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Research Article

Phytoremediation: A Sustainable Alternative for Environmental Challenges

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Abstract: *A brief outline of the development of Phytoremediation (use of plant for treating environmental problems) technologies and processes are presented. The major features and limitations are discussed. An overview of the current state of field applications of technology is sketched:*

Keywords: Phytoremediation, hyper accumulator, heavy metal, Phytomining.

INTRODUCTION

Survival and sustainability of life on this planet largely depends on the quality of encompassing environment around the globe. For ages, it was believed that earth has vast storehouse of Natural resources such as soil, water and air. However, today due to unscrupulous use of Natural resources, world's resources are depleting, because rate of consumption is more than their natural rate of replacement.

The problems associated with contaminated land sites and polluted water is causing havoc worldwide in many countries. Past Industrial activities have resulted in the formation of contaminated land sites and polluted water resources. Due to low education and awareness of health and environmental consequences of production, use and disposal of hazardous substances [1]. It is widely known that the contaminated sites is potential threat to humanity and environment. This has led to environmental efforts to remedy these sites and redevelop for use.

The conventional techniques used for remediation is soil excavation or capping of contaminated site or pumping polluted ground water. These traditional techniques are risky and expensive. A better approach than these traditional methods is to completely destroy the pollutants if possible or transform them into less harmful substances. Some technologies that have been used are high – temperature incineration and various types of chemical decomposition (e.g., base catalyzed dechlorination. UV Oxidation). These technologies have several drawbacks, high cost, and complexity of their nature and lack of public acceptances [2].

Phytoremediation: A new and emerging technology – describes the treatment of environmental and human health problems through the use of plants that mitigate the environmental problems without the need to excavate the contaminated material and dispose of it elsewhere.

It consist of reduction or removal of pollutant concentrations in contaminated soil, water or air with plants able to contain, degrade or eliminate metal, pesticides, solvents, explosives, crude oil and its derivatives. It is very simple cost effective and green technology [3].

VARIOUS PHYTOREMEDIATION TECHNIQUES

Plants may break down or degrade organic pollutants or remove and stabilize metal contaminants. The basic principle on which this technology works is transport and tolerance. There are five main types of Phytoremediation techniques. Classification is based on types of contaminants[4,5].

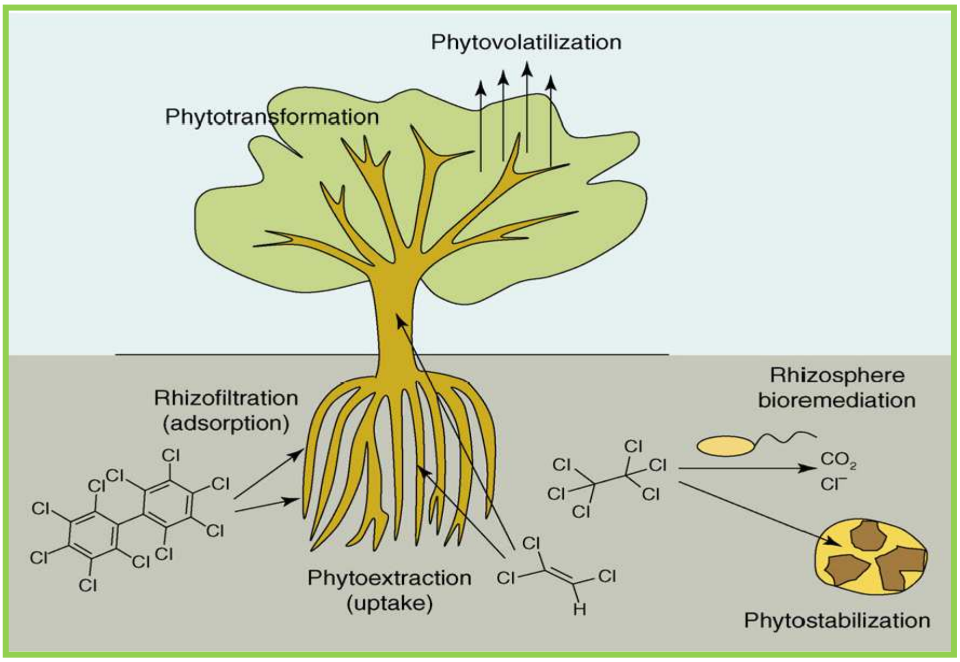

Fig. 1: Different types of Phytoremediation

(1) Phytoremediation of metal contaminated sites

(a) Phytoextraction (Phytoaccumulation): Phytoextraction is the name given to the process where plant roots uptake metal contaminants from the soil and translocate them to their above soil issue. As different plant have different abilities to uptake and withstand high level of pollutants many different plant have been used. This is of particular importance for such sites which have been polluted by more than one type of contaminant. Hyper accumulator plants (plant species that absorb higher amount of pollutants than other plant spices) are used on these sites due to their tolerance of relatively extreme level of pollutants once the plants have grown and absorb the metal pollutants. It is harvested and disposed safely. This process is repeated through several crops to achieve significant cleanup.

Some example of Phytoextraction

(i) Cadmium, using Willow (Salix viminalis): Willow (Salix viminlais) has a significant potential as a phytoextractor of Cadmium (Cd), Zinc (Zn), and Copper (Cu), as willow has some specific characteristics like high transport capacity of heavy metals from root to shoot and huge amount of biomass production; can be used also for production of bio energy in the biomass energy power plant [4].

(ii) Cadmium and zinc, using Alpine pennycress (Thlaspi caerulescence), a hyper accumulator [6].

(iii) Cadmium and zinc, using Alpine pennycress (Thlaspi caerulescens), a hyper accumulator of these metals at levels that would be toxic to many plants. On the other hand, the presence of copper seems to impair its growth [7].

(iv) Salt-tolerant (moderately halophytic) barley and/or sugar beets are commonly used for the extraction of Sodium chloride (common salt) to reclaim fields that were previously flooded by sea water.

(v) Caesium-137 and strontium-90 were removed from a pond using sunflower after the Chernobyl accident [8].

(vi) Mercury, selenium and organic pollutants such as polychlorinated biphenyls (PCBs) have been removed from soils by transgenic plants containing genes for bacterial enzymes [9].

(vii) Copper using Brassica juncea and Triticum aestivum[10].

(viii) Lead, using Indian Mustard (Brassica juncea), Ragweed (Ambrosia artemisifolia), Hemp Dogban (Apocynum cannabinum), or Poplar trees, which sequester lead in their biomass[12].

(ix) Arsenic, using sunflower (Helianthus annus) or the Chinese Brake fern (Pteris Vitata), a hyperaccumulator[15,16].

TABLE 1. Hyberaccumulators and Common Plants Employed in Phytoremediation Research

hyperaccumulators	metal	plants	contaminants and media
Thlaspi caerulescens	zinc (Zn), cadmium (Cd)	indian mustard	heavy metals, selenium and radionuclides in soil
Berkheya coddii	nickel (Ni)	poplar	chlorinated solvents and nitrates in groundwater, heavy metals in soil
Astragalus racemosus	selenium (Se)	cotton wood	chlorinated solvents in groundwater, metals, nitrates
Pteris vittata	arsenic (As)	duck weed	explosive waste in groundwater
Ipomoea alpina	copper (Cu)	mulberry	PAHs in soil
Haumaniastrum robertii	cobalt (Co)	sunflower	radionuclides in groundwater
Iberis intermedia	thallium (Tl)	grasses	heavy metals and petroleum in soil
Gysophila spaerocephala	boron (B)	alfalfa, juniper	petroleum hydrocarbons in soil and groundwater

(b) Rhizofiltration: Rhizofiltration is similar concept to phytoextraction but is concerned with the remediation of contaminated ground water rather than the remediation of polluted soils. The contaminants are either adsorbed on the root surface or are absorbed by plant roots. Plants are grown in clean water, than substituted by polluted water for acclimatization, then it is transferred to polluted site where the roots uptake the polluted water and contaminants along with it. When the roots become saturated they are harvested and disposed of safely. Repeated treatment is required to reduce pollution level of the sites [4].

Some Example of Rhizofiltration

1. Radioactive pollutants are taken out from polluted pool of water in Chernobyl by sunflower [8].
2. Cr, Cu, Mn – using sunflower from ground water at[15,16].

(c) Phytostabilization: This technique is the use of certain plants to immobilize soil and water contaminants. Contaminants are absorbed and accumulated by roots, or adsorbed onto the roots precipitated in the rhizospere. This reduces or even prevents the mobility of contaminants, preventing their migration into ground water or air and reduces their chance of entering into food chain [5].

(2) Phytoremediation of organic polluted sites

(a) Phytodegradation or rhizodegradation : This technique is the breakdown of contaminants through the activity existing in rhizosphere. This activity is due to the presence of proteins and enzymes produced by the plants or soil organism such as bacteria yeast and fungi. Rhizodegradation is a symbiotic relationship that has evolved between plants and microbes. Plants provide nutrients necessary for the microbes to thrive, while microbes provide a healthier soil environment [4, 5]. Plant enzymes have been identified that break down ammunition wastes, chlorinated solvents such as TCE (Trichloraethane) and others which degrade organic herbicides.

Some examples are where Rhizodigandation is used [15, 16].

1. Petroleum & hydrocarbons, using, Juniper, fescue in ground water.
2. Explosive waste, using duck weed, Parrot feather in ground water.
3. Nitrates wastes using hybrid popular in ground water.

Table: overview of phytoremediation applications

Technique	**Plant mechanism**	**Surface medium**
Phytoextraction	Uptake and concentration of metal via direct uptake into the plant tissue with subsequent removal of the plants	Soils
Phytotransformation	Plant uptake and degradation of organic compounds	Surface water, groundwater
Phytostabilization	Root exudates cause metal to precipitate and become less available	Soils, groundwater, mine tailing
Phytodegradation	Enhances microbial degradation in rhizosphere	Soils, groundwater within rhizosphere
Rhizofiltration	Uptake of metals into plant roots	Surface water and water pumped
Phytovolatilization	Plants evaportranspirate selenium, mercury, and volatile hydrocarbons	Soils and groundwater
Vegetative cap	Rainwater is evaportranpirated by plants to prevent leaching contaminants from disposal sites	Soils

(b) Phytovolatilization: This is process where plants uptake contaminants, which are water soluble and release them into the atmosphere as they transpire water. There are varying degree of success with plants as phytovolatilizes with one study suggest poplar trees can volatilize up to 90% of TCE which they absorb[20,23].

- **Advantages of Phytoremediation**
    - (i) It is more economically viable using the same tools and supplies as agriculture.
    - (ii) It is less disruptive to the environment and does not involve waiting for new plant communities to recolonise the site
    - (iii) Disposal sites are not needed
    - (iv) It is more likely to be accepted by the public as it is more aesthetically pleasing then traditional methods
    - (v) It avoids excavation and transport of polluted media thus reducing the risk of spreading the contamination
- **Disadvantages of Phytoremediation**
    - (i) It is dependent on the growing conditions required by the plant (ie climate, geology, altitude, temperature)
    - (ii) Large scale operations require access to agricultural equipment and knowledge
    - (iii) Success is dependent on the tolerance of the plant to the pollutant
    - (iv) Contaminants collected in senescing tissues may be released back into the environment in autumn
    - (v) Time taken to remediate sites far exceeds that of other technologies

MECHANISM OF CLEANING PROCESS

Hyper accumulators like Thlaspi are a marvellous model system for elucidating the fundamental mechanism of transport and ultimately the genes that control the metal transport. There are numbers of sites in the plant that could be controlled by different genes contributing to the hyper accumulation trait.

These genes govern processes that can increase the solubility of metals in the soil surrounding the roots as well as the transport problems that move metals into root cells. From there the metal enters the plants vascular system for further transport to other parts of the plants and is ultimately deposited in leaf cells. A typical plant may accumulates about 100 parts per million (ppm) zinc and 1 ppm Cd. Thalspi can accumulate up to 30,000 ppm zinc and 1500 ppm Cd in its shoots, while exhibiting few or no toxically symptoms. A normal plant can be poisoned with as well as 1000 ppm of Zn or 20 to 50 ppm of Cadmium in shoots [7, 22].

(1) Soil contaminated with uranium, it was found that adding the organic acid citrate to soil greatly increases both that solubility of uranium and its bioavailability for plant uptake and translocation, citrate does it by binding to insoluble uranium in the soil.

(2) A pigweed called Amaranths retroflex us, was up to 40 times more effective than other listed in removing radio cesium from soil.

(3) Aluminium toxically limits crop production on acid soils however some plant species e.g., what, corn and sorghum can tolerant high levels of the metal in acid soils by excluding the metal from root tip. Root tip is the key sites of injury, leading to inhabited root growth, a stunted root system and reduced crop field [7, 12].

The Role of genetics: Breeding programs and genetic engineering are powerful methods for enhancing natural Phytoremediation capabilities, or for introducing new capabilities into plants. Genes for Phytoremediation may originate from a micro-organism or may be transferred from one plant to another variety better adapted to the environmental conditions at the cleanup site. For example, genes encoding a nitroreductase from a bacterium were inserted into tobacco and showed faster removal of TNT and enhanced resistance to the toxic effects of TNT [19]. Researchers have also discovered a mechanism in plants that allows them to grow even when the pollution concentration in the soil is lethal for non-treated plants. Some natural, biodegradable compounds, such as exogenous polyamines, allow the plants to tolerate concentrations of pollutants 500 times higher than untreated plants, and to absorb more pollutants [23].

(i) Cloning of zinc transport genes in Thlaspi enabled the researchers to discover that zinc transport is regulated differently in normal and hyperacumulator plants. In normal plants, the activity of zinc transporter genes is regulated by the zinc levels in plants, in Thlaspi these genes activity is independent of plant zinc levels [7i23].

Phyto-mining: It is the use of plants to mine valuable heavy-metals minerals from contaminated or mineralized soils. The crops of these plants will be grown and harvested and then burnt and ash can be sold. e.g. Ashes of alpine pennycress grown on a high – zinc soil in Pennsylvania yielded 30 to 40 percent zinc, which is as high grade ore [7, 23].

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