A review on potential of field crops in Phytoremediation.

Heavy metals (HMs) are unique products, and as a result of their uniqueness, they cannot be converted into non-toxic forms. Both natural and man-made sources, such as mining, industry, and automobile emissions, release heavy metals into the environment. They enter subsurface waters through waterways or are carried away by runoff into surface waters, damaging both the water and the land at the same time. 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. To remove, transport, stabilise, and breakdown contaminants from soil, sediment, and water, phytoremediation employs plants. Rhizofiltration, phytostabilization, phytovolatization, phytodegradation, and phytotransformation are some of its processes. Due to its advantages as a low-cost, effective, and environmentally friendly way of eliminating dangerous metals from the soil, phytoremediation has grown in favour in recent years. Field crops can create a thick green canopy on disturbed soil, improving the landscape and reducing contaminant movement through water, wind, and percolation. This increases the effectiveness of phytoremediation. More than 400 plant species, including the well-known *Ricinus communis, Thlaspi, Brassica,* and *Arabidopsis, Helianthus annuus, Zea mays*, and *Brassica napus*, have been identified as having potential for soil and water remediation. In this review article, we discuss the factors that contribute to heavy metal pollution, phytoremediation technology, the method by which heavy metals are taken up, and various studies that describe its practical use.

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

Introduction

Since they cannot be converted into non-toxic forms, heavy metals (HM) represent a distinct class of toxicants[1]. Since the start of the industrial revolution[2], the concentration of toxic metals has increased substantially, posing risks to human health and the environment[3]. Once heavy metals have contaminated the ecosystem, they pose a long-term risk. Environmental issues caused by HM pollutants on a worldwide scale. Once heavy metals have contaminated the ecosystem, they pose a long-term risk. Environmental issues caused by HM pollutants on a global scale. Although some of these elements (essential metals) are needed by organisms at low concentrations, HM refers to metals and metalloids with densities greater than 5 g cm-3 and is typically associated with pollution and toxicity[4]. Cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni), and zinc are the most prevalent HM pollutants (Zn)[5]. These heavy metal pollution causes environmental harm that is difficult to reverse naturally,necessitating cleanup activities. The ability of plants to absorb and eliminate organic and inorganic contaminants from the soil and change them into non-toxic forms is known as phytoremediation[17]. The word "phytoremediation" is an umbrella phrase made up of the Latin root medium and the Greek prefix Phyto (plant) (to correct or remove an evil). A new technology called phytoremediation uses specific plants to clean up damaged environments and change their ecological characteristics[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. A wide range of poisons, including organic synthetic compounds, xenobiotics, pesticides, hydrocarbons, heavy metals, and radionuclides, can be successfully remedied by plants[7]. The ability of plants to absorb, collect, and detoxify metals depends on a variety of physical and chemical characteristics of the soil, plant, and metals' bioavailability. Understanding the mechanism underlying a plant's tolerance to a certain metal is necessary for the selection of plants that are suited for phytoremediation of polluted soils. Selection of particular plant species for phytoremediation plays important role into the function of remediation technologies[8]

A rapidly developing new approach for the elimination of hazardous materials (HMs), phytoremediation is economical, non-intrusive, and visually pleasant. It takes advantage of some facilities' capacity to remove pollutants from polluted areas. Physiological and molecular processes for HM tolerance in plants are interconnected. Reduced metal uptake or enhanced internal sequestration, which are caused by interactions between a genotype and its environment, are the foundation of high resistance to HM toxicity. Our knowledge of the mechanisms behind HM tolerance in plants has grown as a result of the expanding interest in molecular genetics, and several transgenic plants have demonstrated improved HM tolerance. Genetic engineering of plants, which involves changing traits including metal uptake, transport, and accumulation as well as plant resistance to metals, creates new opportunities for 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 riskand 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, stylisticpleasing 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

The primary characteristic that permits hyper-accumulation in the rhizosphere and shoot cells is hypertolerance; this is a crucial property for both root and shoot cell hyperaccumulation. These plants must possess the ability to swiftly transport an element from their roots to their branches. However, in hyperaccumulators, shoot metal concentrations can reach root levels. Typically, root Zn, Cd, or Ni concentrations are 10 times or more greater than shoot metal concentrations. 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 cropswith 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] .On the other hand, some plant species 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] .

How are metals absorbed by plants? The main aspect affecting the absorption of metals is their bioavailability. Metals can be found in soils in a variety of chemical forms, where they coexist in a dynamic equilibrium that is controlled by the physical, chemical, and biological activities of the soil. A key factor in the effectiveness of remediation is the bioavailability of soil pollutants, which refers to the portion of the total pollutant mass in the soil and sediment that is accessible to plants. Metal ion interception by roots, metal ion entry into roots, and metal ion translocation to the shoot by mass flow and diffusion are all steps in the metal uptake process by plants. The processes used by plants to absorb, transport, and store these nutrients have become incredibly specialised. For example, proteins with transport activities mediate the passage of metal across biological membranes. Sensitive systems also keep the level of metal ions inside cells within a physiological range. Generally speaking, plants preferentially absorbed some ions over others due to the selective uptake mechanism. Selectivity of ion uptake is influenced by the composition and characteristics of membrane transporters. These features give transporters the ability to identify, bind, and mediate the trans-membrane transit of certain ions. For instance, certain transporters do not detect mono- or trivalent ions but enable the transit of divalent cations. The amount of metal in the root may affect how quickly it metatranslocates to the shoot. As a potential mechanism for metal translocation, phytochelatin (PC)-mediated metal binding in the xylem sap has been suggested. On their way to their final storage locations in the maturing cereal grain, nutrients run against a number of limiting obstacles. Expression profiles have been created for the transfer cells, aleurone layer, endosperm, and embryo in order to identify transporters and chelating substances that may be involved in the transport and deposition of Zn in the barley grain[20]. Phytoremediation technology can be categorised into many categories based on how it works and where it can be used.

The following list includes various Phytoremediation techniques and procedures.

The type of pollutant, its bioavailability, and the characteristics of the soil all have an impact on the method and effectiveness 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 pollutantmass 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: The term "phytoextraction" or "phyto-accumulation" describes how plant roots take in and move metal contaminants from the soil to their above-ground parts. The plants are made in such a way as to collect contaminants from the soil. The plants concentrate and precipitate toxins in above-ground biomass. In addition to permanently removing contaminants from the soil, phytoextraction is relatively viable when compared to conventional procedures due to its low cost. Plants with the ability to extract metals from contaminated soils were first seen as metal hyperaccumulator species[22]. Because most plants like them, nickel, zinc, and copper are the metals that are most commonly extracted by phytoextraction. The amount of waste that must be disposed of is decreased by up to 95%, and in some cases, the contaminant can be recycled from the biomass of the contaminated plant. The utilisation of hyper accumulator species is constrained by their slow growth, shallow root systems, and low biomass yield. Additionally, the plant biomass must be gathered and disposed of in accordance with rules[22]. Metal content of the rhizosphere, rate of metal absorption by roots, Some of the main limiting parameters in the process of phytoextraction include the proportion of metal "fixed" inside the roots, the rate of xylem loading/translocation to shoots, and cellular tolerance to hazardous metals[24]. In general, the approach does not apply to metals and other inorganic materials in soil or silt. . 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].

Hyper-accumulators are plants that absorb extremely high levels of metals in contrast to other plants. More than 400 plant species have been found to have the capacity to improve the quality of soil and water [26]. Numerous different plants can be utilised for phytoremediation because they all have varying capacities to absorb and survive high concentrations of contaminants. Numerous different plants can be utilised for phytoremediation because they all have varying capacities to absorb and survive high concentrations of contaminants. Three methods are employed in the creation of a phytoremediation plant: (a) screening of possible hyperaccumulator plants; (b) plant breeding; and (c) the application of genetic tools to create enhanced hyperaccumulators. The scientific community has spent the most time studying *Thlaspi sp., Arabidopsis sp.,* and *Sedum alfredii sp*. as hyperaccumulators (both genera belong to the family of Brassicaceae and Alyssum). Thlaspisp. are known to hyperaccumulate more than one metal; they are T. rotundifolium for Ni, Pb, and Zn, T. ochroleucum for Ni and Zn[27].

Metal phytoextraction entails the following steps: 1) growing the right plant/crop species on the contaminated site; 2) removing harvestable metal-enriched biomass from the site; and 3) post-harvest treatments (such as composting, compacting, and thermal treatments) to reduce the volume and/or weight of biomass for disposal as a hazardous waste or for its recycling to recover valuable metals. Continuous or natural phytoextraction and induced, accelerated, or chemically assisted phytoextraction have been proposed as the two main methods of metal phytoextraction[28]. Metal phytoextraction entails the following steps: 1) growing the right plant/crop species on the contaminated site; 2) removing harvestable metal-enriched biomass from the site; and 3) post-harvest treatments (such as composting, compacting, and thermal treatments) to reduce the volume and/or weight of biomass for disposal as a hazardous waste or for its recycling to recover valuable metals. Continuous or natural phytoextraction and induced, accelerated, or chemically assisted phytoextraction have been proposed as the two main methods of metal phytoextraction. The metals can occasionally be recycled using a procedure called as phytomining, but this is often only done with precious metals. The bulk of the 400 or so plants that are known to absorb abnormally high levels of metals have a strong propensity for accumulating these metals, making them the greatest candidates for removal by phytoextraction. Research and testing are now being done on plants that can absorb Pb and Cr. The exchangeable form of Cd was reportedly eliminated in part in the presence of vegetation by plant uptake together with nutrient intake[29]. The majority of plant species that can grow in soil solutions with Cd concentrations as high as 35 mol/L (3.9 mg/L) are Cd-hyperaccumulating species[30]. In their experiment, Zhang and their colleagues found that as maize had highest Cd phytoextraction ability the percentage of exchangeable form of Cd in the planted soil reduced. Additionally, plant root exudates and rhizosphere microbes accelerated the stability process of added Cd in soils, which might cause the exchangeable form to change into other relatively stable forms like the organic form and residual form and help lessen the harm that Cd causes to the environment of the soil and water[29].

ii)Rhizofiltration: Rhizofiltration is frequently used to remove metals or other inorganic compounds from groundwater, surface water, or wastewater[24]. Pb, Cd, Cu, Ni, Zn, and Cr, which are predominantly kept inside the roots, are cleaned out using the rhizofiltration procedure[31]. Phytoextraction is used to treat soils, whereas rhizofiltration is typically employed to clean up polluted ground water. Plants produced for rhizoextraction have their rhizospheres submerged in water and are grown in greenhouses or glasshouses. Polluted water is gathered from a waste site and sent to the plants, where it is utilised as a source of water once they have developed a substantial root system. After that, the plants are planted in the polluted area, where their roots take in both the water and the contaminants. When they become saturated with contaminants, the roots are pulled out. The ability to remove lead from water has been studied on a variety of plants, including sunflower, Indian mustard, tobacco, rye, spinach, and corn, with sunflower showing the greatest rhizoextraction results. Sunflowers significantly reduced lead concentrations in a study after an hour of treatment[22]. The use of both terrestrial and aquatic plants for in situ or ex situ applications, as well as the fact that contaminants do not need to be transferred to the shoots, are advantages of rhizofiltration. 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 that will be used for cleaning are grown in greenhouses with water at the roots. The plants are either planted in the contaminated region or contaminated water is collected from a waste site and transferred to the plants, where the roots subsequently absorb the water and the toxins dissolved in it. The roots are removed and carefully disposed of as they get saturated with pollutants. Metals including As, Pb, Cd, Ni, Cu, Cr, V, and radionuclides are cleaned up using rhizofiltration (U, Cs and St). The ideal plant should be able to accumulate and tolerate considerable concentrations of target metals, have a low maintenance cost, be easy to handle, and produce a little quantity of secondary waste that needs to be disposed of. Because they generate longer, more substantial, and frequently fibrous root systems with significant surface areas or metal adsorption, terrestrial plants are more suited for rhizofiltration. Pterisvittata is the first known As-hyper accumulator, often known as Chinese brake fern[32]. Water Hyacinth (*Eichhornia crassipes*), Duckweed (*Lemna minor* L.)[33], and Water Pennywort (Hydrocotyle umbellate L.) are three aquatic organisms that may remove HMs from water (Mart.)[34]. The most promising plants for removing metal from water are sunflower (Helianthus annuus) and Indian mustard (Brassica juncea). Indian mustard efficiently eliminates Cd, Cr, Cu, Ni, Pb, and Zn[35] from hydroponic solutions, but sunflower absorbs Pb and U [36]. Indian mustard was able to efficiently remove Pb concentrations ranging from 4 to 500 mg/L[37]. In order to clean up an aquatic environment contaminated by coal ash including HMs, [38]Karkhanis presented the results of an experiment they did utilising pistia, duckweed, and water hyacinth (E. crassipes) under greenhouse conditions. The findings demonstrated that pistia had a high potential for HMs (Zn, Cr, and Cu) uptake, and duckweed also shown a good potential for HMs uptake close to pistia[38]. Compared to pistia and duckweed, water hyacinth had less Zn and Cu rhizofiltration. [38]Mohanty and Patra recently reported on the potential of water hyacinth (E. crassipes) weeds for phytoremediation of metal-polluted soils by rhizofiltration. High concentrations of hazardous hexavalent (Cr+6) were found in the mine waste water in the Orissa (India) chromite mining region of South Kaliapani. Water from a nearby mine that has been contaminated with Cr+6 could be dangerous to the local biotic population.

iii)Phytovolatilization: The term "phytovolatilization" describes how plants absorb and expel pollutants and other organic substances. The pollutant, which was in the water the plant ingested, moves through the plant or is altered by it before being discharged into the atmosphere (evaporates or vaporizes). As water moves through the plant's vascular system from the roots to the leaves, the pollutant may change along the journey, evaporating or volatilizing into the air around the plant[31&24]**.** Phytovolatilization is the term used to describe the dispersion of pollutants from the stems or other plant parts that the contamination passes through before reaching the leaves[22]. Phytovolatilization is most frequently used for Mercury and can be used to clean up contaminants in soil, sediment, or water. Inorganic compounds like selenium and arsenic as well as volatile organic molecules like trichloroethene have also been found to contain it[24]. The mercuric ion is converted into the less dangerous elemental Hg during phytovolatilization, which has historically been employed to remove mercury[25]. The negative aspect is that mercury released into the atmosphere is probably going to be recycled by precipitation and then dumped back into lakes and oceans, repeating the process by which anaerobic bacteria produce methylmercury[31].

iv)Phytostabilization: The main applications of phytostabilization, also known as in-place inactivation, are the remediation of soil, silt, and sludge[31]. To reduce pollutant mobility and bioavailability in the soil and water, plant roots are used. Roots absorb and accumulate contaminants, which either adsorbed into the roots or precipitated in the rhizosphere. By doing this, the contaminant's mobility is reduced, migration to groundwater is prevented, and the metal's bioavailability in the food chain is also reduced. By reestablishing vegetation in contaminated regions with metal-tolerant species, this technique lessens the likelihood that pollutants may travel through wind erosion and the movement of exposed soil. Sorption, precipitation, complexation, or metal valence reduction can all result in phytostabilization. Lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), and zinc can all be treated with it (Zn). Utilizing the alterations in soil chemistry and environment brought on by plant presence, phytostabilization modifies the environment. This approach has several advantages, such as the fact that hazardous materials and biomass don't need to be disposed of and that it works extremely well when quick immobilisation is required to preserve ground and surface waters[29]. Additionally, plants increase the amount of available water in the system and lessen soil erosion[31]. The presence of contaminants in the soil, the need for extensive fertilisation or soil amendments, and the requirement for routine monitoring are just a few of the significant drawbacks to this cleanup method.

Two cultivars of Agrostistenius and one cultivar of Festucarubra were created by Smith and Bradshaw[39] and utilized for phytoremediation of soils contaminated with Pb, Zn, and Cu. Phytostabilization can treat a variety of surface contaminants, even though it is most successful at sites with fine-textured soils that have a high organic matter concentration[40&41]. Plants with deep roots may be able to convert the very poisonous Cr VI to Cr III, which is less accessible since it is much less soluble[42]. The removal of the hazardous substance or the disposal of the biomass are not necessary for phytostabilization. Sorghum (a fibrous root grass) was used in an experiment under greenhouse conditions to remediate soil contaminated by HMs, and the produced vermicompost was added to the contaminated soil as a natural fertiliser[43]. At higher concentrations of 40 and 50 ppm, HMs were said to negatively impair growth, but lower doses (5 to 20 ppm) were said to stimulate shoot growth and boost plant biomass. Additionally, HMs were effectively absorbed by the sorghum plant's roots at all of the assessed concentrations of 5, 10, 20, 40, and 50 ppm. Zn>Cu>Cd>Ni>Pb was the sequence of HM absorption. The extensive root penetration and vast surface area of sorghum's fibrous roots minimise leaching by stabilising the soil and making HMs more immobile and concentrated in the roots. Recently,[44]Cheraghi and his coworkers did a study on phytostabilization utilising various plant species. According to their findings, C. bijarensis, C. juncea, V. speciosum, S. orientalis, C. botrys, and S. barbata had the ability to phyto-stabilize Mn due to their high bioconcentration factors and low translocation factors.

V)Phytodegradation: It necessitates either simplifying complicated organic compounds or incorporating them into plant tissues[23]. After being absorbed by the plant, pollutants undergo phytodegradation, which breaks them down. Similar to phytoextraction and phytovolatilization, plant absorption only happens when the solubility and hydrophobicity of pollutants fall below a specific threshold. It has been shown that phytodegradation can remove certain organic contaminants like explosives, herbicides, and chlorinated solvents from soil, sediment, or groundwater[24].The disintegration of organic pollutants in plant tissue is known as phytodegradation. Enzymes that aid in catalysing breakdown, such dehalogenase and oxygenase, are produced by plants. It seems that attenuating pollutants is a major function of both the plants and the surrounding microbial communities. The term refers to the breakdown or destruction of organic pollutants by the plant's internal and exterior metabolic activities[27]. Organic substances are hydrolyzed by ex planta metabolic activities into smaller fragments that the plant may absorb. Some pollutants can be taken up by plants and then degraded by plant enzymes. As the plant matures, it may utilise these smaller pollution molecules as metabolites, which would subsequently be integrated into the tissues of the plant. Plant enzymes that digest organic herbicides, chlorinated solvents like TCE (trichloroethylene), and munitions waste have been discovered. The rhizosphere is where plant enzymes that metabolise pollutants may be secreted, where they may actively participate in the transformation of contaminants. Enzymes have been found in plant sediments and soils, including dehalogenase, nitro-reductase, peroxidase, laccase, and nitrilase. This method can decompose organic substances like munitions, chlorinated solvents, herbicides, insecticides, and inorganic nutrients[45]. In the presence of the aquatic plant Myriophyllumaquaticum, which generates nitroreductase enzyme that can partially breakdown TNT, the dissolved TNT (trinitrotoluene) concentrations in flooded soil reduced from 128 ppm after one week[45].

vi)Rhizodegradation: In the rhizosphere, or root zone, of plants, it degrades contaminants. The bacteria or other microorganisms that proliferate in great numbers in the rhizosphere are assumed to be the ones who start this process. The roots offer surface area for microorganisms to flourish in addition to plant exudates like sugars, amino acids, enzymes, and a pathway for oxygen transfer from the environment. A variety of mostly organic chemicals, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, and xylenes, have been found to be effectively treated by the localised process known as rhizodegradation[24]. In order to stimulate microbial and fungal breakdown (rhizosphere), exudates and enzymes are released into the root zone, a process known as plant-assisted bioremediation[46].

Some research evidences on phytoremediation potential of field crops

Mojiri.A[48] investigate the ability of corn (maize) to phytoremediate lead- and cadmium-contaminated soil, an experiment was done in Iran. The fact that roots accumulate more cadmium than shoots does indicates that roots are more active in phytoremediation of cadmium than shoots. Increased phytoremediation of cadmium from soil by corn when soil pollution reached 8 (ppm).

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. The pH has been found to control the phytoavailability of metals. In addition to playing a large role throughout the lifetime, other factors such as electrical conductivity, organic matter, and organic carbon have also been significantly reduced, which is a symptom of the frequent intake of heavy metals by Brassica juncea. Lead was taken up more readily than the other heavy metals, according to the Metal Extraction Ratio. According to the translocation factor in this study, Brassica juncea is a hyperaccumulator. The amount of metal absorbed by the plant in each pot (ppm/pot) was used to assess the proportion of recovery from soil to plant parts. The plant consumes lead (151.5 ppm), zinc (55 ppm), copper (15.4 ppm), chromium (9.6 ppm), and nickel (9.6 ppm) in that order (3.1 ppm). Higher percentages of recovery were seen in Zinc (51.8%), Copper (41.6%), Lead (20.8%), Chromium (11.5%), and Nickel (51.8%). (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] showed in their experiment that the 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; that is, despite the contamination of the soil sample, reduction in soil bacterial count, growth depression, and unfavourable soil conditions, groundnut still beat restrictions to grow and survive, but the other legume (cowpea) germinate. This study showed that groundnut was advantageous.

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. A promising remediation method for cleaning up soils contaminated with inorganic contaminants is phytoremediation. Since it is inexpensive, research relating to this relatively new technology needs to be encouraged, focused, and extended in developing nations. Vascular plants are used in situ by solar-powered technology to store and transport metals from roots to shoots. These pollutants can be permanently eliminated from the soil by harvesting the plant shoots. In situ remediation of shallow soil, ground water, and surface water bodies is possible with the use of this method. Additionally, phytoremediation has been viewed as a less intrusive, environmentally active "green" alternative to more aggressive remedial techniques. Policy-makers are currently paying a lot of attention to the larger significance of safeguarding soils and enhanced management for the services they provide. Fundamental ecosystem services are provided by soils, and these services have significant economic, ecological, and sociological effects on how well society as a whole is doing. A large but previously unappreciated part of the world's soil resource is metal-contaminated soils.

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]

Reference

(1). Jabeen R, Ahmad A, Iqbal M (2009). Phytoremediation of Heavy Metals: Physiological and Molecular Mechanisms. *Botanical Review*. 75:339-364.

(2). Ana M, Antonio R, Paula C (2009). Remediation of Heavy Metal Contaminated Soils: Phytoremediation as a Potentially Promising Clean-Up Technology. *Critical Review Environmental Science Technology*. 39(**8**):622-654.

3). Nriagu JO (1979). Global inventory of natural and anthropogenic emission of trace metals to the atmosphere.*Nature*.**279**:409-411.

4). Adriano DC (2001). Trace Elements in the Terrestrial Environment: Biogeochemistry, Bioavailability and Risks of Metals, 2nd edn. New York: Springer.

5). Lasat MM (2002). Phytoextraction of toxic metals: A review of biological mechanisms. *Journal of Environmental Quality*.**31**: 109-120.

6). Cunningham SD, Berti WR, Huang JW (1996). Phytoremediation of contaminated soils.TIBTECH. 13: 393-397.

7). Suresh, B. and Ravishankar, G. A. (2004). Phytoremediation - A novel and promising approach for environmental clean-up. *Critical Review in Biotechnology,* **24**: 97-124.

8).Singh .,ovLabana.,S.Pandey .G.Budhiraja.,R.Jain.,RK (2003).Phytoremediation :an overview of metallic ion decontamination from soil.*Applied microbial biotechnology*.**84-**32-36

9). Andrade JCM, Mahler CF (2002). Soil Phytoremediation.In 4th International Conference on Engineering Geotechnology. Rio de Janeiro, Brazil.

10). Briggs D (2003) Environmental pollution and the global burden disease. *British Medical Bulletin***68**:1–24.

11). Dixit R, Wasiulah MD, Pandiyan K, Singh UB, Sahu A, Shukla R, Singh BP, Rai JP, Sharma PK, Lade H, Paul D (2015). Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. *Sustainability***7:**2189– 2212.

12). Rakhshaee,. R .Giahi, M and Pourahmad, A. 2009. "Studying effect of cell wall's carboxyl-carboxylate ratio change of *Lemna minor* to remove heavy metals from aqueous solution," *Journal of Hazardous Materials,* 163(**1**)165–173.

13). Salido,A.L., Hasty, K. L. , Lim, J. M. and Butcher, D. J. 2003. "Phytoremediation of arsenic and lead in contaminated soil using Chinese Brake ferns (*Pterisvittata*) and Indian mustard (*Brassica juncea*)," *International Journal of Phytoremediation*.5(**2**) 89–103.

14). Tangahu.,B.V.,Abdullah.,S.R.S., Basri,. H.,Idris.M,. Anuar.,N,and Mukhlisin.,M.2011. A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation.*International Journal of Chemical Engineering* 939161, (**31**).

15). Warrier, R.R. and Saroja, S. 2002. Phytoremediation - A remedy to environmental problems in urban areas. *Indian Journal of Environmental Protection*, 22(**2**): 225- 228.

16). Angelova, V.R., Ivanova, R.V., Delibaltova, V.A., Ivanov, K.I., 2011. Use of sorghum crops for in situ phytoremediation of polluted soils.*Journal Agricultural Science Technology*. (**1**) 693_702.

17). Yang, X., Feng, Y., He, Z., Stoffella, P.J., 2005. Molecular mechanisms of heavy metal hyperaccumulationand phytoremediation. *Journal of trace elements in medicine and biology*.**18**, 339_353.

18). Rascio, N., Navari-Izzo, F., 2011. Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting? *Plant Science*.(**180**) 169_181.

19). Peer, W.A., Baxter, I.R., Richards, E.L., Freeman, J.L., Murphy, A.S., 2006. Phytoremediation and hyperaccumulator plants. In: Tamas, M.J., Martinoia, E. (Eds.), Molecular Biology of Metal Homeostasis and Detoxification. Topics in Current Genetics.Springer-Verlag, Berlin/Heidelberg, pp. **299_**340.

20). Tauris B, Borg S, Gregersen PL, Holm PB (2009). A roadmap for zinc trafficking in the developing barley grain based on laser capture microdissection and gene expression profiling. *Journal of Experimental Botany*.**60**:1333-1347.

21). Cunningham, S. D., and Ow, D. W. (1996). Promises and prospect of phytoremediation.

PlantPhysiology .(**110**)715-719.

22). Raskin, I., and Ensley, B. D. (2000). Recent developments for in situ treatment of metal contaminated soils. In: *Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment*. John Wiley & Sons Inc., New York.

23). Favas PJC, Pratas J, Prasad MNV. 2013. Temporal variation in the arsenic and metal accumulation in the maritime pine tree grown on contaminated soils. *International Journal of Environmental Science and Technology*:10(**4**) 809-826.

24). EPA 2000.Introduction to phytoremediation. National Risk Management Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268.

25). Ghosh M, Singh SP (2005). A review on phytoremediation of Heavy Metals and utilization of its byproducts.*Applied Ecological Environmental Research*.**3**:1-18.

26). Elekes,C.C.2014.Eco-Techonological solutions for the remediation of polluted solution and heavy metal recovery. *Environmental risk assesement o soil contamination* .309-335

27). Lone MI, He ZL, Stoffella, Yang XE (2008). Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives. *Journal ofZhengjiang University Science.B*.**9**(3):210-220.

28). Prasad MNV, Freitas HM, De O (2003) Metal hyperaccumulation in plants-biodiversity prospecting for phytoremediation technology. *Electronic Journal of Biotechnology*.**6**:110-146.

29). Salt DE, Smith RD and RaskinI (1998). Phytoremediation.Annual Review.Plant Physiology.*Plant Molecular Biology*. **49**: 643-668.

30). Zhang, H., Zheng, L. C., and Yi, X. Y. (2009). Remediation of soil co-contaminated with pyrene and cadmium by growing maize (*Zea mays* L.). *International Journal Environmental Science and Technology*.,**6**: 249-258.

31). Xiao X, Tongbin C, Zhizhuang A, Mei L (2008). Potential of *Pterisvittata L.* for phytoremediation of sites cocontaminated with cadmium and arsenic: The tolerance and accumulation. *Journal of Environmental Science*. **20**:62-67.

32). United States Environmental Protection Agency (USEPA). (2000). Introduction to Phytoremediation.EPA 600/R-99/107, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

33). Ma LQ, Komar KM, Tu C, Zhang WH, Cai Y, Kennelley ED (2001). A fern that hyperaccumulates arsenic. Nature 409: 579-580.

34). Mo S, Chol DS, Robinson JW (1989). Uptake of mercury from aqueous solution by Duckweed: the effect of pH, copper and humic acid. *Environmental Health*.**24:**135-146.

35). Zhu YL, Zayed AM, Qian JH, Desouza M, Terry N (1999). Phytoaccumulation of trace elements by wetland plants: II. Water Hyacinth.*Journal of Environmental Quality*.**28**:339-344.

36). Dushenkov S, Vasudev D, Kapulnik Y, Gleba D, Fleisher D, Ting KC, Ensley B (1997). Removal of uranium from water using terrestrial plants.*Environmental Science Technology*.**31**:3468- 3474.

37). Dushenkov S, Vasudev D, Kapulnik Y, Gleba D, Fleisher D, Ting KC, Ensley B (1997). Removal of uranium from water using terrestrial plants.*Environmental Science Technology*.**31**:3468- 3474.

38). Karkhanis M, Jadia CD, Fulekar MH (2005). Rhizofilteration of metals from coal ash leachate.*Asian Journal of Water Environmental Pollution*.**3**:91-94.

39). Mohanty M, Patra HK (2011). Attenuation of Chromium toxicity in mine waste water using water hyacinth.*Journal of Stress Physiology Biochemistry*.**7**:335-346.

40). Smith RAH, Bradshaw AD (1979). The use of metal tolerant plant populations for the reclamation of metalliferous wastes.*Journal of Applied Ecology*.**16**:595-612.

41). Cunningham SD, Berti WR, Huang JW (1995). Phytoremediation of contaminated soils.TIBTECH. 13: 393-397.

42). Berti WR, Cunningham SD (2000). Phytostabilization of metals. In: Raskin I & Ensley BD (eds), Phytoremediation of toxic metals: using plants to clean up the environment. Wiley, New York pp.71-88.

43). James BR (2001). Remediation-by- reduction strategies for chromate-contaminated soils.*Environmental Geochemical Health*.**23**:175-189.

44). Jadia CD, Fulekar MH (2008). Phytotoxicity and remediation of Heavy Metals by fibrous root grass (sorghum). *Journal of Applied Bioscience*. (**10**):491-499.

45). Cheraghi M, Lorestani B, Khorasani N, Yousefi N, Karami M (2011). Findings on the phytoextraction and phytostabilization of soils contaminated with Heavy Metals. *Biological Trace Elemental Research*. 144:1133-1141.

46). Schnoor JL, Light LA, McCutcheon SC, Wolfe NL, Carriera LH (1995). Phytoremediation of Organic and Nutrient Contaminants.*Environmental Science Technology*. 29:318-23.

47). Zhang H, Dang Z, Zheng LC, Yi XY (2009). Remediation of soil co-contaminated with pyrene and cadmium by growing maize (*Zea mays* L.).*International Journal of Environmental Science Technology*.**6:**249-258.

48). Mojri.A.,2011.The potential of corn (*zea mays*) for phytoremediation of soil contaminated with cadmium and lead.*Journal of biological and environmental sciences*. 5(**13**):17-22.

49). Gayatri.,N. Sailesh,A.R.,Srinivas N.2019. Phytoremediation Potential of *Brassica juncea*for removal of selected heavy metalsin urban soil amended with cow dung.*Journal of Materials and Environmental Sciences* 10(**5**)463-469.

50). Manga, S. S. Nwosu, C. O,Bazata, Y. A.,Jabaka R. D. and M. I. Ribah 2020 . Comparative Study of the Phytoremediation Activity of the Rhizobacterial Flora Of *Vigna Unguiculata*(Cowpea) And*ArachisHypogaea*(Groundnut) On Hydrocarbon Contaminated Soil. *Journal of Pharmacy And Biological Sciences (IOSR-JPBS)*.15(**1**)36-43