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PHYTOREMEDIATION: A WAY FORWARD TO ERADICATE CONTAMINANTS OF HEAVY METALS

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Environmental pollution and toxic heavy metal accumulation has increased exponentially over the last decade due to various natural and anthropogenic activities. Pollutants in the environment affect the lithosphere, hydrosphere, atmosphere and as a whole biosphere. Scientists all over the world over the years made significant contributions to eradicate sources of pollution and remedy the already contaminated areas. Since heavy metals are non-biodegradable, they persist in the environment and have the potential to enter the food chain ultimately leading to biomagnification that would put human lives at risk. Thus, remediation of contaminated soil and water takes precedence. Hence, Phytoremediation is a cost-effective and eco-friendly way to mitigate heavy metal contaminations. More than 300 plant species with potential for soil and water remediation have been noted so far. In this paper, a brief review of recent understanding and working progress in research as well as practical applications of phytoremediation for water and soil resources has been undertaken.

Keywords: Heavy metals, Environmental pollution, Phytoremediation, Phytoextraction, Phytostabilization, Phytovolatilization

Introduction

The rapid surge in population coupled with exponential industrial developments poses a serious threat to the environment. As a consequence of various industrial activities, like mining, pesticide application, and improper waste disposal into water and soil, humans have played a significant role in polluting our environment. These Pollutants further enter the ecosystem through the food chain and cause serious damage to plants, animals and humans causing neurological damage and cancer[1].

Heavy metals pose a particular threat to human lives due to their carcinogenic nature. Phytoremediation, the technique of using plant species for cleaning soil and water has gained massive popularity due to its eco-friendly nature and cost-effectiveness. As per the type of pollutant, soil physiology and the plant species used, there are five types of Phytoremediation: phytodegradation, phytofiltration, phytoextraction, phytostabilization and phytovolatilization.

Plants are categorized to be tolerant or hyper-accumulators to heavy metals, when they are capable of rapid growth and can extract and accumulate high amounts of heavy metals in their shoots, without any sign of toxicity when grown in contaminated soil[2].

In this review, efficient phytoremediation approaches, great potentiality of hyper-accumulator plants and some innovative new approaches have been described.

The most prominent heavy metals that are responsible for toxicity in the ecosystem include Lead (Pb), Mercury (Hg), Arsenic (As), Cadmium (Cd), Nickel (Ni), Aluminium (Al) and Chromium (Cr). These metals eventually enter the food chain causing diseases in animals and human beings. Even though some of the heavy metals like Iron (Fe), Copper (Cu), Selenium (Se) and Zinc (Zn) are tolerable in small amounts, their accumulation in higher concentrations in the environment may become quite toxic[3]. Details of the distribution of heavy metals across the globe are given in the Table 1.

Table 1: Distribution of heavy metals across the globe

Heavy metals	Tolerable limit	Average value in soils (ppm DW)	Name of the Country	References
Zn	300	3800	China	Niu *et al.*[4]
	300	1200	Germany	Shaheen *et al.*[5]
Cu	100	448	China	Wang *et al.*[6]
	100	19581	Australia	Sacristán*et al.*[7]
Pb	100	1988	China	Niu *et al.*[4]
	100	711	United Kingdom	Nabulo *et al.*[8]
Cd	3	14	China	Shi *et al.*[9]
	3	19	India	Tiwari *et al.*[10]
Cr	100	590	China	Xu *et al.*[11]
	100	224	Germany	Shaheen *et al.*[5]

Plants growing in polluted soils exhibit several strategies to cope with the toxicity of heavy metals including preventing their accumulation, detoxification or metal excretion from the tissues[12]. There are 2 prominent strategies that are taken up by plants to protect their organs from heavy metal toxicity. The first strategy is deployed by restricting the absorption of heavy metals by the process of precipitation. On the other hand, when it comes to the second strategy, the heavy metals are sequestered within the cell inside vacuoles[13].

Five major and three other phytoremediation mechanisms are as follows

1. Phytoextraction

Phytoextraction leads to the accumulation of contaminants from the soil and water by plants and translocate or concentrate them in above-ground plant parts. This mechanism can be further subdivided into two parts -

A. Continuous phytoextraction, which uses endemic plant species that are hyperaccumulators with the natural capability to accumulate heavy metals

B. Induced phytoextraction, which boosts or intensifies heavy metal accumulation with the help of chelating agents. According to Begonia (2002) plant species *Sesbania exaltata* has been accomplished to remove lead (Pb) from the contaminated soils[55]. *Amaranthus retroflexus* has the tendency to accumulate Copper (Cu) and Molybdenum (Mo) in the shoot while *Melilotus officinalis* prefers storing Zinc (Zn) in its roots rather than shoots[14]. The capacity of phytoextraction differs from species to species. For instance, as per the experimental results of Khalid (2020) on *Alternanthera bettzickiana*, it accumulates twice the amount of copper (Cu) in its shoots compared to the control[37].

2. Phytodegradation

Phytodegradation is the process of degradation of pollutants accumulated by plants through various metabolic processes. It can also refer to the degradation of pollutants outside the plant body by several enzymes that are produced by roots like nitroreductases and peroxidases[15]. *Liriodendron tulipifera* can grow in tissue culture with high amounts of mercury toxicity and further convert the highly toxic form to less toxic non-hazardous form[16]. As per the experimentations carried out by Das P (2010) plant species *Vetiveria zizanioides* were effective in cleaning up 97% TNT (2,4,6-trinitrotoluene) from the soil[56].

3. Phytovolatilization

Phytovolatilization encompasses the strategy of taking up or accumulating pollutants and converting them to less harmful volatile forms. Under this process, pollutants are accumulated by roots then transported to the shoots and finally volatilized through stomata into the atmosphere. Bizily (1999) demonstrated that *Arabidopsis thaliana* transformed organic mercury (Hg) salts to volatile elemental form[57]. Transgenic *Nicotiana tabacum* that carries the merA gene has made great strides in eliminating mercury (Hg) from contaminated soils[17]. Moreover, *Brassica juncea* grown under hydroponic environments has reportedly been able to eliminate 95% of mercury (Hg) from contaminated soil[18].

4. Rhizofiltration

Rhizofiltration is the process of removing contaminants from water and soil using plant roots. As per reports from Yang (2015) *Phaseolus vulgaris* quite efficiently removed radioactive elements Uranium (Ur) and Cesium (Cs) from the soil[58]. Several plant species including *Eichhornia crassipes*, *Salvinia molesta* and *Pistia stratiotes* were effective in removing certain heavy metals including chromium, zinc, copper, cadmium and nickel from industrial sewage[19].

5. Phytostabilization

Phytostabilization mostly refers to the phenomenon of reducing or limiting the movement of heavy metals in soil. *Atriplex halimus* showed promising results in the phytostabilization of cadmium (Cd)[1]. Plant species *Erica australis* contains the ability to uptake copper, cadmium and lead via its roots without causing any significant damage[20]. Moreover, in the case of *Helichrysum microphyllum* large amounts of zinc, cadmium and lead were accumulated in roots[21].

Apart from these five processes, recent strides have been made using genetic variations and using certain microbes for phytoremediation. These are as follows,

A. Biotechnological procedures :
   In recent decades, plants have been genetically modified using the genes of hyper-accumulator plant species and various microbial genes that show heavy metal tolerance in them. The transgenic approach has caught the attention of researchers worldwide. This strategy encompasses the introduction of genes to improve tolerance and hyper-accumulation of toxic and hazardous heavy metals into large plants without causing any hindrance to the growth rate of that particular plant species[22].

B. Earthworm assisted Phytoremediation :
   Earthworms play a vital role in organic matter decomposition, hence, known as “Farmer’s Friend”. Earthworms play a major role in decreasing the pH of soil which enhances the nutrient content and heavy metal availability in soil by secretion of certain acids like humic acid and fulvic acid[23]. According to the experimentations of Wang (2020) incorporation of earthworms in a culture medium enhances the phytoremediation potential of Cadmium (Cd) in the plant species *Solanum nigrum*[59].

C. PGR aided Phytoremediation :
   PGR (Plant Growth Regulators) aids in phytoremediation by improving the heavy metal accumulation in plant tissues. The addition of some phytohormones increases the efficacy of plant species for phytoremediation. For instance, by adding 0.05M of Auxin increases the tolerance level of Arabidopsis thaliana against Cadmium (Cd)[24]. Furthermore, gradually increasing

the concentration of Gibberellic acid 3(GA-3) enhances the phytoremediation efficiency of Solanum nigrum[25].Details of phytoremediation strategies adopted by plant species are presented in the Table 2.

Table 2: Phytoremediation strategies

Heavy metals	Species	Type of Phytoremediation	References
As	*Salvinia molesta*	Rhizofiltration	Da Silva *et al.*[26]
As	*Arundo donax*	Phytovolatilization	Guarino *et al.*[27]
Cd	*Atriplex nummularia*	Phytoextraction	Nedjimi B.[28]
Cd	*Atriplex lentiformis*	Phytoextraction	Eissa M.A.[29]
Cd	*Sesuviumportulacastrum*	Phytoextraction	Ghnaya *et al.*[30]
Cd	*Sedum alfredii*	Phytoextraction	Zhou and Qiu[31]
Cd	*Quercus robur*	Phytoextraction	Sozoniuk*et al.*[32]
Cd	*Acanthus ilicifolius*	Phytostabilization	Shackira and Puthur[33]
Cd	*Atriplex halimus*	Phytostabilization	Nedjimi and Daoud[1]
Cd/Cu	*Salix alba*	Phytoextraction	Matarugа*et al.*[34]
Cd/Zn	*Pennisetum purpureum*	Phytoextraction	Yang *et al.*[35]
Cr	*Genipa americana*	Rhizofiltration	Santana *et al.*[36]
Cr/Zn	*Salvinia molesta*	Rhizofiltration	Kodituwakku and Yatawara[18]
Cu	*Alternanthera bettzickiana*	Phytoextraction	Khalid *et al.*[37]
Cu	*Boehmeria nivea*	Phytoextraction	Rehman *et al.*[38]
Cu	*Sedum alfredii*	Phytoextraction	Liu *et al.*[39]
Hg	*Brassica juncea*	Phytovolatilization	Moreno *et al.*[40]
MCP	*Liriope muscari*	Phytodegradation	Dash and Osborne[41]
Ni	*Sesuviumportulacastrum*	Phytoextraction	Fourati *et al.*[42]
Ni/Zn	*Cannabis sativa*	Phytoextraction	Meers *et al.*[43]
PAHs	*Rhizophora mangle*	Phytodegradation	Sampaio *et al.*[44]
Pb	*Tamarixsmyrnensis*	Phytoextraction	Kadukova*et al.*[45]
Pb	*Pelargonium hortorum*	Phytoextraction	Manzoor *et al.*[46]
Pb	*Brassica juncea*	Phytostabilization	Meyers *et al.*[47]
Se	*Stanleya pinnata*	Phytovolatilization	Parker *et al.*[48]
TCE	*Salix viminalis*	Phytodegradation	Clausen *et al.*[49]
TNT	*Myriophyllum spicatum*	Phytodegradation	Hughes *et al.*[50]
U	*Phragmites australis*	Rhizofiltration	Wang Q *et al.*[51]
Zn	*Halimioneportulacoides*	Phytoextraction	Cambrollé*et al.*[52]
Zn/Pb	*Armeria arenaria*	Phytoextraction	Frérot*et al.*[53]
Zn/Pb	*Pistacia lentiscus*	Phytostabilization	Concas*et al.*[54]

Conclusion

Heavy metal pollution is a major issue and a vital concern worldwide. To prevent heavy metal contamination, several ways have been deployed. Amongst them, Phytoremediation is the most efficient, environment friendly and cost-effective way out compared to other chemical methods of heavy metal decontamination. This procedure includes a series of steps including heavy metal uptake (phytoextraction), breakdown and transformation of heavy metals into non-toxic forms (phytodegradation), emitting non-hazardous volatile form in the atmosphere (phytovolatilization) and their stabilization in the root system (phytostabilization). Extensive research to enhance the phytoremediation capability of plants by transgenic approach, genetic engineering, and phytoremediation using microbes and phytohormones have been deployed. Further, more extensive research on transgenic plants and the determination of new genes will pave the way and ultimately unlock new directions.

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