A review on potential of field crops in Phytoremediation.

Abstract

Heavy metals (HMs) are distinct products, due to this distinctness they are incapable of being broken down into non-toxic forms. Heavy metals are discharged into the environment by both natural and man-made sources, including mining and industrial activity, as well as automotive emissions. They seep into subsurface waters, travelling through water routes, or are swept away by run-off into surface waters, polluting the water and as responsible for a soil pollution. Because of population growth, industrialisation, and urbanisation, HM pollution is on the rise. Organic and inorganic pollutants are now poisoning a large area of the world, with heavy metal pollution becoming a serious problem in recent years. Toxic heavy metal has a detrimental influence on plant growth, which also damages DNA, and causes cancer in animals and humans. Plants are used in phytoremediation to remove, transport, stabilise, and decompose pollution from soil, sediment, and water. It includes phytoextraction, rhizofiltration, phytostabilization, phytovolatization, phytodegradation/phytotransformation.Phytoremediation technique has gained popularity in recent years due to its quality, as a low-cost, effectiveness and ecologically benign method of removing harmful metals from the soil. Field crops have a high phytoremediation effectiveness because they may form a dense green canopy on disturbed soil, enhancing the landscape and limiting pollutant mobility through water, wind erosion, and percolation. More than 400 plant species have been identified to have potential for soil and water remediation, such as *Brassica juncea* (L.), *Helianthus annuus* (L.), *Zea mays* (L.), *Brassica napus* (L.) and *Ricinus communis*, *Thlaspi*, *Brassica*, and *Arabidopsis* is well recognised. Our paper aims to cover the causes of Heavy Metal pollution and phytoremediation technology, including HM uptake mechanism and several research reports describing its application at field level.

Keywords: Efficiency, field crops, heavy metals, phytoextraction, phytoremediation, phytostabilisation, rhizofiltration andtechnology.

Introduction

Heavy metals (HM) are a unique class of toxicants since they cannot be broken down to non-toxic forms[1].Toxic metals concentration has accelerated dramatically since the beginning of the industrial revolution[2] thus, posing problems to health and environment[3]. Once the heavy metals contaminate the ecosystem, they remain a potential threat for many years. HM contaminants causing ecological problems on a global scale. HM refers to metals and metalloids having densities greater than 5 g cm^{-3} and is usually associated with pollution and toxicity although, some of these elements (essential metals) are required by organisms at low concentrations[4]. The most common HM contaminants are: cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn)[5] . These heavy metal pollution causes environmental harm that is difficult to reverse naturally, necessitating cleanup activities. Phytoremediation is the capacity of plants to absorb and remove organic and inorganic pollutants from the soil and transform them to non-toxic forms. [17]The generic term “phytoremediation” consists of the Greek prefix Phyto (plant), attached to the Latin root medium (to correct or remove an evil). Phytoremediation is an new technology using selected plants to clean up the contaminated environment to modify the ecological properties[6]. This technology is an environmentally acceptable method of treating contaminated soil and wastewater with plants. It is made up of two parts: one is produced by root colonisation microorganisms, and the other is produced by plants themselves, which accumulate hazardous chemicals and convert them to non-toxic metabolites. Plants can successfully remediate a variety of toxins, including organic synthetic chemicals, xenobiotics, pesticides, hydrocarbons, heavy metals, and radionuclides[7] .The phytoremediation efficiency of plants depends upon various physical and chemical properties of soil, plant, bioavailability of metals and capacity of plants to uptake, accumulate and detoxify metals. For selections of plants which are suitable for phytoremediation of polluted soils, one has to understand the mechanism underlying plant tolerance towards a particular metal. Proper plant species selection for phytoremediation is critical into the progress of remediation technologies[8].

Phytoremediation, a fast-emerging new technology for removal of toxic HMs, is cost-effective, non-intrusive and aesthetically pleasing. It exploits the ability of selected plants to remediate pollutants from contaminated sites. Plants have inter-linked physiological and molecular mechanisms of tolerance to HMs. High tolerance to HM toxicity is based on a reduced metal uptake or increased internal sequestration, which is manifested by interaction between a genotype and its environment. The growing interest in molecular genetics has increased our understanding of mechanisms of HM tolerance in plants and many transgenic plants have displayed increased HM tolerance. Improvement of plants by genetic engineering, that is, by modifying characteristics like metal uptake, transport and accumulation and plant‟s tolerance to metals, opens up new possibilities of phytoremediation. Phytoremediation can be used to remove not only metals (for example, Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn) but also radionuclides (for example, 90Sr, 137Cs, 239Pu, 234U, 238U) and certain organic compounds[9].

The phytoremediation efficiency of plants depends upon various physical and chemical properties of soil, plant, bioavailability of metals and capacity of plants to uptake, accumulate and detoxify metals. For selections of plants which are suitable for phytoremediation of polluted soils, one has to understand the mechanism underlying plant tolerance towards a particular metal. The HM pollution is a very vast subject, but in this review, we will try to focus on the sources of soil pollution, mechanism of metal uptake by the plants and the different types of phytoremediation and their practical application in soil remediation.

Phytoremediation –need and objectives

Environmental pollution has become a crucial public health problem since it is a major source of health risk and causes a variety of serious diseases all over the world[10]. The presence of hazardous metals is the most severe issue regarding environmental pollution.Toxic metal effects on people have long been recognised, yet their exposure persists and is increasing in many sectors. Heavy metal has a negative impact on people and can possibly kill them[11]. Site regulators, owners, and managers might use phytoremediation as a learning tool to assess the site's suitability for phytoremediation. Phytoremediation has been proposed or used to help restore ecosystems, such as soil, surface water, groundwater, and sediment remediation [12].

Phytoremediation procedures perhaps more publically allowed, stylistic pleasing and less disruptive than traditional physical and chemical cleanup methods[13] . Its contaminant-reduction effectiveness, cheap cost, application to a broad range of pollutants and overall environmental friendly. It uses low-cost biosorbent materials and is successful at decreasing heavy metal ion concentrations to extremely low levels. Phytoremediation is the cleanest and least expensive method available, and it may be used to clean up a variety of hazardous areas. It is cost-effective for huge volumes of water having low concentrations of contaminants and for large areas having low to moderately contaminated surface soils [14]. It may be used to treat a wide range of hazardous metals and radionuclides, as well as a wide range of environmental pollutants, both organic and inorganic.

[6]**Table:1 Some heavy metals have a toxic effect on humans.**

Toxic metal	**Effect**
Silver	The tissue becomes grey or blue grey, causing breathing difficulties, throat discomfort, and stomach ache.
Arsenic	ATP production and oxidative phosphorylation are both affected.
Barium	Barrium's toxicity causes cardiac arrhythmias, respiratory failure, gastrointestinal problems, and high blood pressure.
Cadmium	High doses of cadmium causes serious problems like cancer,mutagenic. endocrine disruptor, lung damage, and other issues"
Chromium	"Hair loss"
Copper	Irritation of the stomach and intestines, as well as brain and kidney damage
Mercury	Autoimmune illnesses, depression, lethargy, insomnia, memory loss, and lung and renal failure are among symptoms of mercury exposure.
Lead	Excessive Pb exposure in children results in delayed development, lower intellect, short-term memory loss, learning impairments, coordination issues, and an increased risk of cardiovascular disease.

Properties of phytoremediant Plants

Hypertolerance is the main quality that enables hyper-accumulation in rhizosphere and shoot cells; hypertolerance is the important attribute that enables hyper-accumulation in root and shoot cells. These plants must be able to move an element quickly from their roots to their branches. Root Zn, Cd, or Ni concentrations are typically 10 times or more higher than shoot metal concentrations; but, in hyperaccumulators, shoot metal concentrations can reach root levels. Along with the plant's fast growth and increased biomass output, the element must be absorbed quickly at levels visible in the soil.The plant must be able to thrive outside of its collection region, be economically valuable, and disease and insect resistant[15].

Field crops as hyperaccumulators and their potential for phytoremediation

Field crops with a 3 to 5 month life cycle are farmed on a wide scale for consumption. Crop plants can be utilised for phytoremediation since they produce a lot of biomass and can rapidly adapt to changing conditions. Crop plants' phytoremediative agents must be able to withstand and accumulate substantial levels of pollutants for phytoremediation to be successful[16] .Certain crops, on the other hand, have the ability to collect different levels of heavy metals, rendering them unsuitable for human consumption. Furthermore, by using a technique known as phytomining, this waste biomass may be utilised to re-extract the accumulated metals. Bioenergy crops, in addition to food crops, offer a lot of promise for phytoremediation since they may be utilised for both energetic generation and environmental cleanup[17].When compared to non-accumulators, hyperaccumulator plants have a higher capacity to absorb pollutants from the [32]soil surface, quicker translocation from rhizosphere to shoots, and superior mechanisms for contaminant sequestration[18] .Crop plants either produce ligands to bind metals or acidify the rhizosphere with the aid of plasma membrane proton pumps to absorb metals from the soil [19] .

<u>Methodology</u>

How do plants uptake metals? Bioavailability of metals is the primary factor responsible for the uptake of metals. In soils, metals exist as a variety of chemical forms in a dynamic equilibrium governed by the physical, chemical and biological processes of the soil. Bioavailability of soil pollutants, a primary basis of remediation efficacy, refers to a fraction of the total pollutant mass in the soil and sediment available to plants. Uptake of metals by plants involves root interception of metal ions, entry of metal ions into roots and their translocation to the shoot through mass flow and diffusion. Plants have evolved highly specific mechanisms to take up, translocate, and store these nutrients. For example, metal movement across biological membranes is mediated by proteins with transport functions. In addition, sensitive mechanisms maintain intracellular concentration of metal ions within the physiological range. In general, the uptake mechanism is selective and plants preferentially acquired some ions over others. Ion uptake selectivity depends upon the structure and properties of membrane transporters. These characteristics allow transporters to recognize, bind and mediate the trans-membrane transport of specific ions. For example, some transporters mediate the transport of divalent cations, but do not recognize mono- or trivalent ions. The rate of metatranslocation to the shoot may depend on metal concentration in the root. A phytochelatin (PC)-mediated metal binding in the xylem sap as a possible mechanism for metal translocation has been proposed. Nutrients destined for the developing cereal grain encounter several restricting barriers on their path towards their final storage sites in the grain. In order to identify transporters and chelating agents that may be involved in transport and deposition of Zn in the barley grain, expression profiles have been generated of four different tissue types; the transfer cells, the aleurone layer, the endosperm, and the embryo[20]. Phytoremediation technology can be subdivided, on the basis of the underlying process and applicability.

Different techniques/methodologies of Phytoremediation are as under.

The kind of pollutant, bioavailability, and soil properties all influence the technique and performance of phytoremediation[21] . Depending on the plant and the place to be remediated, plants clean up or remediate contaminated environments in various ways. The majority of the mechanisms for resolving toxicity in soil are found in the root system of plants. Water, nutrients, and other non-essential contaminants are collected and stored by the root system, which has a huge surface area[22]. Plants can alter pollutant mass in soil, sediments, and water through seven processes, according to this study. Each of these processes will have an impact on the amount of pollutants present, their mobility, and their toxicity.[23]

I):Phytoextraction or phyto-accumulation refers to the absorption and transfer of metal pollutants in the soil by plant roots into the above-ground sections of the plants . The plants are designed to accumulate pollutants from the soil in this method. Toxins are concentrated and precipitated in above-ground biomass by the plants.The low cost of phytoextraction makes it fairly feasible compared to conventional methods in addition to permanent removal of contaminant from the soil. Metal hyper accumulator species of plants opened the vision towards plants having the potential to remove metals from contaminated soils[22]. The metals that are mainly removed by phytoextraction include Nickel, zinc and copper because of their preference by a majority of plants. According to USEPA (2000), the amount of waste material that must be disposed of is reduced by up to 95 percent, and the contaminant can be recycled from the contaminated plant biomass in some situations. Slow growth, shallow root systems, and poor biomass output limit the utilisation of hyper accumulator species. Furthermore, the plant biomass must be collected and disposed of according to regulations [22]. Presence of metals within the rhizosphere, Rate of metal uptake by roots, Proportion of metal "fixed" within the roots, Rate of xylem loading/translocation to shoots and Cellular tolerance to toxic metals are some of the key limiting factors in the process of phytoextraction. Metals and other inorganic substances in soil or sediment are generally excluded from the technique[24]. To make this approach more practical, the plants must collect significant amounts of heavy metals into their roots, translocate the heavy metal into the surface biomass, and generate a big amount of plant biomass [25].

Certain plants, called hyper-accumulators, absorb unusually large amounts of metals in comparison to other plants. More than 400 plant species have been identified to have potential for soil and water remediation [26]. As different plants have different abilities to uptake and withstand high levels of pollutants, many different plants may be used for phytoremediation. The strategies used in developing a phytoremediation plant are (a) screening of hyperaccumulator candidate plants, (b) plant breeding, and (c) development of improved hyperaccumulators using genetic tools. The hyperaccumulators that have been most extensively studied by scientific community include *Thlaspi* sp., *Arabidopsis* sp., *Sedum alfredii* sp. (both genera belong to the family of Brassicaceae and Alyssum). *Thlaspi* sp. are known to hyperaccumulate more than one metal, that is, *T. caerulescens* for Cd, Ni, Pb and Zn, *T. goesingense* for Ni and Zn, *T. ochroleucum* for Ni and Zn, and *T. rotundifolium* for Ni, Pb and Zn[27].

Metal phytoextraction involves: 1) cultivation of the appropriate plant/crop species on the contaminated site; 2) removal of harvestable metal-enriched biomass from the site; and 3) postharvest treatments (that is, composting, compacting, thermal treatments) to reduce the volume and/or weight of biomass for disposal as a hazardous waste or for its recycling to reclaim valuable metals. Two basic strategies of metal phytoextraction have been suggested, continuous or natural phytoextraction and induced, enhanced, or chemically assisted phytoextraction [28]. After the plants have been allowed to grow for some time, they were harvested and either incinerated or composted to recycle the metals. This procedure may be repeated as necessary to bring soil contaminant levels down to allowable limits. If plants are incinerated, the ash must be disposed of in a hazardous waste landfill, but the volume of ash will be less than 10% of the volume that would be created if the contaminated soil itself were dug up for treatment. In some cases, it is possible to recycle the metals through a process known as phytomining, though; this is usually reserved for use with precious metals. Metals such as Ni, Zn, and Cu are the best candidates for removal by phytoextraction because the majority of the approximately 400 known plants that absorb unusually large amounts of metals have a high affinity for accumulating these metals. Plants that absorb Pb and Cr are currently being studied and tested. According to report, in the presence of vegetation, the exchangeable form of Cd was partly removed by plant uptake that accompanied with the intake of nutrition[29]. Cd-hyperaccumulating plant species are almost the only ones that can grow in soil solutions containing Cd concentrations as high as 35 μmol/L (3.9 mg/L)[30]. Zhang and his co workers reported in his experiment expressed that as Cd phytoextraction is observed by maize, the percentage of exchangeable form of Cd decreased in the planted soil. Besides, plant root exudates and rhizosphere micro-organisms accelerated the stability process of added Cd in soils, which might make the exchangeable form transform to other relatively stable forms such as organic form and residual form and might help reduce the harm of Cd to soil and water environment [29].

ii)Rhizofiltration

[5]Rhizofiltration is typically exploited in groundwater surface water, or wastewater for removal of metals or other inorganic compounds[24]. Rhizofiltration technique is used to remediate Pb, Cd, Cu, Ni, Zn, and Cr, which are primarily retained within the roots[31].Rhizofiltration is generally used to remediate polluted ground water, as opposed to phytoextraction, which is used to treat soils. Plants used in Rhizoextraction are grown in greenhouses or glasshouses with their

rhizosphere in water .Once the plants have established a big root system, polluted water is collected from a waste site and sent to the plants, where it is used as a supply of water. The plants are then placed in the polluted region, where their roots absorb the water as well as the pollutants. The roots are taken when they get saturated with pollutants. Sunflower, Indian mustard, tobacco, rye, spinach, and corn have all been tested for their capacity to remove lead from water, with sunflower having the best rhizoextraction results. After one hour of treatment, sunflowers dramatically decreased lead concentrations in a study [22]. The advantages associated with rhizofiltration are the ability to use both terrestrial and aquatic plants for either *in situ* or *ex situ* applications and that contaminants do not have to be translocated to the shoots. Thus, species other than hyperaccumulators may be used. Terrestrial plants are preferred because they have a fibrous and much longer root system, increasing the amount of rhizosphere surface [22].

The plants to be used for clean-up are raised in greenhouses with their roots in water. Contaminated water is both collected from a waste site and brought to the plants, or the plants are planted in the contaminated area, where the roots then take up the water and the contaminants dissolved in it. As the roots become saturated with contaminants, they are harvested and disposed of safely. Rhizofiltration remediates metals like As, Pb, Cd, Ni, Cu, Cr, V and radionucliides (U, Cs and St). The ideal plants should produce significant amounts of root biomass or root surface area, be able to accumulate and tolerate significant amounts of target metals, involve easy handling and a low maintenance cost, and has a minimum of secondary waste that requires disposal. Terrestrial plants are more suitable for rhizofiltration because they produce longer, more substantial and often fibrous root systems with large surface areas or metal adsorption. *Pteris vittata*, commonly known as Chinese brake fern, is the first known As-hyper accumulator[32].Several aquatic species have the ability to remove HMs from water, including Water Pennywort (*Hydrocotyle umbellate* L.) ,Duckweed (*Lemna minor* L.)[33] and Water Hyacinth (*Eichhornia crassipes* (Mart.)[34]. Indian mustard (*Brassica juncea*) and sunflower (*Helianthus annuus*) are most promising for metal removal from water. Indian mustard effectively removes Cd, Cr, Cu, Ni, Pb, and Zn [35] whereas sunflower absorbs Pb and U [36]from hydroponic solutions. Indian mustard could effectively remove a wide range (4 to 500 mg/L) of Pb concentration[36]. Karkhanis [38] reported the result of their experiment conducted on rhizofiltration under greenhouse condition using pistia, duckweed and water hyacinth (*E. crassipes*) to remediate aquatic environment contaminated by coal ash containing HMs. The results showed that pistia has high potential capacity of uptake of the HMs (Zn, Cr, and Cu) and duckweed also showed good potential for uptake of these metals next to pistia. Rhizofiltration of Zn and Cu in case of water hyacinth was lower as compared to pistia and duckweed. In a recent study, the potential of water hyacinth (*E. crassipes*) weeds for phytoremediation of metal polluted soils by rhizofiltration method was reported by Mohanty and Patra [38].The mine waste water at South Kaliapani chromite mining area of Orissa (India) showed high levels of toxic hexavalent (Cr+6). Cr+6 contaminated mine waste water poses potential threats for biotic community in the vicinity. The weeds significantly reduced (up to 54%) toxic concentrations of Cr+6 from contaminated mine waste water when passed through succeeding water hyacinth ponds. The reduction of toxic Cr level varied with the plant age and passage distance of waste water. Cr phytoaccumulation and Bio-Concentration Factor (BCF) was maximum at growing stage of plant that is, 75 days old plant.

iii) Phytovolatilization

Phytovolatilization refers to the uptake and transpiration of contaminants, primary organic compounds by plants. 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 (evaporates or vaporizes). The contaminant may become modified along the way, as the water travels along the plant‟s vascular system from the roots to the leaves, whereby the contaminants evaporate or volatilize into the air surrounding the plant[31& 24]. The diffusion of pollutants from the stems or other plant components that the contamination goes through before reaching the leaves is sometimes referred to as phytovolatilization[22]. Phytovolatilization can be used to remediate pollutants in soil, sediment, or water, and it is most commonly employed for Mercury. It's also been identified in inorganic substances like selenium and arsenic, as well as volatile organic molecules like trichloroethene [24].Phytovolatilization has been primarily used for the removal of murcury, the mercuric ion is transformed into less toxic elemental Hg[25] .Drawback is that the mercury released into the atmosphere is likely to be recycled by precipitation and then deposited back into lakes and oceans, repeating the production of methylmercury by anaerobic bacteria [31].

iv)Phytostabilization

Phytostabilization, also referred to as in-place inactivation, is primarily used for the remediation of soil, sediment, and sludges[31]. It is the use of plant roots to limit contaminant mobility and bioavailability in the soil and water. Contaminants are absorbed and accumulated by roots, adsorbed onto the roots, or precipitated in the rhizosphere. This procedure lowers the contaminant's mobility and inhibits migration to groundwater, as well as the metal's bioavailability in the food chain. This method employs metal-tolerant species to reestablish vegetation in polluted areas, reducing the possibility for pollutants to migrate by wind erosion and the movement of exposed soil. Phytostabilization can occur through the sorption, precipitation, complexation, or metal valence reduction. It is useful for the treatment of lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Phytostabilization takes advantage of the changes that the presence of the plant induces in soil Chemistry and environment. Some of the benefits of this method include the fact that hazardous materials/biomass do not need to be disposed of, and it is highly successful when fast immobilisation is necessary to conserve ground and surface waters[29]. Plants also help to reduce soil erosion and the quantity of water that is accessible in the system[31] . However, there are numerous important drawbacks to this clean-up technique, including the presence of contaminants in the soil, the need for intensive fertilisation or soil amendments, and the requirement for periodic monitoring.

Smith and Bradshaw[39] developed two cultivars of *Agrostis tenius* and one of *Festuca rubra*, which are used for phytoremediation of the Pb, Zn and Cu contaminated soils. Phytostabilization, though most effective at sites having fine-textured soils with high organic matter content, can treat a wide range of surface contamination[40&41]. Deep rooting plants could reduce the highly toxic Cr VI to Cr III, which is much less soluble and therefore, less bioavailable [42]. Phytostabilization does not require soil removal and/or disposal of the hazardous material or the biomass. An experiment was conducted under green house condition using sorghum (fibrous root grass) to remediate soil contaminated by HMs and the developed vermicompost was amended in contaminated soil as a natural fertilizer[43]. It was reported that growth was adversely affected by HMs at the higher concentration of 40 and 50 ppm, while lower concentrations (5 to 20 ppm) stimulated shoot growth and increased plant biomass. Moreover, HMs were efficiently taken up mainly by roots of sorghum plant at all the evaluated concentrations of 5, 10, 20, 40 and 50 ppm. The order of uptake of HMs was: Zn>Cu>Cd>Ni>Pb. The large surface area of fibrous roots of sorghum and intensive penetration of roots into the soil reduces leaching via stabilization of soil and capable of immobilizing and concentrating HMs in the roots. Recently, a study was conducted by Cheraghi with his co-workers [44] on phytostabilization using different plant species. Their results indicated that *C. bijarensis, C. juncea, V. speciosum, S. orientalis, C. botrys, and S. barbata*, had a high bioconcentration factor and low translocation factor for Mn, therefore having potential for the phyto-stabilization of Mn.

V) Phytodegradation

It requires breaking down complex organic chemicals into simpler ones or integrating them into plant tissues [23]. Pollutants are broken down during phytodegradation once they have been taken up by the plant. Plant absorption occurs only when the solubility and hydrophobicity of pollutants fall below a certain threshold, analogous to phytoextraction and phytovolatilization. Phytodegradation, which can address toxins in soil, sediment, or groundwater, has been demonstrated to remediate certain organic pollutants, for example chlorinated solvents, herbicides, and explosives [24].

Phytodegradation is the breakdown of organic contaminants within plant tissue. Plants produce enzymes, such as dehalogenase and oxygenase that help catalyze degradation. It appears that both the plants and the associated microbial communities play a significant role in attenuating contaminants. It is referred to the degradation or breakdown of organic contaminants by internal and external metabolic processes driven by the plant [27]. *Ex planta* metabolic processes hydrolyse organic compounds into smaller units that can be absorbed by the plant. Some contaminants can be absorbed by the plant and are then broken down by plant enzymes. These smaller pollutant molecules may then be used as metabolites by the plant as it grows, thus becoming incorporated into the plant tissues. Plant enzymes have been identified that breakdown ammunition wastes, chlorinated solvents such as TCE (Trichloroethylene), and others which degrade organic herbicideds. Plant enzymes that metabolise contaminants may be released into the rhizosphere, where they may play active role in transformation of contaminants. Enzymes, like dehalogenase, nitro-reductase, peroxidase, laccase and nitrilase, have been discovered in plant sediments and soils. Organic compounds such as munitions, chlorinated solvents, herbicides and insecticides and the inorganic nutrients can be degraded by this technology[45]. The dissolved TNT (trinitrotoluene) concentrations in flooded soil decreased from 128 ppm within one week in the presence of the aquatic plant, *Myriophyllum aquaticum*, which produces nitroreductase enzyme that can partially degrade TNT [45].

vi) Rhizodegradation

It breaks down pollutants in the rhizosphere, or root zone, of plants. This process is thought to be initiated by bacteria or other microorganisms that thrive in large numbers in the rhizosphere. In addition to plant exudates such as sugars, amino acids, enzymes, and a route for oxygen transfer from the environment, the roots provide surface area for microorganisms to thrive. Rhizodegradation is a localised process that has been found to be effective in treating a wide range of mostly organic chemicals, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, and xylenes [24]. It's also known as plant-assisted bioremediation, which involves the release of exudates/enzymes into the root zone to promote microbial and fungal breakdown (rhizosphere) [46].

Some research evidences on phytoremediation potential of field crops

Mojiri.A[48] conducted an experiment in Iran to observe the potential of corn (maize) for phytoremrdiation of soil contaiminated with cadmium and lead. Accumulation of cadmium in root is higher than in shoot, this showed that root of Corn is more active than shoot to phytoremediation of cadmium.Increasing soil contamination to 8(ppm)increased phytoremediation of cadmium from soil by *Corn.*

Table 2: Metal recovery(%) by *Brassica juncea* in soils amended with cow dung

Parameter	Heavy metal concentration in whole plant on 81d (ppm)	Metal absorption by plant/pot (ppm)	% recovery of heavy metal by plant
Cr	0.117	9.611	11.529

Cu	0.188	15.410	41.7
Ni	0.038	3.12	6.16
Pb	1.848	151.5	20.8
Zn	0.671	55.0	51.8

Gayatri and his co-workers [49] conducted an experiment to examine the uptake efficiency and phytoremediation potential of *Brassica juncea* in soils amended with cow dung. It has been observed that pH has regulated the phytoavailability of metals. Other parameters like Electrical Conductivity, Organic Matter and Organic Carbon has also played a significant role throughout the lifecycle and substantial reduction of Organic Matter and Organic Carbon has been observed which represents the regular activity of uptake of heavy metals by *Brassica juncea*. Through Metal Extraction Ratio, it has been observed that the uptake of Lead has been greater than the other heavy metals. Translocation factor indicates that *Brassica juncea* is a hyperaccumulator in the present study. It can be described as the percentage of recovery from soil to plant parts were estimated using the amount of metal absorbed by the plant in each pot (ppm/pot). Lead (151.5 ppm) is the most abundant metal taken by the plant, followed by Zinc (55 ppm), Copper (15.4 ppm), Chromium (9.6 ppm), and Nickel (9.6 ppm) (3.1 ppm). Zinc (51.8%), Copper (41.6%), Lead (20.8%), Chromium (11.5%), and Nickel (51.8%) had higher percentages of recovery (6.1 percent).

Table 3: Cowpea and Groundnut Seed Germination on Crude Oil Contaminated Soil

Crop plant	Crude oil level (%)								
	0.0	0.5	1.0	2.0	2.5	5.0	10.0	15.0	20.0
Groundnut	+	+	+	+	+	+	+	+	+
Cowpea	+	+	+	+	+	-	-	-	-

Manga and his co-researchers [50] demonstrated in their experiment that Phytoremediation effect or strength is higher for groundnut grown on soil sample polluted with crude oil at a specified concentration value ranges from 0.0 to 20.0 to still grow, i.e. despite the pollution of the soil sample, reduction in soil bacteria count, growth depression, and unfavourable soil conditions, groundnut still beat restrictions to grow and survive, but the other legume (cowpea) germinates, In this study, groundnut proved to be beneficial.

Limitations of Phytoremediation Technology

1.Phytoremediation is a time-consuming procedure that can take up to many growing seasons to complete.

2. Plants may be harmed by the intermediates generated by the organic and inorganic pollutants.

3. The age of the plant, root depth, climate, soil, and vegetation all have a role in phytoremediation.

4. Because phytoextraction or degradation might take many years to treat soils, phytoremediation may not be the best option for locations that represent a high danger to humans and other ecological receptors.[14]

Conclusion.

Plants are used to breakdown, absorb, metabolise, or detoxify metal and organic chemical pollution in phytoremediation. Economic advantages, harvesting management, and by-product use are all important factors for plants employed in phytoremediation. Growing field plants based on their habitat and phytoremediation capacity not only adds colour to the landscape, but it also helps to clean up pollutants in both terrestrial and aquatic habitats. Because many plants are not edible, the danger of metals entering the food chain is minimised. This technology will continue to contribute to make agriculture more profitable and sustainable and drastically reduce the contaminant load & the associated negative impact on the environment. Phytoremediation is a potential remediation strategy that can be used to decontaminate soils contaminated with inorganic pollutants. Research related to this relatively new technology needs to be promoted and emphasized and expanded in developing countries since it is low cost. *In situ*, solar driven technology makes use of vascular plants to accumulate and translocate metals from roots to shoots. Harvesting the plant shoots can permanently remove these contaminants from the soil. Phytoremediation does not have the destructive impact on soil fertility and structure that some more vigorous conventional technologies have such as acid extraction and soil washing. This technology can be applied "*in situ*" to remediate shallow soil, ground water and surface water bodies. Also, phytoremediation has been perceived to be a more environmentally-friendly "green" and lowtech alternative to more active and intrusive remedial methods. The broader importance of protecting soils and improved management for the services they provide are currently receiving considerable attention from policy-makers. Soils provide fundamental ecosystem services, with extensive economic, ecological, and sociological influences on the wellbeing of the human society. Metal-contaminated soils provide a significant but previously neglected component of the global soil resource.

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