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Phytoremediation: A Green Approach for Pollution Cleanup

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Abstract

This review provides a brief overview of an environmental remediation technology, including an introduction to its general principles, reported applicability and utilization. Phytoremediation uses plants to clean up contaminated soil and groundwater, taking advantage of plants' natural abilities to take up, accumulate, and degrade constituents of their soil and water environments. Research and development results in phytoremediation processes and techniques report it to apply to a broad range of contaminants, including numerous metals and radionuclides, various organic compounds such as chlorinated solvents, polycyclic aromatic hydrocarbons, pesticides, insecticides, explosives, nutrients, and surfactants. To improve the efficiency of Phytoremediation, a better understanding of the mechanisms underlying heavy metal accumulation and tolerance in plants is indispensable. In this review, we describe the mechanisms of how heavy metals are taken up, translocated, and detoxified in plants as well as future prospects of phytoremediation.

Keywords: Phytoremediation; Remediation Technology; Pollution Cleanup; Contaminated Soil; Heavy Metals; Phytoextraction.

Introduction

Plants are used in phytoremediation techniques to purify polluted soil, water, and air (Das, 2018). The application of green plants, related microbes, appropriate soil supplements, and agricultural approaches to either control, eliminate, or create harmless hazardous environmental toxins is what is meant by this term (Reichenauer and Germida, 2018). The word is a combination of the Greek words phyto (plant) and remedium (remedy) which means restoring balance. Pollution is a major problem faced by everyone (Thompson *et al.,* 2019; Ogundele *et al.,* 2021), therefore, an inexpensive plant-based method of environmental cleanup called phytoremediation was developed. It uses plants' capacity to absorb chemicals and toxins from the surroundings and cleanse different contaminants. The capacity of some plants, known as hyperaccumulators, to bioaccumulate substances is what causes the concentrating effect. The impact of cleanup is very different. Organic contaminants, which can be destroyed, are typically the primary targets for phytoremediation, while toxic heavy metals cannot. Several field tests demonstrated the viability of employing plants for environmental remediation (Lone *et al.,* 2008).

Phytoremediation can be used in environments with contaminated soil or static water. This technology is being studied and used more frequently at locations where the soil is contaminated with heavy metals like cadmium, lead, aluminum, arsenic, and antimony. These metals can harm plant cell membrane integrity, impair nutrient uptake, impede photosynthesis, and reduce chlorophyll in plants. They can also lead to oxidative stress in plants (Reichenauer and Germida, 2018).

The recovery of neglected metal mine workings, the remediation of coal mine discharges, and sites where toxic chemicals are dumped during manufacturing are examples of where phytoremediation has been employed effectively to reduce the effects of contaminants in the air, water and soils. Worldwide, contaminants like solvents, herbicides, metals, explosives, and crude oil have been reduced in phytoremediation operations worldwide (Moosavi and Seghatoleslami, 2013). Numerous plants, including hemp, pigweed, and mustard plants, alpine pennycress, have demonstrated their ability to hyper-accumulate toxins at chemical waste sites.

Due to variations in plant physiology, certain plants cannot absorb organic and toxic metal contaminants (Lone *et al.,* 2008). Even cultivars of the same species can collect contaminants differently. To remove environmental toxins, phytoremediation, the use of plants to bioremediate polluted water, air, and soil, has arisen as a more practical, non-intrusive, and socially acceptable method (Dalvi and Bhalerao, 2013).

Phytoremediation is the employment of plants, either directly or indirectly, to clean up contaminated soil or water. It is possible to employ plants to bind inorganic and organic pollutants, break down organic pollutants, and promote the microbial breakdown of organic pollutants in the root zone. To apply phytoremediation to more contaminated locations, it will be helpful to have a better understanding of the potential processes for removal of contaminants from the root zone and the interaction between plants, microbes, and contaminants (Yan *et al.,* 2020). This review provides an overview of phytoremediation, covering phytoextraction, phytoimmobilization, phytostabilization, phytodegradation, and rhizodegradation. Also included are future prospects in phytoremediation.

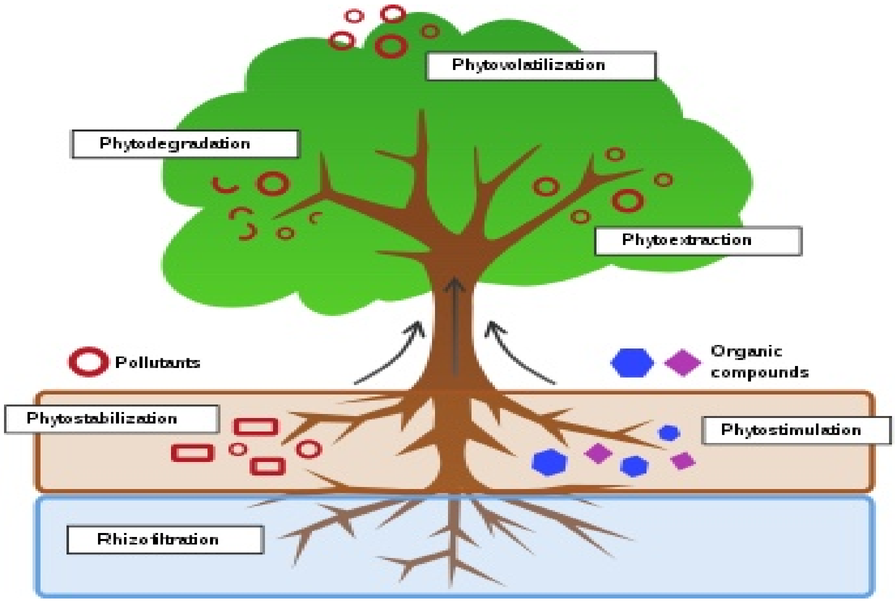

Figure 1: An overview of Phytoremediation

Mechanism of Phytoremediation

➢ Phytoextraction

Utilizing a plant's or algae's capacity to draw impurities out of the soil or water and turn them into usable plant biomass is known as phytoextraction (or phytoaccumulation). The plant's biomass is concentrated above ground by the roots, which absorb nutrients from the water or soil (Ali *et al.,* 2013). Hyperaccumulators are organisms that can absorb significant levels of pollutants (Rascio, 2011). Populus and Salix are examples of plants that can perform phytoextraction. These plants take up low quantities of pollutants, but because of their rapid growth and biomass production, they may remove a significant quantity of toxins from the soil (Nissim *et al.,* 2018). Over the past three decades, phytoextraction has seen a sharp increase in popularity.

Typically, toxic metals and other inorganics are extracted using phytoextraction (Pilon-Smits, 2015). Compared to the initially contaminated soil, pollutants are often concentrated in a much smaller amount of plant matter at the time of disposal. To achieve a significant cleanup, the growth/harvest cycle must typically be repeated through numerous crops because a lesser level of contamination will stay in the soil after harvest. The technique results in the remediation of the soil. Phytoremediation is not a cure-all because many contaminants are known to be toxic to plants. Chromium, for instance, becomes poisonous to most higher plants at concentrations greater than 100 Mg/kg dry weight (Mukherjee *et al.,* 2015).

Phytomining is a potential method of recovering the material by mining these derived metals (Shah and Daverey, 2020). Metallophyte plants frequently exhibit hyperaccumulation. When a chelator or other compound is given to soil to boost metal solubility so that plants can more readily absorb them, the process is known as induced or assisted phytoextraction (Doumett *et al.,* 2008). While these additives may help plants absorb more metals, they may also increase the number of accessible metals in the soil beyond what plants can use, which could leak into the subsoil or groundwater.

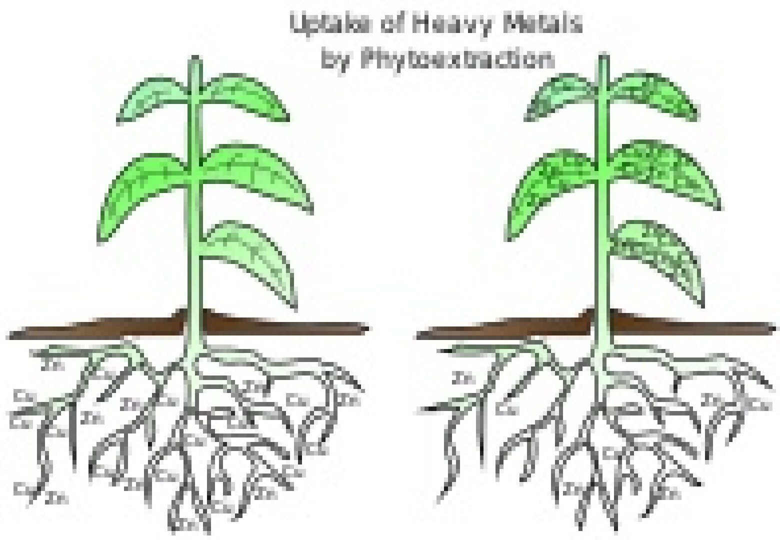

Figure 2: An Overview of Phytoextraction

➢ Phytofiltration

Rhizofiltration uses plant roots or seedlings to filter the water of contaminants, most often metals. The contaminants are still ingested or adsorb to the roots. This method is frequently used to remediate contaminated groundwater by planting vegetation directly in the contaminated area or extracting the toxic water and supplying it to these plants off-site. However, in both cases, plants are often first grown in a greenhouse under specific conditions (Surriya *et al.,* 2015).

Using plants to filter water is known as phytofiltration or rhizofiltration. Contaminants can be absorbed by the plant and removed through biomass. Rhizofiltration is a type of phytoremediation, which is the process of remediating contaminated water by absorbing, concentrating, and precipitating pollutants using plant roots grown hydroponically (Prasad, 2004; Peer *et al.,* 2005). Contaminants may also be taken up and then volatilized. Through accumulation and volatilization, aquatic plants can extract selenium (Se) from agricultural or industrial wastewater (Pilon-Smits *et al.,* 2009). They have identified several species with high potential for selenium phytoremediation in wetlands, including saltmarsh bulrush (*Scirpusrobustus*), cattail (*Typhalatifolia*), iris-leaved rush (*Juncusxiphioides*), parrot's feather (*Myriophyllumbrasiliense*), and iris-leaved rush (Singh *et al.,* 2009) and determined that the most excellent rates of plant selenium uptake and selenate volatilization required microorganisms in the rhizosphere of Indian mustard (*Brassica juncea*).

Plant matter that isn't alive can also act as a biosorbent to eliminate pollutants. It has been demonstrated that living and nonliving plant material can bioaccumulate contaminants like chromium, changing it from the hazardous form Cr(VI) to the benign form Cr(III). The elimination of metal ions through biosorption utilizing plant-based materials has successfully reduced the harmful effects of heavy metals on human health (Lombi *et al.,* 2011).

Many studies have been done on phytofiltration and rhizofiltration. Plants' root and shoot tissues contain binding mechanisms that make it possible to remove pollutants from the environment in a very affordable way. Harmful yet valuable metals can be recovered and used again due tophytofiltration (Peer *et al.,* 2005).

Sekhar *et al.* (2014) suggested a unique phytofiltration technology that might be utilized to extract and recover lead (Pb) from wastewater. The bark from the plant known as Indian sarsaparilla is used in this technology as a plant-based biomaterial (*Hemidesmusindicus*). Their study focused on contaminated groundwater and surface water at locations with a history of industrial contamination. Schulman *et al.*(2012) also examined the rhizofiltration of lead-contaminated water. They created a screening procedure to find *Brassica juncea* mutants with improved lead or cadmium accumulators.

➢ Phytostabilization

Phytostablization is the process of immobilizing hazardous or mobile pollutants in the root zone by absorbing and deposition by roots or precipitation in the soil. Through the root zone, bacteria and soil chemistry as connected to the exudates and carbon dioxide production, phytostabilization will take place. Metals' mobility and solubility can be reduced by phytostabilization (Ettala, 2008). Instead of removing hazardous metals and organic chemicals from the soil, this process could stabilize them at levels suitable for long-term monitoring. Farmers are well aware of the capacity of willows to dry marshy soils. Historical accounts have even stated that willows planted in malaria-affected areas were the most successful at drying up the ground because they evapotranspiration at high rates (phreatophyte-type vegetation) (Going, 2003). In phytostabilization initiatives that aim to manage soil water, the creation of willow vegetative buffer zones or biocurtains has been used to cover landfills, sewage treatment plants, steelworks, and trash dumps (Agnello, 2014; Hasselgren, 2014). It can be beneficial for practical purposes for willows to absorb toxic metals and other toxins in the root systems, stopping their movement throughout the environment (Ettala, 2008). The willows' metabolic power is increased, resulting in an effective dehydration plant that locks up the pollutants. This is made possible by their dense root system, which penetrates deeply into the soil, high transpiration rates that effectively manage soil water, and high filtering capacity.

➢ Phytovolatilization

In some cases, phytotransformation into more volatile and less polluting compounds causes phytovolatilization, which removes substances from water or soil with release into the atmosphere. Contaminants are absorbed by the plant during this process and then vaporize into the atmosphere due to transpiration. Although indirect phytovolatilization happens when pollutants are released from the root zone, this is the sort of phytovolatilization that has received the most attention. Volatilization occurs at the plant's stem and leaves (Marecik *et al.,* 2012).Through phytovolatilization, mercury (Hg) and selenite (Se) are frequently eliminated from soil (Lone *et al.,* 2008). Due to their high transpiration rate, poplar trees are one of the most effective plants for eliminating volatile organic chemicals (Pilon-Smits, 2005).

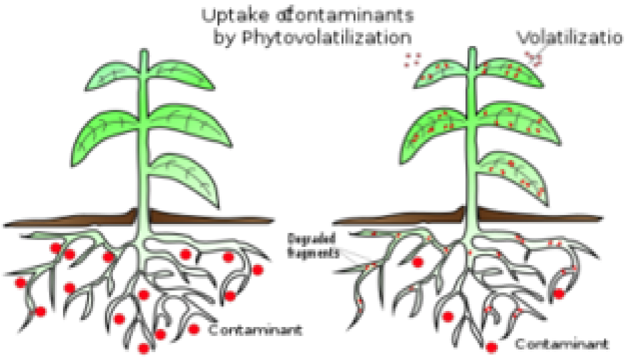

Figure 3: An overview of Phytovolatilization

➢ Phytodegradation

Phytodegradation is the breakdown of organic contaminants in the soil by enzymes secreted by the roots. Plants or microorganisms can be used in Phytodegradation, also known as phytotransformation, to break down organic contaminants in the soil or within the plant itself. Enzymes secreted by the plant roots break down the organic components, and the molecules are subsequently absorbed by the plant and expelled by transpiration. Herbicides, trichloroethylene, and methyl tetra-butyl ether are among the organic pollutants that this technique is most effective at removing (Pilon-Smits, 2005).

Phytodegradation mechanisms are transformed, absorbed, and metabolic activities inside a specific application. The contaminant's polarity, solubility, and hydrophobicity affect uptake and transformation. While it is widely known that poplars may absorb a wide variety of organic pollutants into their plant roots, recent research indicates that willows positively affect the fate of organic pollutants. As a result of an oil spill, Prairie Cascade willow has demonstrated rapid growth on blackened soil and the ability to clear the soil by promoting oil-degrading bacteria linked with their roots (Thompson *et al.,* 2008). Willows have been suggested for the Siberian taiga's re-cultivation of oil-mining regions. In contrast to bare land plots, willow stakes planted in degraded regions without soil amendment immediately created green cover, hastening the removal of toxins.

When herbaceous plants were planted atop a costly imported layer of soil, faster pollution sequestration than in earlier attempts had been observed (Iqbal, 2022). Evidence suggests that on dumpsites for dredged silt, a considerable reduction in mineral oil concentration by 55% on plots planted with willow, compared to 17% on fallow plots took place (Vervaeke *et al.,* 2003). The ability of willows to move oxygen to the root zone via aerenchyma production may help to improve the circumstances for bacterial growth. According to research on willow planting in landfills (Maurice *et al.,* 2009; Kim and Owens, 2010), those sites exhibit higher methane oxidation rates than plots with no trees.

Using their broad root systems, trees may offer methane-oxidizing bacteria a better environment, allowing methane to be released into the atmosphere. Using willow and its tolerance to higher levels of ethanol, promising findings in restoring shallow aquifer sites contaminated with ethanol-blended gasoline spills have been reported (Corseuil and Moreno, 2001). Through root uptake and sorption to plant biomass, weeping willow (*Salix babylonica*) cuttings were able to reduce the levels of ethanol and benzene in an aqueous solution by more than 99% in a laboratory experiment that lasted less than a week. It was proposed that absorption and plant transpiration were closely connected. Willows offer a potential solution for cleaning up cyanide-contaminated locations. Willow's cyanide and ferrocyanide transport and metabolism have helped to degrade these pollutants in the gold mining wastewater (Ebbs *et al.,* 2003). There is some evidence that willow roots and leaves have the quickest rates of cyanide removal even though many plant species manufacture cyanide (mainly in the form of glycosides) for chemical defense and plant cells, in general, have a solid capacity to eliminate free cyanide (Larsen *et al.,* 2004).

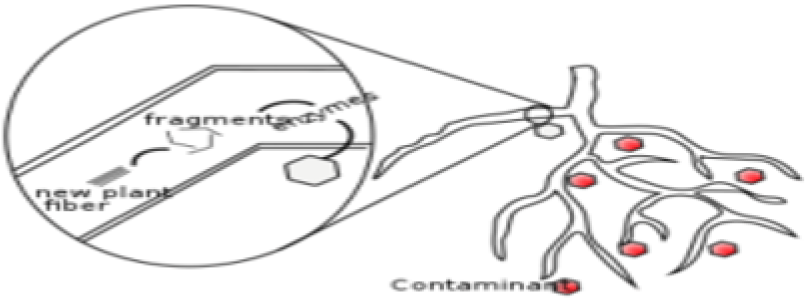

Figure 4: An overview of Phytodegradation

➢ Phytotransformation

As a direct result of plant metabolism, phytotransformation involves the chemical change of ambient elements, frequently leading to their inactivation, destruction (phytodegradation), or immobilization (phytostabilization). Some plants, like Cannas, metabolize organic contaminants, such as solvents, explosives, pesticides, industrial chemicals, and other xenobiotic compounds, rendering them non-toxic (kvesitadze *et al.,* 2006). In other instances, these chemicals may be metabolized in soil or water by microbes that coexist with plant roots. Because plant molecules cannot completely decompose these difficult-to-break-down chemicals into simpler ones (such as water or carbon dioxide), the word "phytotransformation" refers to a change in chemical structure rather than a full breakdown of the substance. "Green Liver" refers to phytotransformation (Sanderman, 2018).

Plants react to the xenobiotic molecule (pollutant) like the human liver (Burken, 2008; Ramel *et al.,* 2012). Plant enzymes add functional groups, such as hydroxyl groups, to the xenobiotics after they have been absorbed, increasing their polarity (-OH). Phase I metabolism refers to this process, comparable to how the human liver raises the polarity of medicines and foreign chemicals (drug metabolism). While enzymes like cytochrome P450s in the human liver are in charge of the early reactions, in plants, enzymes like peroxidases, phenoloxidases, esterases, and nitroreductases play the same role (kvesitadze *et al.,* 2006). To further strengthen the polarity of the polarized xenobiotic, plant biomolecules such as glucose and amino acids are added in the second stage of phytotransformation, known as Phase II metabolism (conjugation). Once more, this is comparable to the processes in the human liver where reactive centers of the xenobiotic undergo glucuronidation (the addition of glucose molecules by an enzyme of the UGT class, such as UGT1A1) and glutathione addition reactions. Although there are many exceptions to the rule, phase I and phase II reactions work to make molecules more polar and less poisonous.

Aqueous channels can easily carry the xenobiotic because of the enhanced polarity. Phase III metabolism, the last stage of phytotransformation, involves the sequestration of the xenobiotic inside the plant. The xenobiotics form a complicated structure inside the plant after polymerizing as lignin does. This guarantees that the xenobiotic is kept safely and does not interfere with the plant's ability to function. Preliminary research has indicated that these plants can be poisonous to small animals (like snails). Thus plants used in phytotransformation may need to be kept in a contained enclosure. As a result, plants, with certain exceptions, lessen toxicity and sequester xenobiotics through phytotransformation. Numerous studies have been conducted on trinitrotoluene phytotransformation, and a hypothesized transformation pathway is now available (Subramanran *et al.,* 2006).

➢ Phytostimulation

Increasing soil microbial activity to break down organic pollutants, often by organisms associated with roots, is known as phytostimulation (or photodegradation). The rhizosphere, or soil layer around the roots, is where this activity occurs. Microorganisms degrade organic pollutants due toplants' carbohydrates and acids (Dzantor, 2007). This indicates that harmful compounds can be broken down and digested by microbes into harmless forms. It has been demonstrated that phytostimulation is effective in breaking down polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons (Pilon-Smits and Elizabeth, 2015). As in the case of the stimulation of atrazine decomposition by hornwort, phytostimulation can also involve aquatic plants that host active populations of microbial degraders (Rupassara *et al.,* 2012).

Table 1: Phytoremediation Potential of Some Plant Species

Metals	Plant Species	Reference
Arsenic (As)	Eleocharisacicularis *Pterisvittata* *Pterisbiaurita* *Helianthus annuus*	Sakakibara *et al.* 2011 Wang *et al*. 2012 Srivastava *et al.* 2006 Marchiol*et al*. 2017
Lead (Pb)	*Brassica juncea* *Euphorbia cheiradenia* *Deschampsiacespitosa* *Ambrosia artemisiifolia*	Muthukumar *et al*. 2017 Chehregani and Malayeri,2007 Kucharski *et al.* 2005 Muthukumar *et al*. 2017
Cadmium (Cd)	*turnip landraces* *Azollapinnata* *Prosopislaevigata* *Salix viminalis*	Li *et al.* 2016 Rai, 2008 Buendía-González *et al.*2010 Greger, 2019
Nickel (Ni)	*Alyssum murale* *Phyllanthusserpentinus* *Alyssum pterocarpum*	Bani *et al.* 2010 Chaney *et al.* 2010 Li *et al.* 2003

Chromium (Cr)	*Pterisvittata* *Solanumlycopersicum*	Kalve *et al.* 2011 Shanker *et al.* 2015
Zinc (Zn)	*Thlaspicalaminare* *Eleocharisacicularis* *Thlaspicaerulescens*	Sheoran *et al.* 2009 Sakakibara *et al.* 2011 Kirkham, 2016
Cobalt (Co)	*Haumaniastrumrobertii*	Marques *et al.* 2009
Manganese (Mn)	*Alyxiarubricaulis* *Schimasuperba* *Maytenusbureaviana* *Alyxiarubricaulis*	Chaney *et al.* 2010 Yang *et al.* 2008 Marques *et al.* 2009 Marques *et al.* 2009
Mercury (Hg)	*Cicer arietinum* *Hordeumspp* *Marrubiumvulgare*	Wang *et al.* 2012 Rodriguez *et al.* 2003 Rodriguez *et al.* 2003
Copper (Cu)	*Pterisvittata* *Eleocharisacicularis* *Ipomoea alpine*	Wang *et al.* 2012 Sakakibara *et al.* 2011 Mitch, 2002

Literature Review

Phytoremediation of lead polluted soil by *glycine max L.*(soybean) plant was carried out by Sesan Abiodun *et al.* (2013). The soil sample used for this study was collected from a depth of 0–20 cm within the Federal University of Technology, Minna, Nigeria. and transported in plastic pots to the Center for Preliminary and Extra-Mural Study (CPES) garden. The taxonomic classification of the experimental soil was loamy sand, with a pH of 6.60. Mature *Glycine max L.* (soybean) seeds were collected at Kure market, Minna, Niger state. The local seeds were used because they have the potential to withstand adverse climatic conditions and are native to the environment. They quickly adapt to harsh environmental conditions, which most transgenic ones may not. The soil sample (loamy sand) was air-dried and perceived with 2mm diameter mesh. 1.599 g of Pbwas dissolved in 1,000 mL of distilled water to make stock solutions of 5, 10, 15, 20, and 25 mL respectively. These different concentrations were then measured from the stock solutions into a 100 mL capacity measuring cylinder and made up to the mark to give 5 ppm, 10 ppm, 15 ppm, 20 ppm, 25 ppm, and 0 ppm (control) metal concentrations. The soil was spiked with different concentrations of lead and thoroughly mixed (Kabta-Pendias, 2015).The setup was completely randomized, and the treatments were replicated three times. The experimental pots were filled with 5 Kg lead-contaminated soil of different concentrations of lead contaminants, pre-sieved with 2 mm sieve size. The seeds (8 seeds per pot, which were later thinned down to 4 after germination) were planted in each pot. The plants were irrigated with 200 mL (per pot) of tap water daily, and the plants were sampled to monitor metal uptake and soil for residual metal contents 12 weeks after planting (Aransiola*et al.,* 2013). All the plants were harvested according to soil treatment, and separated into four compartments: roots, seed, stem, and leaves. The 3 replicates of each treatment were pooled together to give a composite sample of each treatment. The plants were washed in water to eliminate soil, dirt, possible parasites or their eggs, and finally with deionized water (Yusuf *et al.,* 2013). Each subsample was oven-dried at 70°C for 24 hours. The acid digestion method of Yusuf *et al*. (2010) was used for the digestion of grounded plant samples. 1g each of this was weighed into a 50 mL capacity beaker, followed by the addition of a 10mL mixture of analytical grade acids: HNO_3; H_2SO_4; $HClO_4$ in the ratio of 1:1:1. The beakers containing the samples were covered with watch glasses and left overnight. The digestion was carried out at a temperature of 70°C until about 4 mL was left in the beaker. Then, a further 10 mL of the mixture of acids was added. This mixture was allowed to evaporate to a volume of about 4 mL. After cooling, the solution was filtered to remove small quantities of waxy solids and made up to a final volume of 50 mL with distilled water. The pH of the soil after plant harvest (after 12weeks) was 7.07 higher than the pH of the uncontaminated soil, which was 6.0, due to the presence of lead as a contaminant in the polluted soil. The result implies that about 250 mg/kg can be removed in a year at an average of 21 mg/kg in 4 weeks. The value is far lower than Pb concentrations observed at the end of the sampling period (12 weeks) in the *G. max L*. This indicates that this plant is effective in mopping up Pb from contaminated soil. Since the seeds of *G. max L*. bioaccumulate a considerably high lead concentration after 12 weeks, it implies that the efficiency of the plant in cleaning contaminated soil was at the late and last stage of its growth. Therefore, this plant should be harvested around this period for effective results. The plant (*G. max* L.) had the potential to accumulate heavy metal and may be selectively used for phytoextraction of metal contaminated soil. According to Emerging Technology for the Phytoremediation of Metal in Soil. The result of the research showed that glycine max L. has the highest accumulation of lead in its seeds after 12 weeks of remediation (Aransiola*et al.,* 2013).

Phytoextraction of heavy metals in a mining-influenced area with the use of sunflower (*Helianthus annuus*) was carried out by Dirk Merten *et al.*(2014) in Thuringia, Germany. For this study, sunflowers were planted on a small-scaled plot at the test field "Gessenwiese" (GW) in the eastern part of the German Federal State Thuringia near the city of Ronneburg. This test field is situated in the former uranium leaching heap "Gessenhalde" (Jakubicketal, 2007). Soil samples were taken on the day of sowing (May2011) and after the last harvest (October 2011) in duplicates (0–20 cm soil depth). Soil samples were dried at 40 C to constant weight in the oven. The soil samples were stored at room temperature in PVC bottles (Kautex) until further processing. Sunflowers (*Helianthus annuus*, variation "Peredovick") were sown at the beginning of May 2011.They were sampled 34, 66, 96, 108, 140, and 170 days after sowing until physiological maturity was reached. At every harvest, duplicate samples of four plants (34 and 66 days after sowing) and three (96, 108, 140, and 170 days after sowing) were taken, respectively. Plants were harvested as a whole and carefully washed with deionized water. Afterward, stems, leaves, and blossoms (including seeds) were separately dried at 40 C to constant weight in the oven. At the harvest 170 days after sowing, it was impossible to wash the leaves since they were too senescent, so no chemical analysis was carried out on them. Dry biomass weights of the single plants part samples were determined, and the samples were stored in Polypropylene-tubes at room temperature until further processing. Before analysis, the aggregates in the soil samples were softly chopped with a pestle (agate), and then the soil was sieved to 2mm. The soil pH was determined by suspending 10g of soil (2mm) in 25mL of ultrapure water. During the first hour, the suspension was stirred several times and left for 24 h at room temperature. After that, pH was measured in the supernatant with a pH meter.

Bioavailability of elements in dried soil (2mm) was determined with a sequential extraction method (Zeien and Brummer, 2009). The mobile fraction (F_1) was extracted with 1M NH_4NO_3, and the specifically adsorbed fraction (F_2) was extracted with 1M NH_4OAc. Herein after both fractions together are referred to as "bioavailable". The detailed procedure is described in Grawunder *et al*. (2009).For total content analysis, the soil (2mm) was grounded with a mixer mill for 2min at 25Hz. Total digestion was carried out with a pressure digestion system using HF, $HClO_4$ (70 %), and HNO_3 (65 %). Organic carbon contents were determined with a CNSanalyzer.

Total contents of all elements were not significantly different from each other in soil taken in May and October 2011. This was also the case for the mobile (except for Co, Pb, and Ce) and specifically adsorbed fraction contents. For all elements, the bioavailable contents (sum of a mobile and specifically adsorbed fraction) are lower than the total contents. For Cr and Fe. the bioavailable soil fractions were mainly below the limit of detection(LOD). To get an estimation of the BCFs for these elements, they were calculated by multiplying the LOD by the factor of 0.7 (Croghan and Egeghy, 2003). While the total soil content is the maximum content of a contaminant that could be taken up, the bioavailable content reflects the share, easily available for plants and thus could cause direct harm. This study shows that the total extracted masses of elements have to be considered to evaluate plants' phytoextraction potential instead of contents. For sunflowers grown on a former uranium mining site, 140-170 days of growth were optimal to reach a maximum extraction for all 25 investigated elements. By calculating BCFs related to total soil contents, it was shown that sunflowers are especially effective extractors for Cd at the investigated test site. By calculating BCFs related to mobile soil contents, it was shown that except for Uranium and rare earth elements, all other elements are very well extracted by the sunflower shoots from the direct harmful soil fraction. Although the decontamination of the former uranium mining area with sunflower by phytoextraction would take a long time, the advantages outweigh: low costs and simultaneous growth of bioenergy crops without the interference of food production.

The efficiency of phytoremediation in water disposal by Okrut e*t al.*(2020). The studies were conducted between 2016-2018 at the wastewater facilities of the Andropovsky district of the Stavropol Region, which are intended for the biological treatment of industrial and domestic wastewater. The purpose of the research was to assess the efficiency of phytoremediation technology in the wastewater system with the aim of post-treatment of industrial wastewater. During the research, we set up the following tasks: to assess the state of the wastewater intake; to evaluate the operational efficiency of wastewater treatment facilities by using wastewater treatment facilities for post-treatment. A complete analysis was carried out once a month for the following indicators: temperature, the color of the reaction medium, pH, BOD_5, COD, ammonium nitrogen, nitrates, nitrites, phosphates, surfactants, fats, oil products, chlorides, sulfates, solid residue, dissolved oxygen iron. The mass concentration of dissolved oxygen and sulfates in the waters was determined by the titrimetric method, the concentration of the sum of anionic synthetic surfactants in the waters was measured by the extraction-photometric method; the biochemical oxygen consumption in the waters was determined by the flask method. The obtained indicators were compared with the maximum permissible indicators of fishery value (MPC of fish). The mass concentration of dissolved oxygen in the samples of surface water and treated wastewater in the range of 1.0–15.0 mg/dm^3 was determined. The hydrochemical mode of rivers is fraught with regular changes in the chemical composition of water, some individual components over time that are explained by the basin's physical and geographical conditions, as well as anthropogenic impact. During the research, the analysis of the natural waters of the Kursavka River was conducted. These rivers serve as the water intake of the sewage treatment facilities. During the study, water samples with slightly alkaline pH values were noted; the highest concentrations of suspended solids were obtained in July, which may be associated with increased dead organic matter. The difference in the solid matter in spring was 42 mg/liter. The oxygen concentration is traced, which is associated with the processes of its intake and consumption in the aquatic ecosystem. The oxygen content in the studied natural waters ranged from 7.7-10.7 mg/liter, which is a favorable factor, since the concentration of dissolved oxygen in summer should not be lower than 6 mg/liter for fishery reservoirs. The indicator BOD_5 during the research period indicates a high content of easily oxidized organic substances. The maximum values were noted in April during the flood period, primarily associated with the entry into the water disposal of allochthonous organic substances from the catchment area. The indicators of permanganate oxidizability correspond to physical and geographical zonality. Oxidizability is defined as average. Studies on non-organic indicators of water disposal were carried out with a focus on a set of factors and conditions that take part in the formation of the hydrochemical mode of natural waters. The excess of sulfates averaged 2.4 MPC for ammonium nitrogen-1.4 MPC. A slight increase in the maximum permissible concentration (MPC) of phosphates was noted from 1.2 in March and May to 2.6 in July. The presence of phosphates in the waters of the river is due to the transformation processes of organic substances and the influx of wastewater. The iron content in the studied samples was 3.6–2.6 MPC in summer, and 2 MPC in spring. Iron is a heavy metal, and its excess can hurt and harm the inhabitants of the aquatic ecosystem.Along with this, iron is an essential trace element, on which various biological processes depend. The intensity of phytoplankton development and the quality of microflora in water bodies depends on the iron content. The analysis of the season dynamics of the hydrochemical parameters of the water entering the treatment facility showed an excess of ammonia nitrogen from 35.4 MPC to 52 MPC in fish, the maximal value of nitrites amounted to 5.4 MPC in March, and the minimal one was equal to 3.8 MPC in February. For sulfates, the value was not stable, within 1.8 to 2.7 MPC, and for phosphates, from 1.5 to 5.7 MPC. In the studies, an excess of MPC for iron was noted. Since iron belongs to heavy metals, an analysis was made of the seasonal indicators of this substance in the waters of the river where the water intake is. The maximum values were recorded in September, which amounted to 4.9 MPC, and the minimal indicators were recorded in spring, which amounted to 1.8 MPC.

Phytoremediation of industrial mines wastewater using water hyacinth carried out by Priyanka Saha *et al*. (2017). The study was conducted using water hyacinth weeds (*Eichhornia crassipes*) which served as a tool of Phytoremediation. These aquatic weeds were used to reduce Chromium from contaminated untreated mine wastewater. Plants were collected from the local area of Jamshedpur, India. After collection, they were rinsed with tap water to remove any epiphytes and insect larvae grown on plants. A 1-week acclimatization period was set to stabilize the plant. The plants were placed in a tub with tap water without adding any nutrient media under natural sunlight for 1 week to let them adapt to the new environment. Then, the plants of the same size were selected for the following experiments. Water samples were collected from the beneficiation plant's quarry water storage area (tailing pond recirculating water).The analysis of wastewater from mines was carried out for the estimation of physico-chemical parameters before and after the phytoremediation experiments. The experiments were conducted in a series of the rectangular plastic containers containing 5 and 100 L of water from SCM, respectively, at an ambient temperature range (25-30^{o}C). 250 g (for 5 L water) of fresh biomass of *Eichhornia crassipes* was cultured in a tub for a period of 7 days, whereas one of them was used as control, and again, the fresh biomass was noted for the following experiments. A plastic jar with only SCM effluent (not using plant) was used as control. The test durations were 0 (initial day), 5, 10, and 15 days, respectively. Deionized water was added daily to compensate for the water loss through plant transpiration, sampling, and evaporation. The changes in pH, TDS, and Cr(VI) concentrations were determined at regular intervals. After each test duration, *E. crassipes* were separated into leaves, shoots, and roots for the analysis of Cr(VI) accumulation, and bio-concentration factor. The TDS and DO of the treated water were also measured to know the effect of accumulation on the plant. After each experiment, plants were recycled for the next experiment. This is repeated 5–6 times. After a specific time, aquatic plants were harvested. If the plants are not harvested, then nutrients will be released back into the water system after their death and decomposition. Therefore, regular harvesting was done to avoid this process of releasing back of nutrients. After getting successful results, a large-scale experiment was carried out in 100 L chromium-contaminated processed water from SCM. For this experiment, 5 kg (for 100 L water) of fresh biomass of *E. crassipes* was used.

Future Research Prospects in Phytoremediation

The few limitations of the use of plant species for cleanup potential include sluggish growth, which restricts rapid and extensive applications of these plants, as well as tolerance to a wide range of environmental circumstances such as nutrient-poor soils (Gerhardt *et al.,* 2017; Sarwar *et al.,* 2017). In order to ensure that these plants can perform phytoremediation effectively, a strategy is devised by changing and improving some of their features. To increase the growth rate and biomass of hyperaccumulators or to add hyperaccumulation features into fast-growing, high-biomass plants, conventional breeding (plant pollination) or genetic engineering (production of transgenic plants) are used (DalCorso *et al.,* 2019).

It has been established that genetic engineering is a promising method for enhancing plants' capacity for phytoremediation of heavy metal contamination. A foreign gene from a species, such as a plant species, bacteria, or even an animal, is introduced and injected into the genome of a target plant to genetically change it (Marques *et al.* 2009).Another strategy to enhance plant performance for phytoremediation is the use of plant-associated organisms (rhizosperic microorganisms). The microbial rhizosphere community may directly stimulate root growth, hence promoting plant growth, increasing heavy metal tolerance, and improving plant fitness (Fasani *et al.,* 2018).Beyond plant performance, boosting heavy metal bioavailability is a crucial tactic for enhancing phytoextraction's effectiveness. There are times when the heavy metals in the soil are not easily accessible for bioaccumulation. Only a small part of the overall amount of heavy metals in the soil are soluble components that are available for plant uptake (Blaylock and

Huang, 2000). In comparison to other heavy metals, Zn and Cd are more bioavailable to plants (Lasat, 1999). Heavy metals and metalloids can be divided into three categories based on their bioavailability in soil: readily bioavailable heavy metals (Cd, Ni, Zn, As, Se, Cu), moderately bioavailable heavy metals (Fe, Mn, Co), and least bioavailable heavy metals (Pb, Cr) (Prasad, 2003).Nehnevajova *et al.* (2007) treated sunflowers with the chemical mutagen ethyl methanesulfonate (EMS) to produce sunflower "giant mutant" plants that had significantly improved heavy metal extraction abilities, accumulating Cd, Zn, and Pb at rates of 7.5 times, 9.2 times, and 8.2 times, respectively, compared to control plants (Nehnevajova *et al.,* 2007).Similar to this, protoplasts obtained from the zinc hyperaccumulator such as *Brassica napus* and *T. caerulescens* were fused via electrofusion by Brewer *et al.* (1999). The chosen hybrids (somatic hybrid), which had improved hyperaccumulation potential and sensitivity derived from *Brassica napus* and *T. caerulescens* increased biomass yield derived, and demonstrated the capacity to accumulate large levels of Cd and Zn. (Brewer *et al.,* 1999). This study showed that somatic hybridization can successfully transfer the metal hyperaccumulation trait to high biomass plants.

Conclusion

A significant problem for food safety, agricultural production and environment maintenance is heavy metal contamination because of its harmful effects and quick buildup in the environment. Several methods have been developed to stop or lessen heavy metal contamination and replant the contaminated soil. Compared to other physicochemical procedures, Phytoremediation offers several advantages and has been shown to be a potential method for replanting heavy metal-contaminated soil. The simplest method for Phytoremediation is the application of heavy metal hyperaccumulators, and hundreds of these plants have already been discovered. Phytoremediation needs an interdisciplinary approach with inputs from many fields such as botany, physiology, geochemistry, industrial chemistry, agricultural engineering, agronomy, soil science, and genetic engineering to come up with strategic measures for the future Phytoremediation that will become a widely acceptable technology for the plants to remove pollutants especially heavy metals from the environment which is very fascinating field of research. Thus, Phytoremediation is considered one of the most effective methods of environmental control.

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