the huge potential of accumulating heavy metals. Aquatic macrophytic species such as *Eichhornia crassipes* and *Centella asiatica* are noted for their ability to accumulate different concentrations of copper from the contaminated sites (Mokhtar *et al.,* 2011).

**Phytofiltration**

This is another essential technique in phytoremediation. It involves the removal of pollutants from contaminated surface waters or waste waters by plants (Mukhopadhyay and Maiti, 2010a). There are the various forms of phytofiltration: rhizofiltration (use of plant roots) or blastofiltration (use of seedlings) or caulofiltration (use of excised plant shoots) (Dixit *et al.,* 2015, Mesjasz *et al.,* 2004, Rahman, *et al*, 2016)

**Phytostabilisation**

It is the stabilization of contaminants present in the soil by the aid of plants (Singh, 2012). It focuses primarily on heavy metal sequestration only within the rhizosphere. In this phytoimmobilization technique, absorbed pollutants are retained in the rhizosphere and stabilized, rendering them harmless and thereby preventing the pollutants from spreading in the environment (Lone, *et al.,* 2008). Phytostabilization is a better alternative of capturing metals in situ because the pollutants are not taken up into tissues of the plants and do not spread into the environment (Tak *et al.,* 2013). Mobilization of Heavy metals can be minimized by plants through sorption by roots, precipitation, metal valence reduction and complexation (Abbaszadeh-Dahaji, *et al.,* 2016, Freitas *et al.,* 2013, Arora, *et al.,* 2016 Nadarajah, 2016). Metals of different valences vary in toxicity. By excreting special redox enzymes, plants skillfully convert hazardous metals to a relatively less toxic state and decrease possible metal stress and damage. For example, reduction of Cr (VI) to Cr (III) is widely studied, the latter being both less mobile and less toxic (Wu, *et al.,* 2010). It is essential that plants used in phytostabilization should have a broad root system and low mobility of metals from roots to shoots (Islam, *et al.,* 2013, Abbaszadeh-Dahaji, *et al.,* 2016). It has also been found that soil (rhizobium and endophytic) microbes play an important role for the enhancement of phytostabilization, These beneficial bacteria aid phytoremediation technology by improving the immobilization and accumulation rate of heavy metal (Ma, *et al.,* 2011).

**Phytotransformation**

It is the chemical modification of the toxic organic pollutants taken up by the plants into non-hazardous compounds by the metabolic process within the plants by the aid of various specific enzymes such as nitroreductases, dehalogenase and oxygenase (Ali and Sajad 2013, Favas *et al.,* 2014). The degradation of organic pollutants in the soil could also be enhanced by rhizospheric microorganisms through the process of rhizodegradation [breakdown of organic pollutants in the soil by microorganisms in the rhizosphere] (Mukhopadhyay and Maiti, 2010b, Ali and Sajad, 2013; Khanam, 2016).This is made possible because the rhizospheric region of the plant contains elevated levels of exudates containing carbohydrates, amino acids, flavonoids. The release of nutrients-containing exudates by plant roots provides carbon and nitrogen sources to the soil microbes and creates a nutrient-rich environment in which microbial activity is stimulated and aids the degradation of the contaminants (Babalola, 2010). The contaminants that are broken down into simpler and less toxic products are utilized by the plant for their faster growth. (Muthusaravanan *et al.,* 2018.) Phytodegradation is limited to the removal of organic pollutants only because heavy metals are non biodegradable.

**Phytovolatilization**

It deals with the uptake of pollutants from soil by plants and their conversion to volatile form. The transformation of contaminants into volatile forms released during phytovolatilization is due to the metabolic potentials of the plants in association with microorganisms residing inside the rhizosphere (Tak *et al.*, 2013). This technique does not remove the pollutant completely; only it is transferred from one segment (soil) to another (atmosphere) from where it can be redeposited .Selenium, Arsenic and Mercury are some of the toxic metals which can be converted to volatile forms such as dimethyl selenide and mercuric oxide and further evaporated or volatilized into the atmosphere. Tobacco plants have the ability to accumulate highly toxic methyl mercury from Hg-contaminated sites and transform it to the less toxic elemental Hg in a volatile form that escapes through the leaves to the atmosphere (Rayu *et al.*, 2012, Mukhopadhyay and Maiti, 2010a). *Typha latifolia* L. is an aquatic plant which is used for phytovolatilization of selenium-contaminated soil (LeDuc and Terry, 2005). Genetically modifed organisms such as *Arabidopsis thaliana* L. and *Nicotiana tabacum* L. have been genetically modified with mercuric reductase and bacterial organomercurial lyase to absorb elemental contaminants such as Hg (II) and methyl mercury from the soil and release volatile Hg (O) into the atmosphere (Pillon and Pilon, 2000). Large number of plants have the potential and are used for the purpose of phytovolatilization as shown in **Table 3.**

**Table 3: Plants used in phytovolatilization of heavy metals**

| Species | Metals | Refrence |
|---|---|---|
| *Festuca rubra L.* | Cu | Radziemska *et al.*, 2017 |
| *Agrostis castellana* | Cu, Pb, and Zn | Pastor *et al.*, 2015 |
| *Acanthus ilicifolius L.* | Cd | Shackira and Puthur, 2017 |
| *Athyrium wardii* | Pb | Zhao *et al.*, 2016 |
| *Typha latifolia L.* | Zn, Mn, Co, Cd, Cr, Ni and As | Varun *et al.*, 2011 |
| *Alternanthera philoxeroides, Artemisia princeps, Bidens frondosa, Bidens pilosa, Cynodon dactylon, Digitaria sanguinalis, Erigeron canadensis* and *Setaria plicata* | Cd, Mn, Pb and Zn | Yang *et al.*, 2014 |
| *Sorghum bicolor L* | Cd and Zn | Soudek *et al.*, 2012 |
| *Silphium perfoliatum* | Cd | Zhang *et al.*, 2010 |

**Conclusion**

Since contamination of soils and waters by toxic heavy metals is a serious environmental problem, therefore effective remediation methods are necessary.This review highlighted the environmentally effective and sound phytoremediation technique as a better remediation technology to clean up the contaminants from environment by using green plants. To effectively remediate polluted environments, plants use various enzymatic and non enzymatic methods for the detoxification of heavy metals. Moreover these plants possess inherent biological mechanisms that enable them to survive under heavy metal stress conditions .To ward off heavy metal toxicity phytoextraction and phytostabilization phytoremedation techniques have been very effective. It is imperative to explore more suitable plants with high phytoremediation potential for the remediation of heavy metal pollution.

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