A Review: Phytoremediation A Green Tool to Embrace Suitability & Sustainability

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Abstract— The growth in the economic development of all the sectors have put an immense pressure on natural resources and have caused great turmoil to the soil cover which is under great stress due to surplus addition of heavy metals or toxic compounds via various sources of natural as well as anthropogenic origin. It is the need of time to find a sustainable solution to remediate the soil and to regain its fertility. Amongst many proposed technologies phytoremediation proves to be quintessence for a sustainable solution. Hence, various aspects of phytoremediation and its significance in truncating the problem are discussed here.

Key words: Phytoremediation, Heavy Metals, Hyperaccumulator, Phytomining

I. Introduction

Soil contamination is a global phenomenon and has its roots entangled in the rapidly growing activities to strengthen the economy and to prosper in the race of power (Ana et al., 2009). This technologically driven era has left humans skeptical about the outcome of their interventions to the nature and its facets. The excessive use of resources and the mismanagement of the end-products have inundated the matrix of soil with pollutants of organic and inorganic origins. The most pernicious ones are those that cannot be degraded or tend to be persistent in the environment (Garbisu & Alkorta, 2001). Heavy metals being very staunch in their characteristics are inorganic, non-biodegradable and persistent which tend to accumulate easily into the biological systems via food webs (Hann and Lubbers, 1983). The different types of heavy metals of great concern to the environment are Lead (Pb), Cadmium (Cd), Mercury (Hg), Zinc (Zn), Copper (Cu), Nickel (Ni), Aluminum (Al), Cobalt (Co), Chromium (Cr) etc. Though these metals are essential to the living organisms in minute fractions for the enzymatic and metabolic activities but their excessive intake can cause irreversible damage to the biological systems. These heavy metals often make it to the water bodies, soil surfaces and to the atmosphere through many point and non-point sources such as the effluent discharge points and the chimneys of factories and industries, from the vehicular exhausts, agricultural practices, incineration waste, sludge dumping and most importantly the mining activities (Alloway, 1990). Hence, the most noxious effects of heavy metals on the living beings are accompanied by soil contamination. Soil contaminated with heavy metals not only has the potential to leach out and pollute ground water but can also make its way to the tissues of several biota via several interwoven food web. The biomagnification of the heavy metals in the tissue of the human bodies has carcinogenic and teratogenic effects (Knasmuller et al., 1998); therefore, with the progressing temporal scale, it is necessary to ease this problem with a technology which is fathomable and economically viable. Phytotechnology being one such approach is compliant with the present scenario of dealing with the aftermath of industrialization and urbanization (Pilon-Smits, 2005). It encourages the efficient use of the immobile plants to extract, accumulate, sequester, transform and store heavy metals in its above and ground parts, which can be easily dealt with, once the purpose of remediation is served (Chaney et al., 1997). This technology causes minuscule changes to the soil surface being remediated, contrary to the conventional chemical and physical methods such as soil excavation, soil washing, vitrification, incineration, disposal which agitates the soil and renders it infertile and unproductive (McGrath et al., 1995). Since past few years many species have been investigated for their phytoremediation potentials. Few of them which are capable of storing heavy metals in large concentrations without causing any adverse effect to the plants are termed as hyperaccumulator species. The bioavailability of heavy metals also plays a very vital role in determining the rate of heavy metal uptake by these plants. The advantage of using phytoremediation technique to restore heavy metal contaminated sites for developing countries is that it induces less economic pressure on country for waste treatment and disposal. Moreover it gives an additional benefit of using the heavy metal containing by products left after phytoremediation for bioenergy production which again is categorized as a renewable form of energy.

II. Pollution: A Menace for Soil and Plants

A crust not more than few kilometres capable of sustaining innumerable ecosystems has been inundated with various forms of pollutants. Soil matrix being an interface between both the underground and the aboveground atmosphere can cause greater risk to the biosphere if altered from its fertile state. The denser and soluble pollutants can leach out and cause trouble for underground resources whereas the ones which can be volatilized can cause adverse effect to the respiring organisms. Natural as well as man-made sources, both contribute to the surplus addition of these pollutants to the soil (Marchiol et al., 2004). Majority of pollutants can be broken down and made innocuous but few of them rule over by staying intact and persistent in the environment (Garbisu & Alkorta, 2001). Escalating use of heavy metal bearing substances since past few decades has successfully enhanced the problem causing irreversible damage to the soil and its fertility (Ghosh et al., 2005). These recalcitrant pollutants have been a matter of concern since the time of rapid industrialization and have recently been receiving more attention due to adverse effects on humans. Various accidental evidences have claimed them to be lethal at unguarded levels. The most rigid characteristic of heavy metals is that they cannot be degraded completely but can be transformed from one oxidation state to the other (Abollino et al., 2002). Despite of them being recalcitrant, this very nature is used to accumulate them in the plants capable of up-taking them upto certain concentrations (Yasar, et al., 2010). Heavy metals have made their ways to several doorsteps because of their unavoidable incorporation into several frequently used resources (Blaylock and Huang, 2000). The majority of heavy metals adheres to the soil particles and enters the plants via negative geotropism, through the aqueous solution taken up by plants which in turn enters the food chain making its way through several herbivores and finally ending in the tissues of carnivores. Sometimes, the accumulation of excess heavy metals in plants sensitive to them can cause negative physico-chemical response which induces apparent as well as intrinsic deformations due to obstruction in their metabolic pathways. Apparent morphological changes in plant body, deformed organs with symptoms like, chlorosis and necrosis are signs of adverse effect. Whereas intrinsic changes can be understood by analyzing metabolites such as chlorophyll content, carotene, protein, carbohydrates and amino-acids (Moosavi et al., 2013).

III. PLANTS: A TOOL FOR HEAVY METAL REMEDIATION

Plants have an indisputable role in sustaining the life on this planet as the sole life bearers of millions of aerobic organisms. They also contribute in maintaining the biodiversity. These life forms ranging from few millimeters to several meters have a distinctive characteristic of up-taking the pollutants from the substratum and turning it to innocuous or less harmful forms. Such a mechanism when exploited keeping in mind several prospects, turns out to be beneficial for remediation (ITRC 2009). Several studies carried out to check this salient feature of plants have rendered a positive outcome. This initiative gained significance as many species including creepers, herbs, shrubs, trees and many weedy species were found capable of accumulating high concentrations of heavy metals in their roots, stems and leaves based on their storage and heavy metal degrading potential. After observing the mechanism of plants at depth, many attempts were made to hasten the uptake of heavy metals by adding chelating agents to contaminated soil. These chelates at a pH < 6.5 intensify the solubility of heavy metals in the soil and make complexes which can easily be transported to different parts of the plant body (Flores-Magdaleno et al., 2011). Thus, pH also plays a significant role in cleaning up the soils efficiently and speedily (Gruca-Królikowska & Wacławek., 2006). Since the advent of this technique, nearly 400 plant species are noted to be efficient hyperaccumulators of heavy metals. Most of which are angiosperms, but they too face many drawbacks like slow growth, less biomass, climatic dependence etc. (Lone et al., 2008). The application of phytoremediation in the future emphasize on scrutinizing the plant species based on these limitations. Recent advancements also dwell into the path of molecular biology and genetics which have produced hybrid varieties of plants. These hybrids are formed after keeping in mind several favorable factors such as high biomass production (Kramer, 2005).

IV. MECHANISMS OF PHYTOREMEDIATION

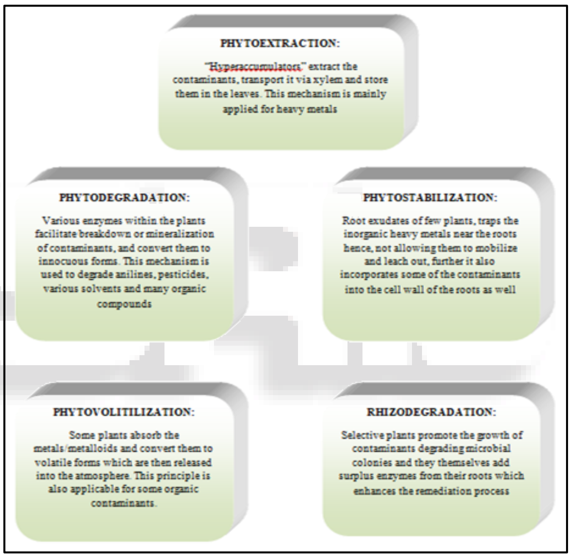

Fig. 1: Mechanisms of Phytoremediation

V. ADVERSE EFFECTS OF HEAVY METALS ON HUMAN BEINGS

The maximum permissible limits as per the World Health Organization (WHO) and Food and Agricultural Organization (FAO) are as under:

Heavy metals	Regulatory limits for soil (µg/g)	Sources	Effects on human health
Lead	100	Vermilion, storage batteries, solders, paints, hair dyes, electric cable insulations, pottery, ceramics and petrol	Burning abdominal pain, peripheral circulatory collapse, and insomnia, cerebellar ataxia in children, paraesthesias, haemolysis, depression, coma and death.
Cadmium	3	Welding, metal-plating, battery and plastic industry	Dyspnea, pleuritic chest pain, emphysema, fractures with osteomalacia, renal faliure, tachycardia, oliguria, noncardiogenic pulmonary edema and fever
Nickel	50	Food processing industries, metallury, catalyst, pigments, tobacco, cigarettes, PVC pipes	skin allergies, lung fibrosis,cancer of the respiratory tract, aminoaciduria and proteinuria, contact dermatitis or asthma
Copper	100	Algicide, molluscicide, fungicide, mordant in electroplating, an agent for	Ptyalism, oliguria, hematuria, hemoglobinuria, albuminuria, uremia, paralysis of limbs, hypotention,

		leather tanning and hide preservation	circulatory collapse, drowsiness, irreversible coma and death
Zinc	300	Used to clean metals before soldering, rodenticide and in cosmetics (baby powder)	Dyspnea, Pulmonary edema, bradycardia, hypocalcemia, metabolic acidosis, convulsions, ulceration of mucous membrane of mouth, esophagus and stomach wall
Arsenic	20	Fruit sprays, sheep-dips, weed-killlers, insecticides, rat poisons, fly papers, calico-printing, taxidermy, wall papers, artificial flowers,as mordent in dyeing and for preserving timber	Hypotention, circulatory collapse, ventricular tachycardia, fibrillation,vertigo, hyperthrmia, tremoes, convulsions, oliguria, uremia, albuminuria, general paralysis and skin eruptions
Chromium	100	Metallurgy, Dye and pigment, Wood preservative, Tanning, Refractory material, Catalysts	Contact dermatitis and irritant dermatitis, ulceration of the skin, sinusitis, nasal septum perforation, respiratory irritation, bronchitis, asthma, and lung cancer

Table 1: The maximum permissible limits as per the World Health Organization (WHO) and Food and Agricultural Organization (FAO)

VI. LIST OF FEW STUDIED PLANTS SPECIES FOR PHYTOREMEDIATION OF HEAVY METALS FROM CONTAMINATED SOILS IN INDIA

Scientific Name	Common Name	Heavy metals	References
Aloe barbadensis	Aloe vera	Cu, Zn, Cd & Pd	Rai, Swapnil, et al (2011)
Brassica juncea	Indian mustard	Zn, Cu Ni & Pd	Purakayastha, T. J., et al (2008)
Cynadon dactylon	Bermuda grass	Cd, Cu & Zn	Maiti, S. K., et al (2016)
Cassia tora	Sickle pod	Cu, Zn, Cr, Ni & Co	Shirbhate Nayana & Malode S. N. (2012)
Catharanthus roseus	Periwinkle	Pd & Cd	Pandey, S., K. Gupta, and A. K. Mukherjee (2007)
		Cd	Subhashini, V., A. V. V. S. Swamy, and Hema R. Krishna (2013)
Datura Inoxia	Datura	Cd and Cr	Gurijala et al (2013)
Eclipta alba	Bhringraj	Cd, Cr, Cu, Pb & Zn	Ashokkumar et al (2014)
Helianthus annus	Sunflower	Cd & Pd	Adesodun, Johnson Kayode, et al (2010)
Pisum sativum	Pea	Zn, Ni, Cu, Cr & Cd	Mallikarjuna et al (2015)
Raphanus sativus	Radish	Cr	Mallikarjuna et al (2015)
Sorghum		Cr	Revathi et al (2010)
Spinacia oleracea	Spinach	Cd	Shrivastava et al (2011).
Trigonellafoenum-graecum	Fenugreek	Pd & Ni	Kaur, L., Gadgil, K., & Sharma, S. (2015)
		Pd	Leela Kaur (2016)
Ipomoea Carnea		Cd & Hg	Kavitha, K. K., and M. Jegadeesan (2014)

Table 2: IST of Few Studied Plants Species for Phytoremediation of Heavy Metals from Contaminated Soils in India

VII. A FLOW CHART OF PHYTOREMEDIATION OF HEAVY METALS

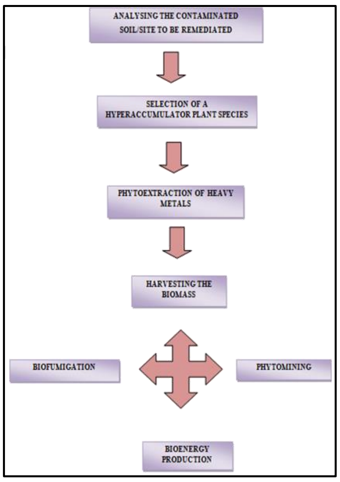

Fig. 2: A Flow Chart of Phytoremediation of Heavy Metals

VIII. FUNDAMENTALS OF PHYTOREMEDIATION:

A. *Screening of Plants*

1) *Characteristics of Plants*

- Plant species should be a potential hyperaccumulator
- It should produce high biomass (Nie et al., 2002)
- It should have high Bioconcentration Factor & Translocation Factor (McGrath & Zhao., 2003)
- It should be a fast growing (Marchiol et al., 2004)
- It should not produce allergic pollens
- It should be a non-invasive species
- It should be stress-tolerant as well as drought-tolerant
- It should be locally available
- It should be tolerant to climatic variations
- It should be capable of growing in nutrient-deficient soils

2) *Characteristics of contaminated soil*

- Soil should be capable of sustaining plant cover

- It should not be too porous to avoid heavy metal leaching into the ground water
- It should not be waterlogged
- pH of the soil to be treated should be slightly acidic
- It should have optimum level of micro and macro nutrients to support plant growth
- It should be capable of retaining moisture
- It should make the heavy metals bioavailable

3) Monitoring

- If in-situ approach is applied then a complete in depth analysis of the contaminated soil is to be carried out prior to selection of any plant species
- To monitor remediation, regular analysis of the plant and soil samples at site is to be carried out
- If the area is highly contaminated, human entry should be prohibited
- Hyperaccumulator species should be selected for metal specific contamination
- Growth promoting substances should be added if essential to enhance the process (Sharma and Reddy, 2004)

IX. Merits of Phytoremediation

- Sustainable way of restoring heavy metal contaminated sites
- Aesthetically pleasing
- Economically feasible
- Fathomable to a layman
- Sequestration and Recovery of heavy metals
- No requirement of trained technicians
- Stores and Stabilizes the contaminants and prevents it leaching into the groundwater
- The post harvest by products of phytoremediation can be used to produce Bioenergy
- Reduces the loss of the fertile topsoil i.e. prevents soil erosion
- Increases the carbon sinks
- Restores the ecological balance of the contaminated site
- Biofumigation
- Saves the cost of transport and hauling

X. Demerits of Phytoremediation

- Prolonged process when compared to the conventional methods
- Only selective plants works efficiently
- Remediates upto certain depth only
- Plants selected should be well adaptive to the localized climatic conditions
- If edible crops are selected for the purpose, it may make its way to the tissues of several living organisms
- Some weedy species may be noxious and invasive which is hard to eliminate once established
- Requires farming and agricultural knowledge
- The left over by products of phytoremediation are difficult to deal with once truncated
- Requires optimum moisture level in the soil
- May require addition of fertilizers and pesticides
- Some exudes are released by plant roots which increases the mobility of the heavy metals which can leach in the ground water
- The actual fate of the contaminants remains hazy with phytoremediation technique

XI. Conclusion

Present scenario with respect to soil contamination emphasizes on forming stringent policies regarding waste discharge, disposal and treatment facilities. At present restoring and maintaining the fertility of soil is the topmost priority, where phytoremediation is the solution to this never ending dilemma. Phytoremediation not only cleans up the contaminated sites but also helps in restoring the lost

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