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Phytoremediation: A feasible remedy for contaminated soils

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Abstract: With ecosystem contamination through both anthropogenic and natural means, utilisation of plants in removing either the polluted soil or water and sequester hazardous substances from the environment; Phytoremediation acts as a remedy and has emerged as cost effective, non-invasive, and publicly acceptable way to address the removal of environmental contaminants in the modern era.

Key Words: *Environment, phytoremediation, soil.*

1. INTRODUCTION:

Surface water, groundwater and top soil gets highly contaminated with hazardous contaminants due to the consequence of natural calamities be it, such kind of contaminants include both inorganic and organic (heavy metals, inorganic acids, nitrates, phosphate and organic chemicals. Over the years, there has been immense progress by mankind nevertheless increase in human activities like- industrial, military and mining as well as farm activities and waste have contaminated large areas in developing countries with elevating levels of organic pollutants and heavy metals. By 2012, worldwide community waste was estimated about 1.3 billion tonnes annually, however, it has been predicted that by 2025 it would hit a rise of about 2.2 billion tonnes per year which is a grave threat to us (1).The remains of heavy metals or synthetic organic materials are well known to adversely affect physiological systems in all animal species studied to date. For instance, soils contaminated with more than a single metal, commonly heavy metals/metalloids- Hg, Cd, As, Zn, Pb, Cu, Cr and Ni ; all these arise from either natural or anthropogenic sources such as produced water generated in oil and gas industries (2), sewage sludge(3) and use of phosphate fertilizers in agriculture (4). This has tremendously alarmed the human race and there has been a race and need for developing efficient, environmentally safe and cost-effective remediation technology to reclaim and restore original soil property. With the presence of contaminants present at high concentrations, highly expensive, causing irreversible changes to the physicochemical and biological properties of soils, which result in the deterioration of the soil property and ecosystem (5). Hence, there has been a cry for need of developing an efficient, environmentally safe and cost-effective remediation technology to reclaim and restore original soil property. In this paper, a review of a not so recent but challenging remedy is provided with tools and mechanisms that are applicable in reality and our day to day lives.

2. PHYTOREMEMDIATION:

The remedy for polluted soils often involves the excavation and removal of soil to ‘‘secured’’ landfills, a technology that is costly and needs site restoration. An eye opening method on cleaning up the environment known as Phytoremediation, has met to the needs on cleaning the soil which we live in. The word “phytoremediation” is derived from the Greek word ‘‘phyton’’, interpretation of “plant”, and Latin “remedium’’, signifying “remedy to correct”. This process is expressed as the utilisation of plants in removing either directly or indirectly the contaminated soil or water, sequester hazardous substances from the environment as a remedy solution and it has emerged as a cost effective, non-invasive, and publicly acceptable way to address the removal of environmental contaminants in the modern era. The accumulation of heavy metals into the water and soil medium pose a threat to the ecosystem, hence these plants used generally accumulate the contaminants without affecting topsoil, hence helps in conserving its property and fertility as well. They also facilitate in improving the soil fertility with various inputs of organic matter and also prevent rain, wind and groundwater flow from carrying away from the site to surrounding areas or deeper underground. Phytoremediation process is a low-risk and attractive cleanup method which automatically cleans up the environment. It is often used to decrease the slow rate of contaminated ground water, the trees then to act like a pump, drawing the ground water through the help of roots to keep it from moving, as it decreases the movement of polluted water towards clean areas offsite. Some certain plants tend to remove more contaminants in comparison than others, as they are able to tolerate the kinds and type of concentration present, plants like ferns and grasses have been used in areas where contamination is found to be shallow while tree roots tend to grow deeper hence, they are used for hydraulic clean up and control of deeper soil contamination and contaminated ground water. Sunflower (*Helianthus annuus*), Canola (*Brassica napus*), Castor (Recinus communis), Corn (*Zea* *mays*), *Brassica juncea, White willow (Salix* spp) are some common plants used in the process of rememdiation. Given below are the mechanism under phytoremediation :

2.1. Phytoextraction: In this procedure, the plant roots hold up the the contaminants along with other nutrients and water are translocated and accumulated above ground biomass i.e., shoots (6). As roots, accounts for 20-50% of plant biomass, extract from the soil and delivers to the shoots most of the contaminants, they are not destroyed but ends up accumulating in the leaves and shoots. This method is used mostly used for wastes containing metals, some metals are stored in the plants aerial shoots, which are harvested and either smelted for potential recovery or are disposed of as a hazardous waste. Extraction of heavy metals and radionuclides is one of the largest economic opportunities for phytoremediation because of the size and scope of environmental problems related with metal contaminated soils and the competitive advantage offered by a plant-based technology. Readily bio-available metals include cadmium, nickel, zinc, arsenic, selenium, and copper; while moderately bio- available metals consists of cobalt, manganese, and iron however, metals like lead, chromium, and uranium are not very easily bio-available. Lead can be converted into more bio-available with the addition of chelating agents to soil body, similarly, uranium and radio-cesium 137 can be made available and enhanced with application of citric acid and ammonium nitrate, respectively. Heavy metals such as lead, cadmium, chromium and zinc are relatively very toxic pollutants which could be significantly associated with bioaccumulation in mangrove plants within a myriad of ecological systems. It has been reported that very low heavy metal concentrations accumulated in leaf tissues because most absorbed heavy metals accumulated in stem and root tissue, however, root tissue is the most commonly used bio-indicator for heavy metal pollution with high reliability and accuracy as compared to leaves (7).

2.2. Phytostabilization: It is the utilisation of plants for stabilization of contaminants in contaminated soils (8), this technique is such that it used to reduce the mobility of pollutants in the soil and prevents the migration into the groundwater or their entry into the food chain (9); they are known to immobilize the activity of organic compounds rather than degrade them by roots, precipitation or metal valence reduction in rhizosphere (10). The main aim is avoiding mobilization of contaminants and limiting their diffusion into the soil medium. Phytostabilization requires a plant that is able to grow in the contaminated soil (i.e., metal-tolerant plants for heavy-metal contaminated soils), with roots growing into the zone of contamination, and that is able to alter the biological, chemical, or physical conditions in the soil.

2.3. Phytodegradation: An important mechanism under organic pollutants is degradation ; this procedure mostly deals with the degradation of organic pollutants within the plants with the aid of specific enzymes such as dehalogenase and oxygenase; it is not dependent on rhizospheric microorganisms (11). The organic pollutants get broken down into simpler forms of molecule and get incorporated into the plant tissues that aid in plant growth. These contaminants are either metabolized or degraded into the plant tissues and cells with enzymes such as- nitroreductases- that degrades nitro-aromatic compounds; laccases- degrades anilines compounds and dehalogenases – degrades chlorinated solvents and pesticides. Phytodegradation is limited to the removal of organic pollutants only because heavy metals are non-biodegradable. Recently, scientists have shown their interest in studying phyto-degradation of various organic pollutants including synthetic herbicides and insecticides. Some studies have reported the use of genetically modified plants (e.g., transgenic poplars) for this purpose (12). Destruction of organic contaminants leads to break down and degradation of TNT in their own tissue. Trinitrotoluene (TNT) is one of the world's most dangerous and persistant explosives, while use and disposal of TNT has resulted in the contamination of many places.

2.4. Phytostimulation: It is also referred to as enhanced rhizosphere biodegradation or plant-assisted bioremediation. This process is known for the root releasing compounds and enhances the microbial activity into the rhizosphere; it is critically known for the applied technology of rhizoremediation that combines phytoremediation and bio-augmentation. This type of rhizosphere phytoremediation can be used as a low-cost approach to remove organic pollutants from the soil. Microbial activity in the rhizosphere is activated as such that compounds, such as sugars, carbohydrates, amino acids, acetates, and enzymes, exuded by the roots enrich indigenous microbe populations; the root systems tend to bring oxygen to the rhizosphere, which ensures aerobic transformations while fine-root biomass increases available organic carbon.

2.5.Phytovolatization: In this process plants take up contaminants from soil and release them in volatile form into the atmosphere through transpiration, elements like Hg, Se and As are absorbed by the roots, converted into non-toxic forms, and then released into the atmosphere. It takes place when growing trees and other plants uptake water along with the contaminants present in water. These contaminants pass through the plants to the leaves and vapour out into the atmosphere at comparatively low concentrations. Plants also play a major role in physically stabilising the soil with the help of their root system. This also aids for preventing erosion, protecting the soil surface, and decreasing the impact of rain. At the same time, plant roots delivers nutrients that help to enhance the growth of microbes to convert it to a rich microbial community in the rhizosphere. The complex interactions between soil type, plant species, and root zone location affects the presence of bacterial community and its composition in the rhizosphere region. Due to availability of nutrients nearby this rhizosphere part of soil and also due to a symbiotic relationship between soil micro-organisms and plants, the population of micro- organisms is generally higher in the rhizosphere compare to the root-free soil. Due to this symbiotic relationship, bioremediation processes can be accelerated. Plant roots also plays role as surfaces provider for absorption or precipitation of metal contaminants. In this remediation process the root zone acts as focus of interest. The root absorbs the contaminants to be eventually stored or metabolised by the plant. The plant enzymes released from the roots degrade contaminants in the soil which is also an important phytoremediation mechanism. Many contaminants prefer route in which passive uptake takes place, via., micropores in the root cell wall and finally into the root, where degradation occurs. The process occurs as growing plants absorb water and organic contaminants. The contaminant, present in the water taken up by the plant, passes through the plant or is modified by the plant, and is released to the atmosphere (vaporizes).As water travels from the roots to the leaves along the vascular system of the plant, it is changed and modified along the way. Then, some of the contaminants move through the plants to the leaves and evaporate or volatilize into the atmosphere. Phytovolatilization has been primarily used to remove mercury; the mercuric ion is converted into less toxic elemental mercury. Plants can interact with a variety of organic compounds, and thereby affect the fate and transport of many environmental contaminants.

2.6. Rhizofiltration: This process includes the use of plants that help to absorb and concentrate the toxic contaminants from affected groundwater. The suitable plants with stable root systems are grown in polluted water get acclimatised and are transferred to the site to collect the substances and once the roots are saturated, the plants are harvested or disposed off. Several toxic metals like Zn^{2+}, Cd^{2+}, Cr^{6+}, Cu^{2+} and Pb^{2+} have been successfully removed from their aqueous state. This in particular is effective in areas with low concentrations and large volumes of water are involved. The roots are act as absorbing units when directly exposed to the contaminated water is in-situ rhizofiltraion; when water is pumped from the site to the site plants from outer sources comes as ex-situ rhizofiltraion. In this process, the water gets purified with aid of the roots.

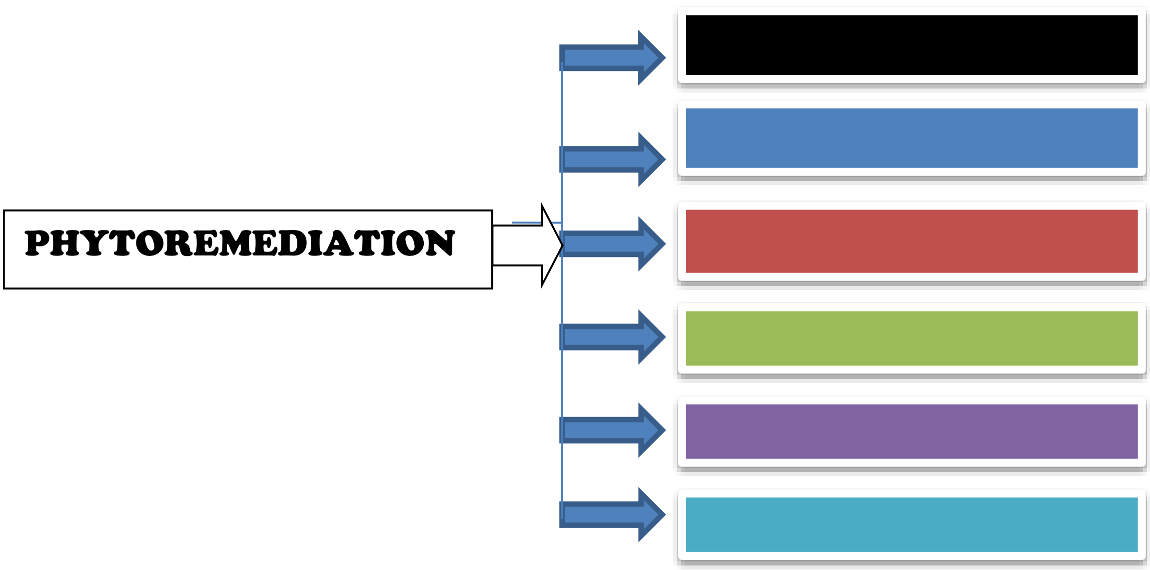

Image 1: Phytoremediation mechanisms

3. REVIEW OF LITERATURE:

Hinchman *et al*., (1995) Phytoremediation is said to be an alternative gate way to the much harsher remediation processes including thermal vaporization, solvent washing technology incineration which drastically eliminates all biological life as well as alters their physical and chemical properties. It is known to benefit the soil, improving the soil property as well as increasing fertility and productivity as it is low cost and inexpensive way of cleaning the environment. Plant growth promoting bacteria are known for their positive effect and influence on plant development and growth either directly or indirectly (Glick *et al*., 1999); hence, they play a vital role in the process of Phytoremediation. They directly promote the growth of plants indirect by providing a compound that can be easily taken in along with the nutrients from the environment or they reduce the influence of malicious effect of phyto-pathogenic compounds. PGPB aid in synthesizing siderophores that assist in solubilising and sequester Fe ions from the soil; synthesize several phytohormones and fixing atmospheric nitrogen.

Zurayk *et al*., (2001) studied the role of various hydrophyte plants including- *Veronica beccabunga, Nasturtium officinale, Cardamine uliginosa* and *Mentha longifolia* under aquatic phytoremediation of Cr under concentrations of 0, 2, 4, 6, and 8 mg L^{-1}. It was concluded that accumulation of Cr in the root had attained about

6700 mg Cr kg^{-1} in the roots of *V. beccabunga* with significant accumulation in the biomass resulting to removal of metals from the soil medium. Through the removing of Cr, observation has been made about the untapped potential of hydrophytes in their contribution towards the environment.

Glick (2003) concluded that phytoremediation has received all glory, with increase in positive reports in relation to this new technology which we require for tidying up of the environment pollutants. Though it is still in its infant stage, it is yet to be used commercially out in the field. However, to understand the full potentiality of the technology, it is necessary for plants to grow as large as possible in the presence of various environmental contaminants

Roychowdhury *et al*., 2017 concluded that metals like Zn, Pb and Cu were accumulated in the sampling parts like stem , roots and leaves of *Brassica juncea* (Indian mustard) from site Changdana, near Baduria, Deganga. Known for being a heavy metal indicator, Indian mustard can accumulate heavy metal in its vegetative parts, thus, reduces metal contamination in the soil medium by the process of phytoremediation. Repeatedly growing of plants in the contaminated areas, until the metal concentration falls under an acceptable level. The order of accumulation in soil sample collected was found Zn>Cu>Pb while in vegetative parts were leaf>root > stem. This experiment cites an example for cost effective, inexpensive way to clean the soil instead of relying on the old conventional ways.

Hawrot-Paw *et al*., 2019 worked on pea (*Pisum sativum L.spp. sativum)* cultivar Blauwschokker; to the test and study the effect of phytostimulation of biodiesel degradation in soil through several pea cultivars. The plants were selected based on the results of a separate experiment in which the germination index was determined according to the characteristics of seed germination and the elongation of roots was measured from top to bottom of the hypocotyls base in the presence of biodiesel introduced into soils at doses of 10−1and 50mgg DM soil (loamy sand and sandy loam). Twenty-four plants (15 species), taxonomically representing six families (Fabaceae, Poaceae, Boraginaceae, Rosaceae, Brassicaceae, Asteraceae), were used in that experiment but cultivar Blauwschokker was the only plant that showed resistance to the diesel and biodiesel fuels present in soil and proved phytostimulation effect.

There are also other strategies and techniques that contribute to Phytoremediation; these include:

Hydraulic barricade: Large trees with deep roots are known to remove large quantities of groundwater, and act as natural pumps when their roots reach down towards the water table. A populus tree, for instance, pumps out of the ground 30 gallons of water a day, while a cottonwood can absorb up to 350 gallons per day. The contaminants in the water are metabolized through plant enzymes, and are simply sequestered in plant tissues.

Vegetation covers: Herbs usually grasses, shrubs or trees, are grown to reduce the infiltration of rain water hence, contain the spread of pollutants; the roots increase soil aeration thus, promoting biodegradation, evaporation and transpiration.

Established wetlands: This is known as the oldest method of wastewater treatment and is not regarded as proper phytoremediation, since it is based on the contributions of the entire system, where the ecosystems consisting of microorganisms, algae and vascular aquatic plants in areas where the water level is at the surface, at least part of the year. All the components work together in the treatment of effluents, through the combined actions of filtration, ion exchange, adsorption and precipitation.

4Phytodesalination: A recent emerging technique that involves utilisation of halophytes to remove excessive salts from saline soils. The potential of *Suaeda maritima* and *Sesuvium portulacastrum* in removal and accumulation of NaCl, from highly saline soils, has been demonstrated.

4. ROLE OF MICROBES IN PHYTOREMEDIATION:

Phytoremediation provides a range of choices and offers the possibility to either destroy or render harmless various contaminants using natural biological processes; as it is relatively cost efficient, includes low-technology techniques, which generally have a high public acceptance and can often be carried out on site. Phytoremediation also includes bioremediation, which is the use of living organisms, primarily microorganisms, to degrade the environmental contaminants into less toxic forms. It uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and/or the environment. Microbial growth and activity are readily affected by pH, temperature, and moisture. Although microorganisms have been also isolated in extreme conditions, most of them grow in optimum conditions over a narrow range, so it is important to achieve optimal conditions for their growth, if the soil has too much acid present, it is possible to control the pH by addition of lime. Temperature affects biochemical reactions rates, and the rates of many of them double for each 10°C rise in temperature. Degradation may take place under aerobic, as well as under anaerobic conditions. The aerobic process is predominantly used for bioremediation and it can also be classified as ex-situ and in situ. Selection of appropriate technology among the wide range of bioremediation technologies developed to treat contaminants depends on three basic principles – the amenability of the pollutant to biological transformation, the accessibility of the contaminant to microorganisms and the opportunity for optimization of biological activity.

5. COMPONENTS THAT AFFECT THE UPTAKE MECHANISM:

Vegetative Species: Vegetative varieties are usually screened carefully and those with superior effects and characteristics are chosen. The uptake of a compound is affected by plant species characteristic. The success of the phytoextraction technique depends upon the identification of suitable plant species that hyperaccumulate heavy metals and produce large amounts of biomass using established crop production and management practices.

Soil property: Agronomic practices are developed to enhance remediation (pH adjustment, addition of chelators, fertilizers). For example, the amount of lead absorbed by plants is affected by the pH, organic matter, and the phosphorus content of the soil. To reduce lead uptake by plants, the pH of the soil is adjusted with lime to a level of 6.5 to 7.0.

Root area: Root zone area is of special interest in the process of phytoremediation. It can absorb contaminants and store or metabolize it inside the plant tissue. Degradation of contaminants in the soil by plant enzymes exuded from the roots is another phytoremediation mechanism.

Vegetative Uptake: Vegetative Uptake is affected by the environmental conditions. The temperature affects growth substances and consequently roots length. Root structure under field conditions differs from that under greenhouse condition. The success of phytoremediation, more specifically phytoextraction, depends on a contaminant-specific hyperaccumulator. Understanding mass balance analyses and the metabolic fate of pollutants in plants are the keys to proving the applicability of phytoremediation .

Increment of Chelating factor: The increase of the uptake of heavy metals by the energy crops can be influenced by increasing the bioavailability of heavy metals through adding of biodegradable physicochemical factors such as chelating agents, and micronutrients, and also by stimulating the heavy-metal-uptake capacity of the microbial community in and around the plant. This faster uptake of heavy metals will result in shorter and, therefore, less expensive remediation periods. However, with the use of synthetic chelating agents, the risk of increased leaching must be taken into account. The use of chelating agents in heavy-metal-contaminated soils could promote leaching of the contaminants into the soil.

Properties of medium: Agronomical practices are developed to enhance remediation (pH adjustment, addition of chelators, fertilizers). For example, the amount of lead absorbed by plants is affected by the pH, organic matter, and the phosphorus content of the soil. To reduce lead uptake by plants, the pH of the soil is adjusted with lime to a level of 6.5 to 7.0.

6. CONCLUSION & RECOMMENDATIONS:

Phytoremediation is more than just simply planting crops with minimal maintenance, then assuming that the contaminant will disappear; it requires an understanding of the processes that need to occur, the plants selected, and what needs to be done to ensure plant growth and also requires a commitment of resources and time, but has the potential to provide a lower-cost, environmentally acceptable alternative to conventional remedial technologies at appropriate sites. On recent times, their role in slowing the rate of global warming has been further appreciated in both the scientific and popular press. Phytoremediation is a fast developing technology, which over decade a lot of field application were initiated globally, including both for wastes under organic and inorganic. Most of the studies have been done in developed countries and knowledge of suitable plants is particularly limited in India. Fast growing plants with high biomass and good metal uptake ability are needed. In most of the contaminated sites hardy, tolerant, weed species exist and phytoremediation through these and other non-edible species can restrict the contaminant from being introduced into the food web. Perception and optimization of this process and proper disposal of its biomass is required to implement it skilfully worldwide. One way to achieve this goal is to utilize plant growth-promoting bacteria to facilitate the growth of the plants used for phytoremediation, which we ought to initiate and could really be useful for cleaning the environment we live in.

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