Phytoremediation: A way towards sustainable Agriculture

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***Abstract*— *Phytoremediation means utilizing the potential of a variety of plants to remediate soil, sludge, sediment and water (surface water and underground aquifers) contaminated with heavy metals at the point or non-point sources. Phytoremediation is solar energy-driven technology, eco-friendly and a cost-effective way of making soil and water pollutants free. It is a process of onsite remediation by using different biological processes of plants. Phytoremediation is known widely by different terms viz., green-remediation, botanic-remediation, agro-remediation, and vegetative-remediation, etc. Pollutants occur in different forms, like organic, inorganic, metallic and non-metallic, etc. Plants can be utilized for phytoremediation of heavy metal polluted soil and water resources. This review gives current understanding of the mechanism of heavy metal remediation by different plant species, therefore encouraging research and development in this area. Phytoremediation further needs a profound understanding of the underlying mechanism and requires pilot level as well as field level studies.*

***Keywords*— Phytoremediation, Sustainable agriculture, Heavy metals, Eco-friendly.**

I. INTRODUCTION

Phytoremediation is a dynamic process that eventually degrades or extracts pollutants in different proportions as they are hazardous and toxic to all living beings. The pollutants are degraded either through accumulation, filtration or dissipation. In the current scenario, the need of the hour is realizing the consequences of heavy metal pollutants in soil and water (Kaur, 2018). Heavy metal pollutants, the half-life is much more than that of organic pollutants like pesticides and petroleum by-products. Uranium in groundwater aquifers of Rajasthan is a great concern to environmentalists as in some or other ways it is affecting the natural occurrence of biogeochemical cycles (Daud *et al.*, 2018). As different phases of the industrial revolution have passed, a variety of remediation technologies have also come into the market to deal with a variety of pollutants. Out of these contaminants, heavy metals like Uranium pose a great threat to the surrounding environment (Papazogloua and Fernandob, 2017). Due to mining and milling, radionuclide contaminants is prevalent in subsurface sediments throughout India. Due to the overexploitation of underground water resources, the water level has declined beyond environmentally acceptable and recoverable levels. Subsequently, heavy metals have found its way to the subsurface level thus entered into water and soil, contaminated them as a result of waste-disposal practices (Bora and Sarma, 2020).

Table 1: Different Plants showing Phytoremediation Potential

Metal	Plant	Mechanism	Medium	Reference
Zn, Cd	*Thlaspi caerulescens*	Phytoaccumulation	Soil/Water	Robinson *et al.*, 1998
Trinitrotoluene (TNT)	*Myriophyllum aquaticum*	Phytoextraction	Hydroponic	Bhadra *et al.*, 1999

Ethanol blended Gasoline	*Weeping willow*	Rhizofiltration	Water	Corseuil and Fabio, 2001
TNT, Pyrene, Aroclor 1248	*Festuca arundinacea Schreb.*	Phytoextraction	Soil	Chekol and Vough, 2002
Polycyclic Aromatic Hydrocarbons (PAHs)	*Clover and Ryegrass*	Phytoextraction	Soil	Joner and Leyval, 2003
Polycyclic Aromatic Hydrocarbons (PAHs)	*Meliotus officinalis*	Phytoaccumulation	Soil	Parrish *et al*., 2004
Zn, Cd, Cu	Agricultural Crops, Woody Plants	Phytoaccumulation	Soil	Kayser *et al*., 2004
Se	*Brassica juncea* L.	Phytoextraction	Soil	Banuelos *et al*., 2005
Herbicides	Transgenic *Oryza Sativa*	Phytoextraction	Soil	Kawahigashi*et al*., 2006
Hg	Chloroplast Tobacco Transgenic	Phytoaccumulation	Soil	Hussein *et al*., 2007
Hg	*Polypogon monospeliensis*	Phytoextraction	Soil	Su *et al*., 2008
Pb	*Scrophularia canina*	Phytoextraction Phytostabilization	Mining Site	Cao *et al*., 2009
Pb, Zn, Cd	*Common sunflower*	Phytoaccumulation	Soil	Mukhtar *et al*., 2010
Radionuclides	*Wolffia arrhiza*	Rhizofiltration	Water	Louis *et al*., 2010
Cr	*Switch grass*	Phytoextraction	Soil	Li *et al*., 2011
Ar	*Ludwigia octavalvis*	Phytoextraction	Soil	Totah *et al*., 2012
Heavy Metals	*Salsola soda*	Phytoextraction Phytostabilization	Soil	Lorestani *et al*., 2013
Cd, Ni,Cu	*Indian hemp*	Phytoaccumulation	Soil	Girdhar *et al*., 2014
Cu,Zn	*Phalaris arundinacea* L.	Phytoextraction	Water	Polechonska and Klink, 2014
Co, Cr	*Pennisetum purpureum*	Phytoaccumulation	Soil	Lotfy and Mostafa, 2014
Heavy Metals	*Annual wageweed*	Phytostabilization	Soil	Lum *et al*., 2014
Cd, Pb, Zn, Cu	*Paulownia*	Phytoaccumulation	Soil	Tzvetkova *et al*., 2015
Pb, Ni	*Brassica nigra*	Phytoextraction	Soil/Water	Singh *et al*., 2015
Ar	*Pteris vittata*	Phytoextraction	Soil/Water	Lampis *et al*., 2015
Ar	*Lupinus microcarpus*	Phytoaccumulation	Soil	Diaz *et al*., 2016
Cd	*Tradescantia pallida*	Phytostabilization	Soil/Water	Areekijseree *et al*., 2016
U	*Carex nebrascensis*	Phytoextraction	Water	Gaikwad and Gavande, 2017

Heavy Metals	*Cannabis Sativa*	Phytostabilization	Soil	Kumar *et al*., 2017
Landfill Leachate	*Lemna minor*	Phytoextraction	Soil/Water	Daud *et al*., 2018
Cu	*Bruguiera cylindrica* L.	Phytostabilization	Soil	Sruthi and Puthur, 2019
Heavy Metals	Native Herbaceous Macrophytes	Phytostabilization	Wetlands	Bora and Sarma, 2020

II. PHYTOREMEDIATION

The underlying methods encompassing phytoremediation are degradation, accumulation, dissipation, immobilization, etc. The different ways of phytoremediation are described individually in this review. The process of phytoremediation can be applied to a variety of potential pollutants, viz., petroleum hydrocarbons, organic contaminants, chlorinated compounds, heavy metals, radionuclides, agro-waste, pentachlorophenol (PCP), polycyclic aromatic hydrocarbons (PAHs), etc (Pivetz, 2001). The term hyper accumulator was coined and used for the first time by the late Professor, Robert Brooks (Brooks et al., 1980). Hyper accumulators as per Brooks and his co-workers are defined as plants that can accumulate different metalloids above the threshold concentration of 10,000 to 100 mg/kg (shoot dry weight) (Baker and Brooks, 1989; Brown *et al*., 1994). Moreover, a particular plant species will be called hyper accumulator, if it is able to accumulate more than 0.1 % of heavy metals of its dry weight (Kirkwood, 2002). However, the plant should show tolerance to heavy metals without having necrotic, chlorotic or any other cellular damage symptoms (Titah *et al*., 2012; Kumar and Chauhan, 2016).

If plants accumulate more than 51 % of heavy metal of its dry weight overnight than it is considered as a potential agent for phytoremediation. The hyper accumulators are mainly documented from particular plant families, *viz*., Brassicaceae, Cunouniaceae, Caryophyllaceae, Asteraceae, Euphorbiaceae, Cyperaceae, Fabaceae, Lamiaceae, Violaceae, Poaceae, etc (Padmavathiamma and Li, 2007). A plant with phytoremediation potential has to have specific qualities, viz., high growth rate, high biomass accumulation, elongated and adventitious root system, high bioaccumulation coefficient, fantastic metal-accumulating strength, etc. Till now, around 500 plant species have been documented as hyper accumulators and recommended for phytoremediation of polluted soil and water resources (Bhaskar and Rajanna, 2018). Additionally, diverse plant species (crops as well as woody plants along with transgenic lines) showing phytoremediation capabilities are enlisted in Table 1.

Factors affecting Uptake Mechanism

1. Plant Species 2. Properties of Medium 3. Root Zone

4. Vegetative Uptake 5. Addition of Chelating Agent

III. PHYTOEXTRACTION

The literal meaning of phytoextraction is, "Phyto" meaning plant and "Extraction" meaning removing (Henry and Fabio, 2001) (as shown in Fig.1). The process of phytoextraction involves translocating the pollutants from the rhizosphere to different plant parts, viz., shoot, leaf, stem, flower, etc. Few plant species have the potential to extract both essential (Cu, Mg, Mo, K, Fe, Mn, Ni, P, and Zn) as well as non-essential metals (Se, B, Cd, Co, Cr, Ag, and Hg). Essential metals are those required by plants in optimum amounts for their growth and development, whereas non-essential metals are toxic even in low amounts (Tang *et al*., 2019; Gupta *et al*., 2020).

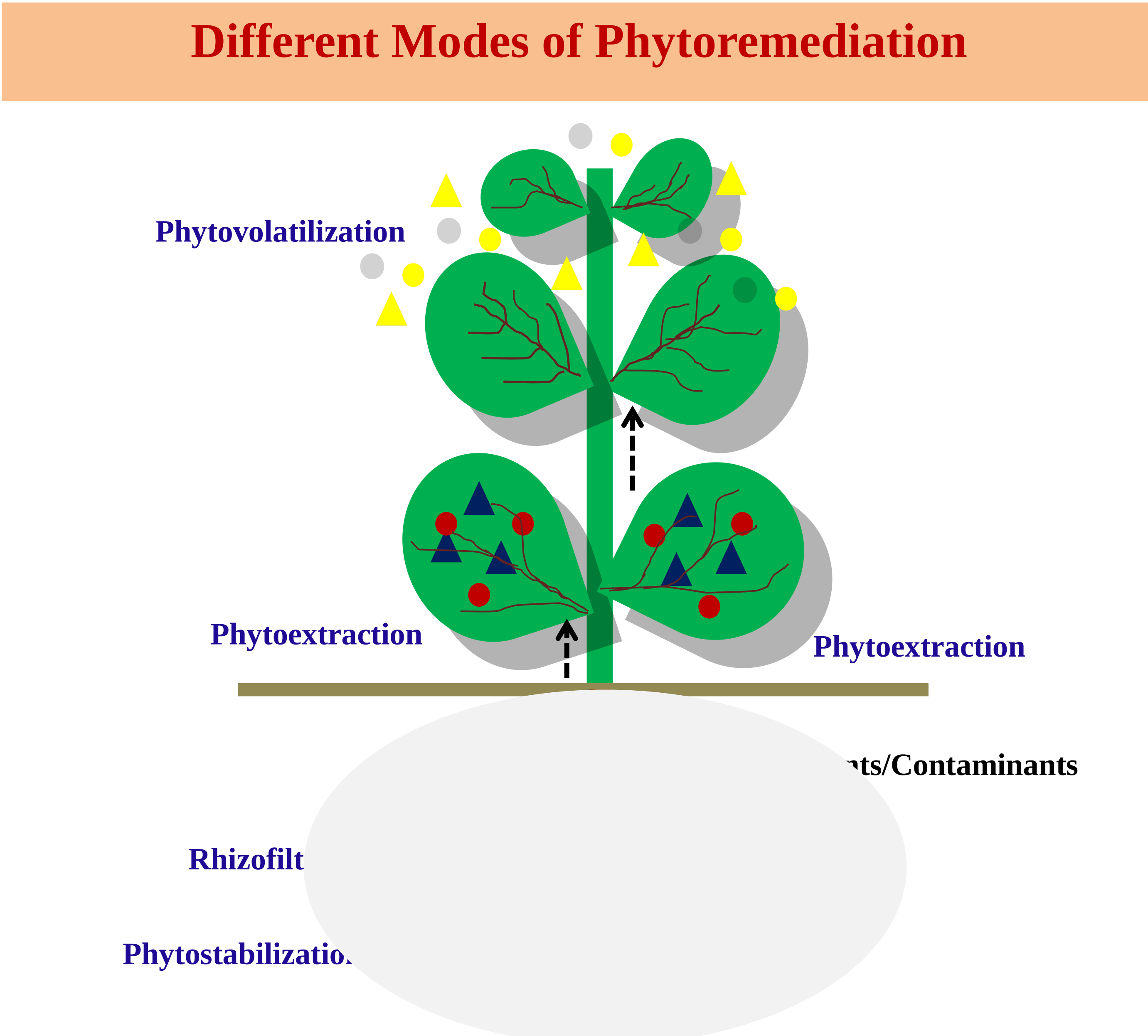

Fig.1: Different Modes of Phytoremediation

IV. RHIZOFILTRATION

The ability of plants to filtrate contaminated water aquifer, surface water, and wastewater with heavy metals, agri-waste (Pesticides and Insecticides) through a bunch of roots or adventitious root is known as Rhizofiltration (Akob *et al.*, 2007) (as shown in figure 1). Therefore, it is a modified phytoextraction method by using aquatic vegetation and adsorption of toxic elements primarily into the root zone (Beans, 2017). Initially, instead of soil, plants are grown in the hydroponic system and allowed to acclimatize in contaminated water under greenhouse conditions (Bibi *et al.*, 2016). Subsequently, plants are planted on the contaminated sites, where the adventitious roots will accumulate the toxins from the rhizosphere to roots and then transmission to the

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aerial parts (Cho and Choo, 2019). The factors affecting the rate of adsorption, concentrate, precipitate onto root surface are the concentration of hazardous elements and plants dry weight. A set of plants used for hemofiltration are sunflower, tobacco, spinach, rye and Indian mustard (Soliman and Sugiyama, 2016). The most widely used choice for hemofiltration is terrestrial plants as they possess fibrous roots and rapid growth rate. The process of hemofiltration can be applied to wetlands, ponds and constructed water tanks. The ultimate fate of rhizofiltered pollutants is rhizodegradation (degradation in roots) and then phytodegradation (degradation in aerial parts of the plant) (Gonzalez *et al.*, 2017).

V. PHYTOSTABILIZATION

It is the process in which plants store toxic metals at a particular site in a non-toxic metallic and immobile form, hence the metal is not able to mobilize to other organelles thus do not interfere with cellular metabolism (as shown in figure 1). Subsequently, the rate of migration of metals gets reduced (Oscar *et al.*, 2016). Therefore, the soil need not be free from contaminants and on-site phytoremediation can be done with potential plants whose roots are capable of growing under polluted soils and thus helps in metal immobilization through root adsorption, metal precipitation, complex formation or reduction (Barcel and Poschenrieder, 2003). Additionally, the metals are stabilized within plant cells from mobile and toxic to immobile form, for example, toxic Cr^{6+} gets transformed to Cr^{3+}, which is less mobile (James, 2001). The process of phytostabilization seems to be more efficient in the case of fine soils having high organic matter content (Berti and Cunningham, 2000).

VI. PHYTOVOLATIZATION

In this process, plants utilize transpiration to converts heavy metals from more toxic form to less toxic volatile form, thus eradicate pollutants from soil and water (as shown in figure 1). The metals that get volatized through transpiration are, Arsenic, Mercury (Hg, more toxic to Hg^{2+}, less toxic) and Selenium (Se, more toxic to (CH_3)2Se, 600 times less toxic), etc. Plant species that adopt the phytovolatilization process for removing contaminants are Arabidopsis thaliana and Musk grass.

VII. CONCLUSION

Phytoremediation of contaminated soil and water resources has proved to be a sustainable technology and emerged as one of the eco-friendly agriculture practices. Phytoremediation has a high potential when compared with other traditional and conventional approaches for heavy metal removal. A variety of plant species have shown high performance in hyper accumulation of heavy metals *viz.*, Cadmium, Copper, Mercury, Lead, Zinc, and Uranium, etc. Plants belonging to different families have different abilities to accumulate, detoxify and sequester a variety of heavy metals. However, the phytoremediation research studies are very few in number predominantly at field level. Hence, the need of the hour for phytoremediation research is on developing novel experimental design both at pilot as well as field level in polluted soil and water resources. Furthermore, the procedure for removal of heavy metals augmented biomass necessities to be additionally developed. Additionally, the current circumstances stresses on using the amalgamation and collaboration of traditional methods along with recent phytoremediation practices to deliver an advanced way of heavy metal remediation from both contaminated soil and water resources.

DISCLOSURE

The manuscript does not have any conflict of interest with any author, organization, institute, *etc*.

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