Cadmium Toxicity And Its Phytoremediation A Review

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Abstract:

Cumulative effect of urbanization, industrialization and population growth is increasing pressure on the limited natural resources. The change in living style has aggravated the problems. Among the diverse environmental problems, the discharge of heavy metals in environment through industrial, agricultural and domestic activities is of great concern. Removal of heavy metal from environment is a challenge as these toxic metals are non-biodegradable and bioaccumulate in living organisms. Sustainable development requires the use of green technologies to treat the wide range of contaminated aquatic and terrestrial habitats. Phytoremediation is an alternative to conventional methods for treating waste compounds. This review discusses the occurrence and toxicity of cadmium, the various remediation techniques with emphasis on phytoremediation of cadmium. Phytoremediation by plants occupying different taxonomic position is discussed. The scientific literature reveals that this technology has tremendous potential to cater for the needs and can be effectively used for environmental protection, sustainability and management.

Index Terms: Cadmium, Toxicity, Remediation techniques, Phytoremediation, Hyperaccumulators.

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1 INTRODUCTION:

CADMIUM is a soft, silvery white, easily fusible metallic element. It is slightly malleable, ductile, flexible and heavier than zinc. It is present in the environment not as a pure metal but often as complex oxides, sulphides and carbonates in zinc, lead and copper ores in the natural conditions. Cadmium is readily soluble in nitric acid, slowly in hydrochloric acid and slightly soluble (0.005 wt %) in water. It is having the atomic number 48 and atomic weight 112.41; its density is 8.642 g/cm^3 at 20°C.

Cadmium, represented with symbol Cd, is a heavy metal with a high toxicity. Among the heavy metals, it is considered most serious metal contaminant since the occurrence of Itai- Itai disease in Japan [1]It is a non-essential highly toxic heavy metal having half-life of ten to thirty years [2]Cadmium is toxic at very low exposure levels and has acute and chronic effects on health and environment. It is non degradable in nature and hence once released to the environment, stay in circulation. Cadmium and its compounds are relatively water soluble [3] as compared to others. Being more mobile they are easily bioavailable and bioaccumulate.

Cadmium is among top twenty most polluting chemicals [4].It is harmful as it can replace essential elements from active sites of enzymes and also due to its affinity for sulfhydryl groups [5].Cadmium shows high mobility in soil-plant systems taken up through the roots. Cadmium speciation adsorption and distribution in soils is governed by factors like soil pH, clay content, soil type, soluble organic matter content, presence of organic and inorganic ligands, hydrous metal oxide content and presence of other metal ions in the soil. Humans get exposed to Cd through inhalation of polluted air, inhalation of tobacco smoke or eating contaminated food [6].

1.1 SPECIATION AND BIOAVAILABILITY

The different physico-chemical forms of Cadmium are, $CdCl_2$, $CdCl_3$, $CdCl^+$and free Cd^{2+}.These form influence the bio-geological distribution / transportation, bioavalability, bioactivity, toxicity and impact within our body. Soluble Cd^{2+} induces more harm than metallic cadmium and Cadmium Oxide powder. The mobility of cadmium with respect to partitioning between the water and sediment reservoir depends on speciation of Cadmium.

Bioavailability of cadmium is determined by its exchangeable fraction rather than the total cadmium present in the sediments. It is a dynamic process, comprising of exposure and uptake route of cadmium, chemical fluxes for specific biological species and its redistribution within the species. Different factors affecting amount of exchangeable cadmium held in the sediment include the particle size of the sediment, level of organic matter, pH and redox potential of the sediment. Another important influential factor is partitioning of cadmium between the adsorbed- in- sediment

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state and dissolved-in-water state. Fractionation of geochemical forms (exchangeable, reducible, organic bound, carbonate, oxides and acid extractable) determine the biological form of the cadmium available. Cadmium is absorbed by organisms directly from the water in its free ionic form in aquatic systems. The toxicity of cadmium to aquatic organisms is related to availability of free ionic concentration.

The cadmium being in low concentration in aquatic ecosystem may not directly impart toxicity to the organisms. However, it get accumulated in aquatic organisms through bioaccumulation and the bioconcentration in the food chain process eventually threatening human health. In the aquatic environment dissolved cadmium is absorbed by algae and suspension feeders. The organism of higher trophic levels in the marine food chain may uptake the cadmium via food dominates, while in fresh water uptake by fish.

1.2 TOXIC EFFECTS:

Cadmium is a non-essential metal and is very slowly eliminated from our body. Cadmium causes different toxic effects. Several plant physiological processes like Nitrogen-metabolism and oxidative reactions are inhibited by Cadmium [7].Presence of Cadmium in plants causes necrosis, leaf chlorosis, leaf roll, reduction in plant growth, damage of photosynthetic machinery specially PS-I and PS-II (photosystem) and reduction in chlorophyll synthesis. Uptake and transport of mineral nutrients is also affected [8].

Chronic cadmium exposure produces a wide variety of acute and chronic effects in animals and humans. Consumption of agricultural crops, horticultural crops or products derived from them are portals of intake of cadmium in animals and humans. 70% of intake of Cadmium in humans is through vegetable intake ([9]of excessive amount of cadmium dust causes salivation, choking, nausea, vomiting, diarrhea, abdominal pain, dizziness and headache followed by convulsions, shock and unconsciousness.

In the human body it accumulates especially in the kidneys. Kidney damage (renal tubular damage) is probably the critical health effect. Other effects of cadmium exposure are disturbances of calcium metabolism, hypercalciuria bone fracture, formation of stones in the kidney, psychological disorders, damage to central nervous system, diarrhea, stomach pain, severe vomiting, reproductive failure and even infertility and DNA damage. High exposure can lead to lung cancer and prostate cancer. It is classified as Group I in list of human carcinogens given by International agency for Research on Cancer [11]Therefore removal of cadmium from soil and water is necessary.

2 CADMIUM REMEDIATION TECHNIQUES:

2.1 Conventional methods

For soil remediation techniques include:
Isolation and Containment,
Soil dressing
Soil flushing and
Inerting [12]

These techniques are not only expensive requiring special equipments and intensive labour but are also environmentally destructive. They leave soil infertile and pollute the ground water. Moreover when the pollutants are low in concentration or when the affected area is large then these techniques are not suitable.

There are various physical and chemical methods used to treat mining and industrial effluents containing Cd (II). The chemical methods for cadmium remediation include precipitation and cementation techniques. Simple precipitation of metals as insoluble hydroxides, carbonates, or sulfides is used in about 75% of electroplating facilities. Cadmium can also be precipitated by addition of lime and magnesium [12]to wastewater [13]

Different types of membrane processes are employed to remove cadmium from aqueous solutions such as liquid membrane, [14]hollow fiber supported liquid membrane, [15]supported liquid membrane, [16]emulsion liquid membrane [17].But these processes tend to suffer from the instability of the membranes in salty or acidic conditions and fouling by inorganic and organic substances present in wastewaters. In electrolysis the metal ions are removed from the solution in a solid metallic form for recycling. No additional chemicals are required and sludge is not generated. But it is inefficient at low metal concentration. Ion exchange usually requires a high equipment as well as high operational cost. Hence it is not a popular method for Cd (II) remediation from wastewaters.

Solvent extraction is a powerful technique for recovering /separating metal ions from aqueous solutions having higher concentrations to obtain high pure solutions but can be used for separation of cadmium from multi-cation containing solutions rather than for remediation of Cd (II) for treatment of waste waters.

2.2 Phytoremediation:This emerging green technology has recently attracted researchers towards remediation of contaminated soil and water. It is new cheap, efficient, versatile and eco-friendly technique for treating polluted soils and water. In comparison with physical and chemical techniques of remediation, phytoremediation is a cost-effective and environmental friendly green technology using the capacity of hyperaccumulator plants to extract heavy metals from soil [18],[19].

All plants have the potential to extract metals from soil but some plants have shown the ability to extract, accumulate and tolerate high levels of heavy metals. These are considered as hyperaccumulators, which are taxonomically widespread throughout the plant kingdom [20],[21],[22]. Hyper accumulator plants can tolerate, uptake and translocate high levels of certain heavy metals that would be toxic to most organisms. They are defined as plants whose leaves may contain > 100 mg/kg of Cd, > 1000 mg/kg of Ni and Cu, or > 10 000 mg/kg of Zn and Mn (dry weight) when grown in metal-rich medium [23].More than 400 plant species have been identified as natural metal hyperaccumulators, representing < 0.2% of all angiosperms [24].

Plants used for phytoremediation should have following characteristics;
fast growing,
high biomass,
deep-rooted (in the case of immobile contaminants at depth),
easy propagation and
accumulate the target metal.

Accumulation of the target metal is of paramount importance; ideally the species used should have a high bioaccumulation coefficient. It is defined as the plant/soil metal concentration quotient. If a plant accumulates more than 0.1% of the heavy metal in its dry weight; it is termed as hyperaccumulator [25]If a plant removes 50% of the heavy metal within a day then it is a good phytoremediation agent [26]. Apart from having high bioaccumulation coefficient a hyperaccumulator should show tolerance to that heavy metal.

Tolerance to heavy metals in plants is due to inter-linked physiological and molecular mechanisms. The major processes involved in hyperaccumulation of trace metals from the soil to the shoots by hyperaccumulators include:
(a) Bioactivation of metals in the rhizosphere through root microbe interaction;
(b) Enhanced uptake by metal transporters in the plasma membranes;
(c) Detoxification of metals by distributing to the apoplasts like binding to cell walls and chelation of metals in the cytoplasm with various ligands, such as phytochelatins, metallothioneins, metal-binding proteins;
(d) Sequestration of metals into the vacuole by tonoplast-located transporters [27].Many reviews have been written on this novel green technology[28],[29],[30];[31],[,32][33],[34],[35],[36],[37],[38].These reviews highlight the processes associated with applications and underlying biological mechanisms. The present review is intended to give information with respect to phytoremediation of cadmium.

2.3 Cadmium Uptake and Transport in Plants:

Cadmium is a mobile element due to its weak affinity for soil colloids so it is easily absorbed and transported to the shoots [39].The degree to which higher plants are able to uptake Cd depends on its concentration in soil and its bioavailability, organic matter present in the soil, pH, redox potential, temperature and concentration of competing elements.

Generally, Cd enters first the roots, which are the first to experience Cd damage [40].Through the cortex it penetrates the root and is translocated to above ground tissues[41].Ligands like organic acids /phytochelatins form complexes with cadmium reach the xylem [42],[43].Only a small amount of Cd is transported to shoots as roots retain these ions [44].Generally the order of Cd accumulation in plants is: roots > stems > leaves > fruits> seeds [45].

2.4 Cadmium Hyperaccumulator Plants

In 1865, Thalpsi calamainare (Thalpsi carulescens) was first reported to show hyperaccumulation. The term hyper accumulator was first coined by Brooks et al. [46] to define plants that showed Ni concentrations higher than 1,000μg g-1dry weight (0.1%). Cadmium hyperaccumulator is defined as the plant species capable of accumulating more than 100 μg g1cadmium in the shoot dry weight. Plants occupying different taxonomic positions have been studied for their capability to hyperaccumulate Cd. Following is an attempt to bring together work of different researchers in this field.

2.4.1 Phytoremediation By Algae:

Some algae exhibit tolerance mechanisms result in high capacity for accumulation of heavy metals. Production of high biomass these species is an advantage leading to high absorption and accumulation of heavy metals.

Two major mechanisms exist for removal of heavy metals from polluted waters in microalgae; in the first metal is a metabolically taken into their cells at low concentrations, the second is a non-active adsorption process on cell wall [47].

Features that make them suitable candidates for the selective removal and concentration of heavy metals include high tolerance to heavy metals, large surface area/volume ratios, can grow both autotrophically and heterotrophically, phytochelatin expression and can be genetically manipulated [48].

Microalgae have been used extensively to measure heavy metal pollution and marine environments throughout the world. Exclusion, compartmentalization, forming complexes and synthesing binding proteins such as metallothioneins (MTs) or phytochelatins (PCs) and translocating them into vacuoles are the different defense mechanisms by which
they respond to heavy metal stress [49],[50]]. Cadmium induces phytochelatins PC2, PC3, PC4 in the conjugating alga *Micrasterias denticulata* [51]. *Chara,* a macroalga is effective at phytoextraction of mixed heavy metal contamination in sediments. Green algal species such as *Chlorella vulgaris, Scenedesmus quadricauda* [52]and *Chlorella homosphaera*[53]) have also been studied apart from marine algae [54]for their biosorption capacities. The metal uptake in dried biomass of *Spirogyra hyalina* was concentration-independent phenomena for Cd[55].

Formation of complexes is the basic mechanism of metal ion sequestration. Metal ion complexes with a functional group(s) on the surface or inside the porous structure of the cell membrane. The carboxyl groups of alginate play a major role in the complexation. Different species of algae and the algae of the same species may have different adsorption capacity [56]. Potential ligands for heavy metals that play a role in tolerance and detoxification are amino acids histidine (His) and nicotianamine (NA), carboxylic and phosphate derivatives (phytate) such as citrate, malate, and oxalate. [57],[58],[59],[60],[61],[62].

High negatively charged surface (cell wall) components are responsible for the adsorption, phytosorption and affinity of algae for heavy metal cations in wastewater treatment [63]. Production of phytochelatins in great amounts, in two marine algae, *Thalassiosira weissflogii* and T*halassiosira pseudonana*, due to the higher activity of phytochelatin synthase, results in greater affinity for the glutathione substrate or metal ions [64]. Entry via zinc (Zn2+), iron (Fe^{2+}) and calcium (Ca^{2+}) transporters is the molecular basis of Cd^{2+} uptake into plant cells [65]. Higher phosphorus concentrations lead to increase in Cd accumulation in the alga *Scenedesmus obliquus*. Shehata et al.[66] cultured *Scenedesmus* in different concentrations of cadmium to evaluate their effects on the growth of algae.

The concentration of 2 mg/L for Cd metal reduced *Scenedesmus* growth. Cd^{2+} contamination in surface water comes mainly from phosphatic fertilizers used in agricultural operations, which is reflected in municipal water supplies drawing water from river sources.

Various studies have been carried out to show the role of algae in the bioremediation of heavy metals. Some metals such as copper (Cu), lead (Pb), cadmium (Cd), cobalt (Co) are removed by *Cladophora glomerata* and by *Oedogonium rivulare* as short term and others such as nickel (Ni), chromium (Cr), iron (Fe), manganese (Mn) as continuous uptake. Biosorption of heavy metals from aqueous solution by fresh water filamentous algae *Spirogyra hatillensis* was also observed [67] Hence for this reason removal of Cadmium, mercury and lead from aqueous solution using marine macroalgae as low cost adsorbents has been in use.

2.4.2 Cadmium Removal By Bryophytes (Mosses)

Bryophytes are important members of various ecosystems. They help in maintaining soil stability in the face of wind and water erosion and also increase the rate of infiltration of water through the soil. Mosses have little or no developed cuticle. This is the reason why ions from the surface have direct access for cationic exchanges in the cell membranes. They have a great capacity for trace element retention [68],[69].Mosses have been used to monitor pollutant input in both aquatic [70],71],[72] terrestrial [73],[74]ecosystems. *Bryum capillare* and *Ceratodon purpureus* can be considered hyperaccumulator species for heavy metals, as their content in them comprises more than 0.1% dw [75].Cell wall in bryophytes have more proteins and less fibers, hence making available more cation exchange sites. Presence of more binding sites accounts for greater capacity of Bryophytes to remove metal ions from surroundings as was observed in *Ricciocarpus natans* [76].

Cadmium does not induces formation of phytochelatins in Bryophytes. Instead it stimulates the synthesis of glutathione as a chelating agent of Cd. This triggers an antioxidant response to the stress provoked by the presence of this heavy metal in the tissues of the mosses. Glutathione has been described as a transitory chelating agent in bryophytes, since this compound is capable of Glutathione transports Cd to the vacuole of the cells where it is stored and immobilized as $Cd_3(PO_4)_2$[77], [78].

Cadmium in *Leptodictyum riparium* causes induction of Heat Shock Protein (HSP70) Cadmium causes the most severe modifications in the ultrastructure of mosses, largely localized to chloroplasts. It showed decrease in the soluble protein content and enhances proteins reacting versus HSP70 antibodies, suggesting that these might be involved in the resistance to toxic effects of cadmium. Therefore, the induction of HSP70 in *L. riparium* would confer a higher resistance to pollutants under stressful conditions lethal for other mosses and higher plant species. These results suggest that the moss *L. riparium* can tolerate heavy metals stress without incurring severe cellular/subcellular damage. Therefore it can be used as a useful indicator of heavy metals accumulation [79].

Effect of presence of other bivalent ions on metal absorption by plant varies with species. Liver moss shows high potential as an economic and abundant material for the removal of metal ions from aqueous solution but the removal cadmium was markedly inhibited in the presence of calcium ion and heavy metal ions mixture in solutions [80]. Cadmium uptake was unaffected by the presence of calcium ions in *Fontinalis antipyretica* [81]. The biosorption of cadmium (II) onto dried Fontinalis antipyretica, a widely spread aquatic moss, was independent on temperature and averaged 28.0 mg g−1 moss. But pH does effect the metal uptake, optimum adsorption pH value was determined as 5.0.

Mosses overcome the stress created by Cd (II) by the enhancement of the GSH pool as in the water moss *Fontinalis antipyretica*. Cysteine and γ-glutamyl-cysteine may also show low level increase. Uptake experiments with Cd (II) showed a fast regulation of equilibrium between the Cd(II) content of the medium and the plant surface, followed by a slow migration of Cd(II) to intracellular sites. The main storage compartment of heavy metals in *Fontinalis* are the vacuoles, where they are precipitated as phosphates. In the cytoplasm, the S-content increased during Cd(II) exposition. Cd(II) is chelated by SH-groups. Thus, GSH plays an essential role in heavy metal detoxification during the transport of the metals through the cytoplasm.[78]

Biomass of moss *Rhytidiadelphus squarrosus* was studied as a potential biosorbent for cadmium, removal from single and binary solutions [82].It was shown that solution pH significantly influenced Cd biosorption. Maximum uptake was reached at pH 5.0-6.0 and negligible biosorption was observed at pH 2.0. Results revealed that the presence of Cd more significantly decreased the sorption of Co in binary Cd-Co mixtures than vice versa. In Cd-Zn binary system, both cadmium and zinc were sorbed with equal efficiency.

The *Sphagnum* peat moss would act as a good low-cost natural adsorbent for most heavy metal removal from single-constituent metal ion aqueous solutions, multi-constituent metal aqueous solution 196 and aerated synthetic landfill leachate *Sphagnum* moss peat, an inexpensive natural material, was used to re move cadmium and chromium from aqueous solutions[83].

2.4.3 Cadmium Removal By Pteridophytes (Ferns):

Many fern species have been identified to absorb metals through the roots [84] and to accumulate toxic metals (i.e., As) in the fronds [85].Roots in *B.orientale* recorded more metal concentration than shoot. The translocation factor (TF) and bioaccumulation factor (BF) of *B. orientale* was less than 1.0 at both sites indicating the immobilization of metals in the roots [86]and a BF < 1 showed the exclusion of metals from soils [87]. *B.orientale* did not have a good ability to transport heavy metals from the roots to the fronds [88].

Pteris vittata is known to be hyperaccumulator of arsenic. But foliar absorption in *Pteris* spp., have been investigated for its efficiency in remediation of cadmium. Biomass reduction and loss of photosynthetic efficiency were taken as the symptoms of phytotoxicity. Cd treatment produced a stronger negative impact on plant health, reducing significantly the biomass and photosynthetic efficiency [89].24 h of Cd salt treatment showed maximum foliar absorption of 70 mg kg−1 dry weight in the tip region of the frond [90].150 mM of Cd salt treatment up to 48 h showed increased proline concentration irrespective of the position of the frond. Cadmium exposure results in the increase in total protein content up to 72 h.

The potential of *Salvinia* for heavy metal removal has been studied extensively[91],[92],[93],[94,[95],[96],[97]. Biological processes such as intracellular uptake, though slow, help in Cadmium translocation from roots to leaves [97]The uptake was maximum during the first few hours, though availability of adsorption sites limits sorption capacity. Direct sorption of heavy metals occur through leaves as they are in direct in contact with the solution [98]and propose that as the main cause of increase in metal in the aerial parts [99].

High metal removal capacity of *Salvinia* biomass has been attributed to great specific surface (264 m2 g−1) that is rich in carbohydrates (48.50%) and carboxyl groups (0.95 mmol g−1) [100].Proteins behave as important ligand atoms and also play an important role in metal sorption. Among various *Salvinia* species, *S. minima* and *S. herzogii*, are considered as a hyperaccumulator of cadmium because they show high bioconcentration factor (BCF) [101[]both in batch systems and in continuous systems [102].*Azolla* sp. for long has been used for remediation of water. Many species of these genus these have been studied. 12 day exposure of *A.caroliniana* to 1mg/L of cadmium accumulated 259 µg/g of Cd [103]. Exposure of *Azolla* to cadmium results in reduction in growth rate and water content, leakage of cations, change in texture and color of shoots. Relative mobility of the cadmium is greater as compared to other heavy metals. Heavy metal content in root was 2-7 times higher than in shoots. Chlorophyll fluorescence and total chlorophyll can be used as physiological indicators to understand the mode of action of cadmium on the photosynthetic apparatus of *Azolla* fern [104]Cadmium causes disorganization of chloroplasts, resulting in inhibition of chlorophyll biosynthesis in 3 day exposure in *A.caroliniana*. *A. filiculoides* is also capable of accumulating cadmium. It showed the phenomenon-hormesis i.e. small concentration increases response whereas high concentration reduces the response [105].It exhibited response that was dependent on concentration. The accumulation decreased with increase in cadmium concentration [106].Comparing the accumulation of cadmium among the three sp. of *Azolla: A.filiculoides*, *A.pinnata* and *A. microphylla* the maximum accumulation was found to be in A.pinnata followed by *A.filiculoides* and then *A.microphylla*[107].

A.pinnata fronds when exposed to Cd showed increase in fresh mass upto 0.1mg/l, but with increase in exposure time i.e. after 96 hrs of exposure, *Azolla* showed increase only upto 0.05 mg/l, in comparison to control. Cd accumulation in the fronds increased with increase in concentration [108].The amount of metal accumulated depends on initial dose. The higher the initial dose the greater is the accumulation. Comparing with lead, cadmium is more toxic, as is evident from higher accumulation of lead in *Azolla caroliniana* fronds, suggesting that plant is more tolerant to lead than cadmium [103]. The rate at which Cd is adsorbed from the external medium varies with time. It is faster in the starting but slows down with passage of time reaching equilibrium after some time [109]. In the batch experiment in fixed *Azolla filiculoides* dose the capacity to remove Cd^{2+} depends on treatment conditions of biomass type of activator material, activation pH and biosorption process [110]

2.4.4 Cadmium Hyper-accumulation by Angiosperms:

With the increase in interest in this cost –effective and eco-friendly technology, more and more angiosperms are being tested for their remediation of heavy metals from polluted soils and water. *Thlaspi caerulescens* shows promising phytoremediation potential. It is well known cadmium and zinc accumulator [111]. *Thlaspi caerulescens* has 8 times higher capacity to remove Cd from soil than Brassica oleracea (white cabbage) [112].Production of high biomass is an essential character of hyperaccumulator which is true for Poplar and Willows. According to Greger et al [113], 12 yr of growth is required to remove the Cd accumulated in Swedish soils. Hybrid willow also showed the capability of removing Cd [114].Levels of Cd in poplar growing in-situ on contaminated soils show better bioaccumulation factor than those obtained from those in shade houses [115].

Use of ornamental plants for Cd remediation from soil serves dual advantage of beautification as well as remediation. It has a realistic and important purpose [116].For effective hyperaccumulator concentration of metal in shoot must be higher than in shoots. A study was conducted on three ornamental herbaceous plants: *Impatiens balsamina, Calendula officinalis* and *Althea rosea* with reference to tolerance and accumulation of cadmium. In *Calendula officinalis* Cd concentration in shoots was lower than in roots, suggesting limited ability to transfer Cd from roots to shoots. Hence it may find use in phytostabilisation of soils. Althea rosea exhibited both high tolerance and had high translocation factor, both under natural as well as induced conditions [117].

Cadmium owing to its high mobility is transferred easily to crops[118]. Thlaspi sp. and ecotypes of *Silena vulgaris* are found to be Cadmium accumulator [119],[120].*Brassica juncia* can tolerate and accumulate Cd at a very fast rate[121]).

Plants accumulate Cd and distribute it between tissues proportional to its level in soil [122].Nine crop species were compared for their capacity to take up heavy metals. Red beet exhibited maximum cadmium concentration ratio (shoot/root). Within the red beet, field pumpkin, chicory, common bean, white cabbage and parnship maximum Cd content was in leaves. Though the gradient of Cd concentration in plant is in the order roots > leaves > seeds, but differences occur in some species. Ciura et al.[123] reported that field pumpkin was ost effective in phytoremediation of cadmium (2.06mg/m2yr). According to McKenna et al.[124] Cd may be complexed in Cd binding peptides in roots and old leaves that hinder the transport of cadmium to young organs. Harrison and Chirgavi [125] showed that foliar translocation of air-borne components was generally low. Tlustos et al. [126] showed that pods and seeds of green beans had lowest Cd concentration as compared to spinach, radish, carrot and oat. He also proved that Cd content in grains increased in response to Cd content in solution.

Physalis minima L. shows a very high concentration factor of 51.02, hence is a good hyperaccumulator [127],[128] suggested *Datura innoxia* as a suitable candidate for Cd remediation. It has lower biomass but can accumulate higher concentrations from soil. In 90 days study it accumulated maximum Cd as compared to *Acacia nilotica*, *Ricinus communis* and *Calotropis giganta*. In all these plants maximum leaves showed maximum absorption than in stem or roots. Even in the leaves there occur variations in the amount of Cd accumulated. The Cd content was found to be greater in yellow leaves Morus alba than in green leaves, roots and stem. This could be either due to increase in accumulated Cd with increase in time could be transfer of metal from roots & stem into leaves during falling period[129]. This variation was not observed in *Populus alba* which is a better accumulator than *Morus alba*. This is attributed to its rapid growth, high biomass production and well developed root system.

Cadmium availability in soil varies with soil pH. With increase in soil pH, organic colloids strongly bind cadmium hydroxide ions, along with aluminium, & iron oxide reducing its availability to plants [130].Efficiency of a crop to clean soil polluted with Cd depend on its production of biomass and its distribution in crop tissues [123]The extent to which plant can extract cadmium varies with species, environmental conditions and exchangeable fractions of the soil in which the metal occur, as was observed by [98] in his study on two species of *Brassica* i.e. *Brassica juncea*.L and *Brassica oleracea* L. var. *capitata* L. *Avena sativa* (Oat) and *Zea mays* (corn) are two important crops in animal and human nutrition. Higher moisture content increases the Cd uptake. But oat is better remediator as it can accumulate more Cd in shoots [131].

Spinach, a common vegetable which can be easily grown with minimum agricultural practices could easily take up Cd from soil to a significant level [132].

Jatropa curcas which is usually being used for production of bio-diesel could be used or phytoremediation of cadmium and lead if the initial concentration was about 50mg/kg of soil [133]. *Chrysopogon zizansoides* (Vetiver grass) which is being used for soil erosion control and slope stabilization can also be used for phytostabilization of Cd on highly contaminated soils[134].

Field studies on *Solanum nigrium* showed that it can extract Cd from soils even at a very low concentration. Agronomic practices employed like double cropping, sequential harvesting enhanced the efficiency for phytoremediation as was evident from increase in biomass yield [135].Perennial halophyte *Aeluropus littoralis* from Poaceae family is another hyperaccumulator that can be used in both saline and non-saline soils. With its high growth rate, high biomass production and well developed root system, it could accumulate efficiently even at Cd concentration of 250 mg/kg of soil [136].

Industrial effluents are usually discharged in water bodies. Aquatic macrophytes can be used for the remediation of Cadmium from wastewaters. *Pistia stratoites* is suitable for Cd removal from surface waters. Though plant could tolerate upto 20 mg/L Cd in hydroponic system for 21 days, biomass of root and shoot declined with increasing Cd concentration [137].Stress symptoms in the form of chlorophyll content reduction and increased transpiration rate was observed but it exhibited increased accumulation of Cd with time, with 6 times more accumulation in root than leaves [138] *Typha angustifolia* is a root accumulator [139].

An interesting observation was made in case of *Hydrilla verticillata* by Dulay[140].It showed maximum absorption at ambient growth temperature (15-250C), but it excluded some of its absorbed metal content in solution between 5pm to 5am which otherwise showed decline during the day time. *Ceratophyllum demersum* and *Lemna minor* are considered good accumulator of Cd at low concentration because of high accumulation capacity, fast growth [141],[142],[143].

Metal hyperaccumulation pattern in water hyacinth was found to be of order leaves stems roots[144],[145].). Nakada et al [146] found high bioaccumulation values for Cd (1700) in *Elodea nuttallii*.

Many other terrestrial plants like *Helianthus annuus, Phaseolus vulgaris, Alyssum sp., Arabidopsis thaliana, Pisum sativum, Daucus carota* and *Hibiscus cannabis* have been tested for their role in Cd removal from soil.

3 CONCLUSION :

Rising levels are leading to increase in human diseases and reduced plant production due to its toxic effect. For sustainable development, the environmental management using green technologies is the need of the hour. The application of diverse phytoremediation technologies based on sound and reliable scientific research is the best remediation technique available. But for successful implementation of this technology knowledge of different disciplines such as ecology, plant physiology, plant genetics and biochemistry along with biochemical and bioprocess engineering is essential. Increased use of this green technology is required for the protection of environment and human welfare.

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