PHYTOREMEDIATION - A PROMISING APPROACH FOR POLLUTION MANAGEMENT

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Abstract

Environmental collapse is a universal issue in today's fast-paced culture. Polluted environments brought on by anthropogenic activity (mine, oil, agricultural spray, and fertilisation) are harmful to both humans and the biosphere. Urban soil and water contamination from fast urbanization is increasingly acting as a sink for a range of contaminants, such as heavy metals, pesticides, petroleum waste, radioactive molecules, etc. A low-cost, very effective way to extract or remove contaminants from the environment is through phytoremediation. Decontaminating heavy metal-contaminated locations using phytoremediation may be an effective approach, especially if the biomass created during the procedure can be used to generate bioenergy at a reasonable cost. The present study discusses a number of phytoremediation approaches, including phytodegradation, phytoextraction, phytostimulation, phytostabilization, phytofiltration, phytovolatilization, etc., that can be used to treat places where metals and other inorganic chemicals are present. In an effort to remove, detoxify, or immobilise environmental toxins in a growth matrix, a new method called phytoremediation uses the natural, biological, chemical, or physical activities of plants. As a result, this strategy is a cutting-edge instrument that has a great chance of decontaminating soil and water. In order to ensure the sustainability of current generations and lessen pollution, phytoremediation is a viable technology.

Keywords: Phytoremediation, Sustainable environment, Techniques, Biosphere, Contaminants.

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INTRODUCTION

Phytoremediation

The use of plants to clean up environmental media is known as phytoremediation, and it is being researched as a novel method for cleaning up contaminated soils, waterways, and groundwater. A kind of phytoremediation known as plant-assisted bioremediation uses the interaction between plant roots and the microbes connected to these root systems to clean up soils with high levels of organic chemicals. With less secondary waste and less of an impact on the environment than would be produced using conventional remediation procedures, these techniques may offer efficient ways to clean up soils and groundwater that have been contaminated with metals, radionuclides, and different kinds of organic materials (Padmavathiamma and Li, 2007; Devi et al., 2021; Gavrilescu, 2022; Sharma et al., 2023).

All plants utilize the soil and water surroundings to extract vital nutrients, including metals. Many metals, including some that don't seem to be necessary for plant function, can be stored by some plants known as hyper-accumulators. Additionally, plants have the ability to absorb different organic molecules from the environment and break them down or otherwise process them for use in physiological processes. Technologies for phytoremediation are still in the early stages of development; process definition and method improvement are being done in laboratories and in a few small-scale field tests. To enhance the natural ability of plants to carry out remediation tasks and to examine other plants with potential phytoremediation applications, additional research—including genetic engineering—is being done (Van Aken, 2009; Abhilash et al., 2012; Neilson and Rajakaruna, 2015; Rai et al., 2021).

Heavy metal pollution of the environment has become a major issue on a global scale. With rising urbanization and disruption of the natural biogeochemical cycles, the problem of heavy metal pollution is getting worse and worse. Heavy metals are fundamentally nonbiodegradable, in contrast to organic things, and hence they build up in the environment. The ecosystem and human health are at risk from the buildup of heavy metals in soils and streams. These substances build up in the tissues of living things (a process known as bioaccumulation), and their concentrations rise when organisms move from lower to higher trophic levels (a process known as biomagnification). Heavy metals in soil have toxicological effects on soil microorganisms, which could result in a decline in their activity and population (Khan et al., 2010; Parmar and Singh, 2015; Thakur et al., 2016; Yan et al., 2020; Yaashikaa et al., 2022).

Phytoremediation - A Green Solution to the Problem of Environmental Pollution

There are several phytoremediation techniques that can be used to clean up heavy metal-contaminated soils, including (i) phytostabiliza-tion, which involves using plants to lessen the bioavailability of heavy metals in soil, (ii) phytoextraction, which involves using plants to extract and remove heavy metals from soil, (iii) phytovolatilization, which involves using plants to absorb heavy metals from soil and release them as volatile compounds into the atmosphere, and (iv) phyto filtration, which involves Rhizodegradation and phytodegradation are two more phyto remediation techniques that break down organic contaminants. Here, we concentrate on the four most popular phytoremediation techniques—phytostabilization, phytoextraction, and phyto volatilization—for cleaning up soil that has been contaminated with heavy metals (Ogundola et al., 2022).

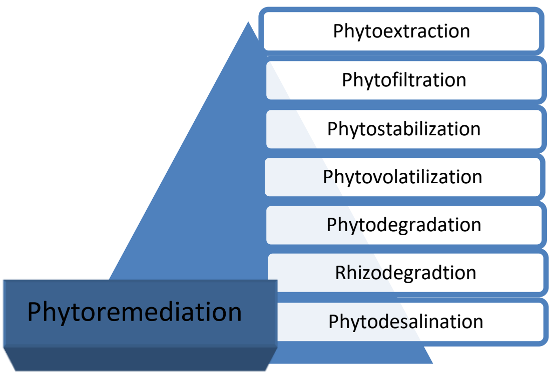

Figure 1: Various Strategies Involved in the Phytoremediation

Metal ions at their higher concentration are toxic to plants, but they are necessary as trace elements. As well as being harmful to the environment generally, several heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) also have a detrimental effect on human health. They have a detrimental effect on both human and animal health because they survive in the environment for very long periods of time, often for hundreds to thousands of years (Alengebawy et al., 2021). According to Shah and Daverey, (2020), long-term exposure to heavy metals through the air, water, soil, and food causes a number of diseases like cancer, neurological effects, myocardial infarction, high blood pressure, skin lesions, organ system damage, and problems with the urinary, reproductive, and respiratory systems.

1. Phytoextraction

The process of pollutants being taken up by plant roots from soil or water and then moving to and accumulating in aboveground biomass, such as shoots, is known as phytoextraction (also known as phytoaccumulation, phytoabsorption, or phytosequestration) (Rafati et al., 2011). Because harvesting root biomass is typically impractical, metal translocation to shoots is an important biochemical step that is desired in an efficient phytoextraction (Lasat, 2002; Zacchini et al., 2009; Tangahu et al., 2011).

2. Phyto filtration

The process of using plants to filter contaminants out of contaminated surface waters or waste fluids is known as phytofiltration. Rhizofiltration (using plant roots), blasto filtration (using seedlings), and caulofiltration (using excised plant shoots; Latin caulis = shoot) are three types of phytofiltration. The pollutants are absorbed or adsorbed during phytofiltration, which reduces their migration to subsurface waterways (Mesjasz-Przybylowicz et al., 2004; Mukhopadhyay and Maiti, 2010; Javed et al., 2019).

3. Phytostabilization

The use of specific plants for stabilising pollutants in polluted soils is known as phyto stabilization or phytoimmobilization (Singh, 2012). By reducing the mobility and bioavailability of contaminants in the environment, this approach stops them from moving into groundwater or the food chain (Erakhrumen and Agbontalor 2007). The process of phytostabilization reduces the buildup of heavy metals in biota and their leakage into groundwater. Nevertheless, phytostabilization is merely a temporary fix because the heavy metals still exist in the soil and can still travel about. It is actually a management technique for inactivating (stabilising) potentially harmful pollutants (Vangronsveld et al., 2009).

4. Phytovolatilization

Phytovolatilization is the process by which pollutants are taken up by plants from the soil, transformed into a volatile state, and then released into the atmosphere. Both organic contaminants and some heavy metals, such cadmium and selenium, can be removed with this method. The fact that it simply moves the pollutant from one segment (soil) to another (atmosphere), where it can be redeposited, rather than totally removing it, limits its use. The most contentious phytoremediation technique is phytovolatilization (Padmavathiamma and Li, 2007).

5. Phytodegradation

According to Vishnoi and Srivastava (2008), phytodegradation is the process by which plants break down organic pollutants with the aid of enzymes like dehalogenase and oxygenase. This process is independent of rhizospheric microbes. Organic xenobiotics can be accumulated by plants from polluted surroundings, where they are then detoxified by metabolic processes. Green plants can be thought of as the biosphere's "Green Liver" from this perspective. Heavy metals cannot be removed by phytodegradation; it can only remove organic contaminants. Scientists have recently expressed interest in researching the phytodegradation of numerous organic contaminants, such as synthetic pesticides and herbicides. Studies have suggested using genetically engineered plants for this, including transgenic poplars (Doty et al., 2007).

6. Rhizodegradation

Rhizodegradation is the term used to describe how microorganisms in the rhizosphere break down organic contaminants in the soil (Mukhopadhyay and Maiti, 2010). The rhizosphere, which surrounds the root and is under the control of the plant, is roughly 1 mm in diameter (Pilon-Smits, 2005). The growth in the number and metabolic activity of the microorganisms is probably the primary factor causing the improved breakdown of contaminants in the rhizosphere. Plants can increase microbial activity in the rhizosphere by roughly 10-100 times by secreting exudates that contain sugars, amino acids, and flavonoids. Exudates from plant roots that contain nutrients are released into the soil, where they act as sources of carbon and nitrogen for soil microbes and promote microbial activity.

7. Phytodesalination

It is an emerging approach that has only recently been disclosed (Zorrig et al., 2012). In order to enable salt-affected soils to maintain normal plant growth, phytodesalination refers to the employment of halophytic plants to remove salts (Manousaki and Kalogerakis, 2011; Sakai et al., 2012). According to Manousaki and Kalogerakis (2011), halophytic plants are more naturally able to deal with heavy metals than glycophytic plants.

Limitations to Phytoremediation

The remediation of heavy metal-contaminated soils using phytoremediation is a promising strategy, but it also has some drawbacks (Clemens, 2001; Suresh and Ravishankar, 2004; Mukhopadhyay and Maiti, 2010; Ramamurthy and Memarian, 2012).

- The length of time needed for cleanup.
- The low biomass and sluggish development rate of the majority of metal hyperaccumulators often limit their phytoremediation capacity.
- The decreased bioavailability of the pollutants in the soil due to difficulty in mobilising the more firmly bound fraction of metal ions from soil.
- Because plant development cannot be supported in soils with high levels of metal contamination, it is appropriate to places with low to moderate metal pollution.
- The depth of the treatment zone is determined by plants used in phytoremediation. In most cases, it is limited to shallow soils. High concentrations of hazardous materials can be toxic to plants. It involves the same mass transfer limitations as other biotreatments.
- In the event of poor management and inadequate care, there is a risk of food chain contamination.

CONCLUSIONS AND FUTURE TRENDS

Effective remediation techniques are required because hazardous heavy metal contamination of soils and streams is a severe environmental issue. Significant drawbacks of physical and chemical approaches for heavy metal contamination treatment and restoration include high costs, irreversible changes to soil properties, destruction of native soil microflora, and development of secondary pollution issues. In comparison, phytoremediation is a more effective approach to the issue. Solar-powered phytoremediation is an environmentally friendly and ecologically sound method that enjoys widespread support. It is a fairly new technology that is primarily in the research stage. Since the research is so broad, it necessitates a foundation in environmental engineering, soil chemistry, plant biology, ecology, and soil microbiology. Thankfully, interdisciplinary research and study are valued and strongly promoted in open-minded scientific communities around the world, and it is really believed that the fusion of scientific fields will be extremely productive. The effectiveness of phytoremediation is being studied, as well as the screening of native plants for the phytoremediation of target heavy metals. Additionally, studies are being done on genetically altering a few eligible plants for enhanced phytoremediation of heavy metals and other xenobiotics. The many proteins involved in the cross-membrane trafficking and vacuolar sequestration of heavy metals are being studied as well. Understanding the mechanism and improving the effectiveness of phytoremediation would be substantially aided by advancements and successes in such molecular investigations. A better understanding of how heavy metals are absorbed by plants from the soil may also aid in the promotion of phytomining, a form of plant-based, environmentally benign metal extraction that can be utilised to recover metals even from low-grade ores. Future heavy metal phytoremediation and phytomining processes are predicted to be financially viable using heavy metal phytoextraction. Researchers will be able to fine-tune the phytoremediation process by having a better understanding of the coordination chemistry of metals in plant tissues. Despite its many difficulties, phytoremediation is seen as a green remediation technique with a lot of promise.

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