LGU Journal of
LIFE SCIENCES

LGU Society of Life Sciences

Review Article
Vol 2 issue 1 Jan-March 2018

LGU J.Life.Sci
ISSN 2519-9404
eISSN 2521-0130

Phytoremediation- A Green Technology for Cleaning the Environment

Samrah Tahir Khan and Fouzia Qamar*

Department of Biology, Lahore Garrison University, Lahore, Pakistan.
*Corresponding Author's Email: fouzia_qamar@lgu.edu.pk

ABSTRACT: *The use of "bioremediation" as a technology and tool was mainly introduced to reduce the high toxic levels of pollutants to a low level by the aid of micro-organisms. But it is less successful when extensive metal and organic pollutants are considered. Heavy metals are poisonous for microorganisms as they explicit direct influence on the biochemical and physiological processes. Thus, to overcome this, a new technology of treating the pollutants was introduced, widely known as phytoremediation. Phytoremediation is a combination of techniques used by the employment of plants to accumulate or extract the pollutant on site within its plant parts. It is considered as the one of the best alternative to detoxify pollutants from soil and water. This review comprehensively explains about phytoremediation and the various techniques adopted to deal with the contaminant.*

Keywords: Phyto-therapy, remediation, heavy metals, green technology, pollutants.

INTRODUCTION

Soil is the major component of the terrestrial ecosystem and is also regarded as a non-renewable resource. The soil is a complex mixture of nutrients serving as a substrate, for the sustenance and survival of many life forms. The soil is traditionally the "waste disposal site". In dumping and disposing off, introduction of detrimental compounds capable of causing pollution occurs, thus leading to the contamination of soil, which ultimately has dire consequences. Soil pollution usually occurs when the components of the soil interact with materials that are not a natural component or are toxic in nature. Due to anthropogenic activities, geological changes, rapid industrialization and urbanization, the introduction of the organic compounds and elements, predominately, the heavy metals have led to elevation in pollution; particularly "heavy metal pollution" (Dembitsky, 2003; Kavitha et al., 2013). Soil is open to the introduction of heavy metals as it serves as an interface between the atmosphere and the earth's crust and is the "substrate" for agricultural and natural ecosystem (Alloway, 1990). The excessive application of fungicides and pesticides has also contributed to be one of the source for accumulation of heavy metals in the soil. These effluents are usually released out as a result of multiple processes occurring at commercial and industrial level. These processes end up in the soil “the traditional disposal site” and makes the soil polluted.

Heavy metals in actual are toxic, non-biodegradable materials with density greater than 5gcm^{-3}. Due to their immutable nature, they remain persistent in the environment and thus are pollutants of grave concern (Garbisu and Alkorta, 2001). The heavy metals can be transformed from its oxidation stage to another. The pollution due to heavy metals is a problem experienced globally at the present (Singh and Gauba, 2014). Accumulation of heavy metals in soil has been reported world widely and utmost attention is therefore required, as it not only provides us an environmental threat, rather poses health risks affecting human beings, plants and animals. Approximately, about 20 metals classified as toxic elements have been reported to introduce pollution and threats of high risk to health of human population (Akpor and Muchie, 2010). The recent advancements and developments in agricultural and industrial sectors have although elevated the economics but have also been responsible to introduce, population in the environment (Ikhuoria and Okieimen, 2000). This pollution of toxic metals has been reported to increase rapidly with the advancement in the industrialization. Heavy metals are not degraded easily, and can accumulate through the food chain by human beings and other flora and fauna producing potential health risks. The heavy metals contaminate the environment in several ways. The effluents discharged from residential dwellings, industries and other commercial processes contain heavy metals (Akpor and Muchie, 2010). The occurrence of heavy metals and their accumulation is directly or indirectly related to anthropogenic activities and various other human sources (Hussein et al., 2005; Martin-Gonzalez et al., 2006). The release of heavy metals without proper treatment poses a potential threat to the public health. The heavy metals can cause damage to human health such as:

- cause reduction in growth
- have carcinogenic effect
- have harmful effects on the organs and systems of the body
- In severe cases, can be fatal
- Autoimmunity with complications related to kidneys and joints

Acute and chronic diseases also occur due to the accumulation of heavy metals at successive levels of the food chain (Fuggle, 1982; Lone et al., 2008). The heavy metals also have pernicious effects on the soil microbial properties and functionality (Yang et al., 2012). Taxonomical diversity also gets effected due to these harmful elements (Vacca et al., 2012). Bio magnification i.e., the increase in the concentration from lower to an elevated level as the element is passed to higher trophic levels in the food chain; is also an important factor to consider as the elements present in the food chain beyond the threshold has health related effects. These elements become toxic beyond a certain level and infer the normal metabolic processes occurring in the living organisms. The toxic effects produced by certain heavy metals on plants and human beings has been listed in Table.1 (Pendias and Pendias,2001; Ali et al., 2013).

Sr. No	Heavy Metal	Effects caused to plants when contained in the soil as a contaminant
1.	Cadmium	• Decreases germination of seed • Stunted growth • Reduces lipid content • Responsible for the production of phytochetalin; which has important role in the detoxification of the plants
2.	Chromium	• It decreases: Growth Enzymatic Activity • Results in Chlorosis • Causes damage to roots, membranes of the plant body.
3.	Mercury	• It enables the accumulation of phenol. • Reduces: the uptake of water photosynthesis • Reduction in the antioxidant enzymes
4.	Lead	• Reduction in: Chlorophyll Plant growth
5.	Nickel	• Reduction in: Seed germination Protein production Chlorophyll Enzyme production
6.	Zinc	Reduces: Toxicity of nickel Seed germination Ratio of chlorophyll
7.	Copper	• Disruption in the process of Photosynthesis • Stunted growth • Affected reproductive processes • Reduction in the area of thylakoid surface

Treatment Methods for Heavy Metal Containing Sites

Due to the human activities, the interference with the environment has caused the soil problem. It has got contaminated. As, Cd, Cr, Hg and Pb are the non-essential heavy metals, while Cu, Ni and Zn are essential metals responsible to cause heavy metal pollution with the causation of adverse effects to the human and plant life. To address the unsolved problem of pollution of heavy metals, the treatment usually adopted as an alternative to treat these contaminated sites includes;

- The process of excavation
- Landfilling the excavated site
- Encapsulation, which may either be complete or partial.
- In-situ and ex-situ treatment.
- Remediation, which involves the use of mechanical, thermal and biological processes that can restore the characteristic properties of the soil, making it useful and fertile for future use.

Several remediation technologies have been developed. A few include (Marques et al., 2009):

- Soil washing
- Soil Flushing
- Solidification
- Soil Vapor extraction
- Immobilization
- Vitrification
- Encapsulation
- Electro-kinetics
- Thermal Desorption (Hamby, 1996; Ohosen and Jensen, 2005)

These technologies remove heavy metals but are expensive and sometimes make the land useless for further activities such as crop cultivation. Nowadays attention towards biology based technology is gaining more attention and thus brings us the remediation technology in which living organisms are employed for the accumulation and excavation of the pollutants. The remediation technology comprises of the following major categories:

- Bioremediation; referring mainly to the employment of bacteria for treatment.
- Myco-remediation; referring to the use of Fungi.
- Phytoremediation; the usage of plants for removal and cleaning up of pollutants.

Bioremediation techniques was a miraculous way of treating pollutants but, it too has limitations. The heavy metals can also affect the micro-organisms, and can explicit direct influence on the biochemical/ physiological procedures including disruption and deterioration of the cell organelles, and preventing essential metabolic activities needed by these microorganisms to thrive e.g., photosynthesis. Thus, to deal with this issue, an effective green technology was introduced, known as “Phytoremediation”. Plants have the incredible ability of metabolizing substances present in the ecosystem. Therefore, they can be applied as an approach to detoxify pollutants to a level where the area can be remediated and regarded as safe, while pollutants can be easily used after being accumulated by the plants (Vidali, 2001; Mangkoedihardio and Surahmaida, 2008). It would therefore not be incorrect to state, phytoremediation as a promising technology to clean up the contaminated areas.

Phytoremediation

Phytoremediation has been derived from Greek words, “Phyto” and “remediation”, meaning plant and restore respectively (Cunningham et al., 1996). The term actually refers to naturally occurring or genetically engineered plants, for eliminating or cleaning the environment (Flathman and Lanza, 1998; Long et al., 2002; Jadia and Fulekar, 2009). The contaminants found in the environment that are unable to be eliminated via biodegradation that is that they cannot be broken down to simpler substances or are difficult to be accumulated due to their peculiar properties, can be processed using any technology of phytoremediation. Hence, it is the best desired solution towards the increasing issue of soil pollution currently faced round the globe, due to the rapid industrialization. Due to degree of its application and elegance in the technique, Phytoremediation has gained quite attention at both commercial and scientific level (Kramer and Chardonnens, 2011; Peuke and Rennenberg, 2005).

Phytoremediation makes use of wild and genetically engineered plants (GMPs) to extract pollutants and organic compounds from soil and water. Phytoremediation and its use in treating heavy metal pollution is not a new application. The use of phytoremediation in treating several heavy metals has been reported in the literature from time to time. A list of plants capable of conducting phytoremediation have been discussed in Table.3.

Sr. No	Heavy Metal	Plants (Scientific Name)	References
1.	Arsenic	*Pteris vittata*	Gardea-Torresdey et al., 2005
		Pityrogramma calomelanos	Dembitsky and Razanka, 2003
		Corrigiola telephiifolia	Garcia-Salgado et al., 2012
		Eleocharis acicularis	Sakakibara et al., 2011
		Pteris biaurita	Srivastava et al., 2006
		Pteris cretica	Zhao et al., 2002; Srivastava et al., 2006
		Pteris quadriaueita	Srivastava et al., 2006
		Pteris ryukyuensis	Srivastava et al., 2006
		Pteris vittata	Baldwin and Butcher, 2007; Kalve et al., 2011
2.	Cadmium	*Brassica juncea L.*	Thorsten et al., 1999; Gardea-Torresdey et al.,
			2005
		Salix	Gardea-Torresdey et al., 2005
		Thlaspi caerulescens	Lombi et al., 2001; Wu et al., 2004
		Helianthus annus	Jiang et al., 2003; Wang et al., 2007

		Zea mays	Spirochova et al., 2003
		Bidens pilosa	Sun et al., 2007
		Lonicera japonica	Sun et al., 2007
		Solanum nigrum L.	Sun et al., 2007
		Ambrosia artemisiifolia	Huang et al., 1997
		Sedum alferedii	Sun et al., 2007
		Azolla pinnata	Rai, 2008
		Eleocharis acicularis	Sakakibara et al., 2011
		Rorippa globosa	Wu et al., 2011
		Solanum photeinocarpum	Zhang et al., 2011
3.	Lead	*Brassica juncea*	Gardea-Torresdey et al., 2005
		Helianthus annus	Spirochova et al., 2003
		Zea mays	Gardea-Torresdey et al., 2005
		Piptatherum miliaceum	Garcia et al.,2004
		Thlaspi praecox	Mikus et al., 2005
		Heonidesmus indicus	Sekhar et al., 2005
		Ambrosia artemisiifolia	Gardea-Torresday et al., 2005
		Helicotylenchus indicus	Sekara et al., 2005
		Thlaspi caerluescens	Wu et al., 2004
		Minuarti vernia	Reeves and Baker, 2000
		Armenia maritime	Reeves and Baker, 2000
		Agrostis tenuis	Reeves and Baker, 2000
		Euphorbia cheiradenia	Chehregani and Malayeri, 2007
4.	Zinc	*Piptatherum miliaceum*	Garcia et al., 2004
		Helianthus annus	Spirochova et al., 2003
		Zea mays	Spirochova et al., 2003
		Eleocharis acicularis	Sakakibara et al., 2011
		Thlaspi caerulescens	Knight et al., 1997
		Thlaspi tatrense	Reeves and Baker, 2000
		Cardaminopsis	Reeves and Baker, 2000
		Dichapetalum galonioides	Reeves and Baker, 2000
		Viola calaminaria	Reeves and Baker, 2000

5.	Copper	*Clerodendrum infortunatum*	Rajakawna and Bohm, 2002
		Croton bonplandianus	Rajakawna and Bohm, 2002
		Thordisa villosa	Rajakawna and Bohm, 2002
		Pistia stratiotes	Odjegba and Fasidi, 2004
		Eleocharis acicularis	Sakakibara et al., 2011
		Aeollanthus subacaulis	Reeves and Baker, 2000
6.	Nickel	*Alyssum lesbiacum*	Cluis, 2004
		Brassica junceae	Saraswat and Rai, 2009
		Psycotria vanhermanni	Reeves and Baker, 2000
		Psycotria glomerata	Reeves and Baker, 2000
		Psycotria osseana	Reeves and Baker, 2000
		Garcinia bakeriana	Reeves and Baker, 2000
		Streptanthus polygaloydes	Reeves and Baker, 2000
		Alyssum bertolonii	Li et al., 2003
		Alyssum caricum	Li et al., 2003
		Alyssum corsicum	Li et al., 2003
		Alyssum heldreichii	Bani et al., 2010
		Alyssum murale	Li et al., 2003; Bani et al., 2010
		Alyssum pterocarpum	Bani et al., 2010
		Alyssum serpyllifolium	Prasad, 2005
		Berkheya coddii	Mesjasz-Przybylowicz et al., 2004
		Pistia stratiotes	Odjegba and Fasidi, 2004
		Isatis pinnatiloba	Altinozlu et al., 2012
7.	Chromium	*Brassica junceae*	Saraswat and Rai, 2009
		Pistia stratiotes	Odjegba and Fasidi, 2004
8.	Cobalt	*Haumaniastrum robertii*	Reeves and Baker, 2000
		Pteris vittata	Kalve et al., 2011
9.	Selenium	*Lecythis ollaria*	Reeves and Baker, 2000
		Astragalus racemosus	Reeves and Baker, 2000
10.	Magnese	*Alyxia rubricalis*	Revees and Baker, 2000
		Maytenus bureaviana	Reeves and Baker, 2000
		Schima superba	Yang et al., 2011

The plants have the ability to accumulate 'essential' and the 'non-essential' metals from the solution. The essential metals include Ca, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Se, V and Zn while the non-essential (as they have known biological function) includes; Al, As, Au, Cd, Cr, Hg, Pb, Pd, Pt, Sb, Te, Ti and U (Djingova and Kuleff, 2000). The metals as they cannot be broken down into simpler substances get accumulated to a toxic level and can cause abnormality in the metabolic activities such as disruption of the cell membranes and enzymes present in the cytoplasm. However, it has been reported that some plants have the ability to evolve and can tolerate the presence of metals (Baker, 1981). To do so plants adopt the following 3 ways; Exclusion, Inclusion and Bio-accumulation.

1. **Exclusion:**

   In this method, the plants accumulate the metals in their shoots, can restrict their movement and maintenance of their concentration is ensured over a wide range of soil levels.

2. **Inclusion:**

   The shoots accumulate the metals and the shoot metal concentration reflects those in metals in the soil in a linear relationship.

3. **Bio-accumulation:**

   The metals accumulate the metals in lower and higher concentrations in the upper plant parts and the roots.

The severity and levels of pollution differ from place to place depending on the geographical region and degree of anthropogenic activities being conducted. The use of phyto-remediating methods have been categorized, to deal with each level and type of pollutant.

PHYTOREMEDIATION TECHNOLOGY

Can be categorized into following techniques:

1. Rhizosphere biodegradation/ Phyto-stimulation

In this technique, the exudates and enzymes released out by the plants stimulate the microbial fungal and bacterial degradation of the pollutants. The exudates and enzymes are usually released in the root zone where the residing microbial population gets stimulated to perform the degradation.

2. Phyto-stabilization

It is a technique in which the bio-availability of pollutants is reduced by immobilizing the pollutants or by binding the pollutants to the soil matrix (Vangronsveld et al., 1995; Jadia and Fulekar, 2009). It is mainly used to remediate Cd, Cu, As, Zn and Cr. Use of perennial ryegrass *(Loliumperenne L.)* is considered to be potentially effective for phytostabilizing the contaminents as reported by Alvarenga and his coworkers in his publication (Alvarenga et al., 2009). Treatment of sewage, sludge, residues, Municipal solid waste and garden waste compost can be done using this technique.

3. Phyto-filtration

This involves the removal of pollutants from waste water and surface water effectively. Phyto-filtration can be;

1. **Rhizofiltration:**

   It is the removal of the contaminants from aqueous site by use of plant roots for accumulation of plant roots for accumulation of the pollutants (Pivetz, 2001). For example, use of Limnocharis Flava (L.) for the removal of Cadmium from water (Abhilash et al., 2009). Others include; Eichhornia crassipes (Water Hyacinth), Lemna minor (Duckweed), Pistia species (Karkhanis et al., 2005). Absorption and adsorption of pollutants from aqueous waste and water can be achieved by rhizo-filtration.

2. **Blastofiltration:**

   This filtration technique uses seedlings.

3. **Caulofiltration:**

   This filtration involves shoots.

Phyto-filtration minimizes the overall movement of the pollutant in the water.

4. Phyto-volatilization

It takes the pollutants by using the growth matrix, transform them into simpler components and allow them to be released into the atmosphere. The contaminants are taken up by roots into the leaves and are then volatilized through stomata (Vroblesky et al., 1999). It is majorly adopted for mercury contamination (Heaton et al., 1998). Hg and Se can be treated using this technique (Karami and Shamsuddin, 2010).

5. Phyto-degradation

It is also termed as Phyto-transformation. It takes up and accumulate the pollutant in its biomass, where it is degraded and stored, thus leaving clean soil for use. Sludge, soil contaminated with herbicide, insecticides and various organic solvents.

6. Phyto-extraction

It removes the organics from the soil by taking up the contaminant and accumulating it in the biomass i.e., in the harvestable plant plants. The uptake of contaminants from the roots and translocation of the contaminants takes place in the “above ground biomass”, resulting in effective harvesting of the pollutant, as harvesting them from root biomass is not feasible (Tangahu et al., 2011). Phyto-extraction is also known by synonymic terms; phyto-accumulation, phyto-absorption, phyto-filtration, phyto-volatilization, phyto-degradation (Rafati et al., 2011).

7. Hydraulic Control

It is the regulation and control of the “water table” and “soil field capacity” by using plant canopies (Schwitzguebel, 2004).

8. Phyto-mining

It is the method of attaining the metal after being accumulated in the plant tissue. E.g., acquisition of potassium (potash) is a simple example of phyto-mining that has been adopted by human beings for centuries.

Advantages of Phytoremediation:

Phytoremediation has multiple advantages a few include:

- It is cheap and cost effective technique.
- It is a carbon dioxide neutral technology.
- It is the best alternative for removal of contaminants and is regarded as safe and eco-friendly.
- On incineration, no additional CO2 released except for what was originally assimilated by the plants.

Disadvantages of Phytoremediation:

The disadvantages include:

- The techniques used in phyto-remediation are time taking as they have slow pace to minimize the metal contamination, requiring several years (McGrath and Zhao, 2003).
- There can be economic issues as the site contaminated, remains unavailable for sale or rent.
- The basic research in this area needs to improve to provide sound knowledge about the detoxification mechanisms.

CONCLUSION

Phytoremediation is one of the best recommended heavy metal treatment, and can be used according to the need and scale of contamination faced in a particular site. However, more research in this area would broaden the use and application of plants in remediating the environment.

REFERENCES

1. Abhilash P, Pandey VC, Srivastava P, Rakesh PS, Chandran S, Singh N and Thomas AP (2009). Phytofiltration of cadmium from water by Limnocharis flava (L.) Buchenau grown in free-floating culture system. J. Hazard. Mater. 170(2-3):791-797.

2. Akpor OB, Muchie M (2010). Remediation of Heavy metals in drinking water and wastewater treatment systems. Processes and applications. International Journal of the Physical Sciences. 5(12): 1807-1817.

3. Ali H, Khan E and Sajid MA (2013). Phytoremediation of heavy Metals-Concepts and applications. Chemosphere; 91: 869-881.

4. Alloway BJ, Ayres DC (1997). Chemical Principles of Environmental Pollution. Blackie Academic, London, 168.

5. Altinozlu H, Karagoz A, Polat T and Ünver I (2012). Nickel hyper-accumulation by natural plants in Turkish serpentine soils. Turk. J. Bot. 36: 269–280.

6. Alvarenga P, Gonçalves AP, Fernandes RM, de Varennes A, Vallini G, Duarte E and Cunha-Queda AC (2009). Organic residues as immobilizing agents in aided phytostabilization: (I) Effects on soil chemical characteristics. Chemosphere. 74(10):1292-1300.

7. Baker AJM (1981). Accumulators and excluders – strategies in the response of plants to heavy metals. J. Plant Nutr. 3: 643-654.

8. Baldwin PR, Butcher DJ (2007). Phytoremediation of arsenic by two hyper-accumulators in a hydroponic environment. Microchem. J. 85: 297–300.

9. Banasova V, Horak O, Nadubinska M and Ciamporova M (2008). Heavy metal content in *Thlaspi caerulescens* J. et C. Presl growing on metalliferous and non-metalliferous soils in Central Slovakia. Int. J. Environ. Pollut. 33(2):133-145.

10. Bani A, Pavlova D, Echevarria G, Mullaj A, Reeves RD, Morel JL and Sulçe S (2010). Nickel hyperaccumulation by the species of *Alyssum and Thlaspi* (Brassicaceae) from the ultramafic soils of the Balkans. Bot. Serb. 34: 3–14.

11. Chehregani A, Malayeri BE (2007). Removal of heavy metals by native accumulator plants. Int. J. Agri. Biol. 9: 462–465.

12. Cluis C (2004). Junk-greedy Greens: phytoremediation as a new option for soil decontamination. BioTech J. 2:61-67.

13. Cunningham SD, Ow DW (1996). Promises and prospects of root zone of crops. phytoremediation. Plant Physiol. 110: 715-719.

14. Dembitsky VM, Rezanka T (2003). Natural occurrence of arsenic compounds in plants, lichens, fungi, algal species, and microorganisms. Plant Sci. 165(6):1177-1192.

15. Djingova R, Kuleff I (2000). Instrumental techniques for trace analysis. In: Trace elements: Their distribution and effects in the environment. Vernet, JP (eds) Elsevier Science Ltd., United Kingdom, pp. 146.

16. Garbisu C, Alkorta I (2001). Phytoextraction: A cost-effective plant-based technology for the removal of metals from the environment. Bioresour. Technol. 77(3):229-236.

17. Garcia G, Faz A and Cunha M (2004). 'Performance of *Piptatherum miliaceum* (Smilo grass) in edaphic Pb and Zn phytoremediation over a short growth period', International Bioremediation & Biodegradation 54: 245-250.

18. Garcia-Salgado S, Garcia-Casillas D, Quijano-Nieto MA and Bonilla-Simon MM (2012). Arsenic and heavy metal uptake and accumulation in native plant species from soils polluted by mining activities. Water Air Soil Pollut. 223: 559–572.

19. Gardea-Torresdey JL, Peralta-Videa JR, de la Rosa G and Parsons JG (2005). 'Phytoremediation of heavy metals and study of the metal coordination by X-ray absorption spectroscopy'. Coordination

chemistry reviews.

20. Hamby DM (1996). Site remediation techniques supporting environmental restoration activities—a review. Sci. Total Environ. 191: 203–224.

21. Heaton ACP, Rugh CL, Wang N and Meagher RB (1998). "Phytoremediation of mercury and methyl mercury-polluted soils using genetically engineered plants." J. Soil Contamination. 7: 497-510.

22. Huang, JW, Chen J, Berti, WR, and Cunningham, S.D. (1997). Phytoremediation of lead contaminated soils: Role of synthetic chelates in lead phyto-extraction. Environmental Science and Technology. 31: 800–862.

23. Hussein H, Farag S, Kandil K and Moawad H (2005). Resistance and uptake of heavy metals by *Pseudomonads*. Process Biochem. 40:955-961.

24. Ikhuoria EU, Okieimen FE (2000). Scavenging Cadmium, copper, lead, Nickel and Zinc ions from aqueous solution by modified cellulosic sorbent. Int. J. Environ Studies. 57(4): 401.

25. Jadia CD, Fulekar MH (2009). Phytoremediation of heavy metals: Recent techniques. Afr. J. Biotechnol. 8(6):921-928.

26. Jiang XJ, Luo YM, Zhao QG, Baker AJM, Christie P and Wong MH (2003). 'Soil Cd availability to Indian mustard and environmental risk following EDTA addition to Cd-contaminated soil'.Chemosphere: 50(6):813-818.

27. Kabata-Pendias A, Pendias H (2001). Trace elements in soils and plants. CRC Press, London.

28. Kalisova-Spirochova I, Puncocharova J, Kafka Z, Kubal M, Soudek P and Vanek T (2003). 'Accumulation of heavy metals by *in vitro* cultures of plants'. Water Air and Soil Pollut: Focus. 3: 269-276.

29. Kalve S, Sarangi BK, Pandey RA and Chakrabarti T (2011). Arsenic and chromium hyper-accumulation by an ecotype of Pteris vittata-prospective for phytoextraction from contaminated water and soil. Curr. Sci. 100: 888–894.

30. Karami A, Shamsuddin ZH (2010). Phytoremediation of heavy metals with several efficiency enhancer methods. Afr. J. Biotechnol. 9(25):3689-3698.

31. Karkhanis M, Jadia CD and Fulekar MH (2005). Rhizofilteration of metals from coal ash leachate. Asian J. Water, Environ. Pollut. 3(1): 91-94.

32. Kavitha B, Johtimani P, Ponmani S and Sangeetha R (2013). Phytoremediation of Heavy metals- A Review. International Journal of Research Studies in Biosciences 1(2): 17-23.

33. Knight B, Zhao FJ, McGrath SP and

Shen ZG (1997). ‘Zn & Cd uptake by the hyperaccumulator *Thlaspi caerulescens* in contaminated soils and its effects on the concentration and chemical speciation of metals in soil solution’. Plant & Soil. 197: 71-78.

34. Krämer U, Chardonnens AN (2001). The use of transgenic plants in the bioremediation of soils contaminated with trace elements. Appl. Microbiol. Biotechnol. 55: 661–672.

35. Kumar PBAN, Dushenkov V, Motto H and Raskin L (1995). Phytoextraction: The use of plants to remove heavy metals from soils. Environmental Science and Technology, 29: 263–290.

36. Li YM, Chaney R, Brewer E, Roseberg R, Angle JS, Baker A, Reeves R and Nelkin J (2003). Development of a technology for commercial phyto-extraction of nickel: economic and technical considerations. Plant Soil 249: 107–115.

37. Liu Z, He X, Chen W, Yuan F, Yan K and Tao D (2009). Accumulation and tolerance characteristics of cadmium in a potential hyperaccumulator-*Lonicera japonica* Thunb. J. Hazard. Mater. 169(1-3):170-175.

38. Lombi E, Zhao FJ, Dunham SJ and McGrath SP (2001). Phytoremediation of heavy metal-contaminated soils: natural hyper-accumulation versus chemical enhanced phyto-extraction. J. Environ. Qual. 30: 1919–1926.

39. Lone MI, He Z, Stoffella PJ and Yang X (2008). Phytoremediation of heavy metal polluted soils and water: progresses and perspectives. J. Zhejiang Univ. – Sci. B 9, 210–220.

40. Long X, Yang X and Ni W (2002). Current situation and prospect on the remediation of soils contaminated by heavy metals. Ying yong sheng tai xue bao= The journal of applied ecology/Zhongguo sheng tai xue xue hui, Zhongguo ke xue yuan Shenyang ying yong sheng tai yan jiu suo zhu ban 13(6):757-762.

41. Marques APGC, Rangel AOSS and Castro PML (2009). Remediation of Heavy metal contaminated soils: Phytoremediation as potentially promising clean up technology. Critical Reviews in Environmental Science and Technology. 39: 622-654.

42. Martin-Gonzalez A, Diaz S, Borniquel S, Gallego A and Gutierrez JC (2006). Cytotoxicity and bioaccumulation of heavy metals by ciliated protozoa.

43. McGrath SP, Zhao FJ (2003). Phytoextraction of metals and metalloids from contaminated soils. Curr. Opin. Biotechnol. 14: 277–282.

44. Mesjasz-Przybylowicz, J, Nakonieczny M, Migula P, Augustyniak M, Tarnawska M, Reimold WU, Koeberl C, Przybylowicz W and Glowacka E (2004). Uptake of cadmium, lead, nickel

and zinc from soil and water solutions by the nickel hyperaccumulator *Berkheya coddii*. Acta Biol. Cracov. Bot. 46: 75–85.

45. Mikus KV, Drobne D and Regvar M (2005). ‘Zn, Cd, and Pb accumulation and arbuscular mycorrhizal colonization of pennycress *Thlaspi praecox Wulf* (Brassicaceae) from the vicinity of lead mine and smelter in Slovenia’, Environ. Pollut. 133: 233-242.

46. Odjegba VJ, Fasidi IO (2004). Accumulation of trace elements by *Pistia stratiotes*: implications for phytoremediation. Ecotoxicology 13(7):637-646.

47. Ottosen LM, Jensen PE (2005). Electro-remediation of contaminated soil. *In:* Lens P, Grotenhuis T, Malina G and Tabak H. (eds.) Soil and sediment remediation. London: IWA Publishing. 264–287.

48. Pivetz BE (2001). Ground Water Issue: Phytoremediation of contaminated soil and ground water at hazardous waste sites pp.1-36.

49. Prasad MNV (2005). Nickelophilous plants and their significance in phyto-technologies. Braz. J. Plant Physiol. 17: 113–128.

50. Rafati M, Khorasani N, Moattar F, Shirvany A, Moraghebi F and Hosseinzadeh S (2011). Phytoremediation potential of *Populus alba* and *Morus alba* for cadmium, chromuim and nickel absorption from polluted soil. Int. J. Environ. Res. 5: 961– 970.

51. Rai PK (2008). Phytoremediation of Hg and Cd from industrial effluents using an aquatic free floating macrophyte *Azolla pinnata*. Int. J. Phytorem. 10: 430–439.

52. Rajakaruna N, Böhm BA (2002). Serpentine and its vegetation: A preliminary study from Sri Lanka. J. Appl. Botany-Angewandte Botanik. 76:20-28.

53. Reeves RD, Baker AJM (2000). Metal-accumulating plants. *In:* Raskin I and Ensley B D (eds.). Phytoremediation of toxic metals: Using plants to clean up the environment. New York: Wiley, pp. 193–229.

54. Sakakibara M, Ohmori Y, Ha NTH, Sano S and Sera K (2011). Phytoremediation of heavy metal contaminated water and sediment by *Eleocharis acicularis*. Clean Soil, Air, Water 39, 735–741.

55. Saraswat S, Rai JPN (2009). Phytoextraction potential of six plant species grown in multimetal contaminated soil. Chem. Ecol. 25(1):1-11.

56. Schneider T, Angela HK, Maetz M, Niecke M, Povh B, Rausch T and Schussler A (1999). Micro-PIXE studies of elemental distribution in

Cd-accumulating *Brassica juncea* L. Nucl. Instrum. Methods Phys. Res. B. 158(1-4): 329-334.

57. Schwitzguebel, Jean-Paul (2004). 'Potential of phytoremediation, an emerging green technology: European trends and outlook'. *In:* Proceedings of the Indian National Science-Academy, Part B: Biological Science 70(1): 131-152.

58. Sekara A, Poniedzialeek M, Ciura J and Jedrszczyk E (2005). Cadmium and lead accumulation and distribution in the organs of nine crops: Implications for phytoremediation. Polish J. Environ. Stud. 14(4):509-516.

59. Sekhar KC, Kamala CT, Chary NS, Balaram V and Garcia G (2005). 'Potential of *Hemidesmus indicus* for phytoextraction of lead from industrially contaminated soils'. Chemosphere. 58: 507-514.

60. Singh A, Gauba P. (2014). Mycoremediation: A Treatment for Heavy Metal Pollution of Soil, Journal of Civil Engineering and Environmental Technology. 1(4): 59 – 61.

61. Srivastava M, Ma LQ and Santos JAG (2006). Three new arsenic hyper-accumulating ferns. Sci. Total Environ. 364: 24–31.

62. Stegmann R, Brunner G and Calmano W, Matz G (2001). 'Treatment of Contaminated Soil, Fundamentals, Analysis, Applications', Berlin: London: Springer.

63. Sun Q, Ye ZH, Wang XR and Wong MH (2007). Cadmium hyperaccumulation leads to an increase of glutathione rather than phytochelatins in the cadmium hyperaccumulator *Sedum alfredii*. J. Plant Physiol. 164(11):1489-1498.

64. Sun Y, Zhou Q and Diao C (2008). Effects of cadmium and arsenic on growth and metal accumulation of Cd-hyperaccumulator Solanum nigrum L. Bioresour. Technol. 99(5):1103-1110.

65. Sun Y, Zhou Q, Wang L and Liu W (2009). Cadmium tolerance and accumulation characteristics of *Bidens pilosa L.* as a potential Cd-hyperaccumulator. J. Hazard. Mater. 161(2-3): 808-814.

66. Tangahu BV, Abdullah SRS, Basri H, Idris M, Anuar N and Mukhlisin M (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. Int. J. Chem. Eng. 2011: pp31.

67. Vidali M (2001). "Bioremediation: An overview." Pure and Applied Chemistry, 73: 1163-1172.

68. Vroblesky DA, Nietch CT and Morris JT (1999). Chlorinated ethanes from ground water in tree trunks. Environmental Science and Technology, 33: 510– 515..

69. Wu Q, Wang S, Thangavel P, Li Q, Zheng H, Bai J and Qiu R (2011). Phytostabilization potential of *Jatropha curcas* L. in polymetallic acid mine tailings. Int. J. Phytorem. 13: 788–804.

70. Wu QT, Xu Z, Meng Q, Gerard E and Morel JL (2004). 'Characterization of cadmium desorption in soils and its relationship to plant uptake and cadmium leaching'. Plant Soil. 258(1): 217-226.

71. Yang SX, Deng H and Li MS (2008). Manganese uptake and accumulation in a woody hyperaccumulator, *Schima superba*. Plant Soil Environ. 54:441–446.

72. Zhang X, Xia H, Li Z, Zhuang P and Gao B (2011). Identification of a new potential Cd-hyperaccumulator *Solanum photeinocarpum* by soil seed bank-metal concentration gradient method. J. Hazard. Mater. 189:414–419.

73. Zhao FJ, Dunham SJ and McGrath SP (2002). Arsenic hyper-accumulation by different fern species. New Phytol. 156: 27–31.