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Tree species as a sustainable green solution for cadmium phytoremediation

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ABSTRACT

Cd is recognized as highly toxic to living organisms and humans. It is present in the atmosphere, rocks, sediments, and soils. Cd enters ecosystems via numerous anthropogenic activities and emissions to the environment. Further, development in industries has built up a higher concentration of Cd in soils. Its presence in food in excess amounts may cause severe conditions in humans, therefore prevention of cadmium entering the food chain and its removal from contaminated soils is important. Over the past several years, many chemical and biological approaches for the remediation of Cd have been proposed. Phytoremediation, often called green remediation involves the use of plants (herbaceous, tree species) for the soil clean-up. This review is an attempt to summarize current information on the use of different plants and potential tree species for Cd phytoremediation from contaminated soils and the preferred accumulation of this heavy metal in different plant parts.

Keywords: *Heavy metals, Cadmium, phytoremediation, herbaceous plant, potential tree species, family Meliaceae, metal accumulation.*

Introduction

Heavy metals are metallic chemical substances with a relatively high density and are poisonous and toxic even at low concentrations (Zulfiqar et al. 2019). These metals include cadmium (Cd), aluminum (Al), arsenic (As), beryllium (Be), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), nickel (Ni), thallium (Tl), and zinc (Zn) (Karimpour et al. 2018). Among these, Cd is recognized as highly toxic to living organisms and humans [14]. Industrial development in the last few decades has built up a higher concentration of Cd in soils [10]. Cd enters ecosystems via numerous anthropogenic activities and emissions to the environment [1]. The deposition of Cd in polluted soil poses serious problems to the health of animals and humans due to its high mobility in contaminated soils [15] which affects multiple organs of the human body mainly kidneys and causes serious damage, including pulmonary emphysema, renal tubular damage, and kidney stones [53]. Chronic Cd poisoning, termed *itai-itai* disease first discovered in Japan in the early 20th century, causes renal tubular dysfunction, osteomalacia, and osteoporosis due to competition with Ca and other nutrients [42].

Apart from this, Cd affects plant growth at both the morphological and physiological levels as noticeable from a reduced leaf area, dry matter yield, and stunted growth [83,84]. Cd toxicity also includes leaf chlorosis, growth rate reduction, respiration and photosynthesis inhibition [64], increased oxidative damage, and decreased nutrient uptake ability [61]. Efficient and economical remediation of Cd-contaminated urban and agricultural lands is crucial for sustainable agriculture development.

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Different methods, like chemical, physical, and biological; electrokinetics; and phytoremediation; have been used for the remediation of heavy metal contaminants from soil. Some of them face limitations due to mechanical limitations, logistical problems, time, and cost [75].

Phytoremediation is considered an eco-friendly measure for the remediation of soil, often called green remediation [9]. Depending on the mechanism phytoremediation can be divided into five types: phytostabilisation, phytostimulation, phytotransformation, phytofiltration, and phytoextraction [74]. Phytoextraction includes the elimination of heavy metals by absorption, translocation, and accumulation of the metals by plant families like Scrophulariaceae, Lamiaceae, Asteraceae, Euphorbiaceae, and Brassicaceae [88]. Currently, several plants species are identified as Cd hyperaccumulating plants such as *Brassica juncea*, *Brassica rapa*, *Brassica nigra* [106], *Vigna unguiculata*, *Solanum melongena*, *Momordica charantia* [2] and *Nicotiana tabacum* [49].

However, on a large scale, phytoremediation of heavy metal from contaminated sites using trees may be preferred to annual/ biennial crops due to their capacity to produce large biomass, extensive deep root system, and ability to accumulate toxic metals in a form that is not biologically hazardous [79, 17]. In addition, tree species provide several beneficial attributes such as cost-effectiveness, aesthetic advantage, long-term applicability, and site stability [70]. The use of timber tree species for this purpose has additional benefits as these tree species can seize heavy metals in the timber for a long time. Many woody species like *Melia azedarach, Populus alba* [41], *Salix discolor*, *Salix eriocephala* [62], *Eucalyptus camaldulensis* [52], *Leucaena leucocephala* and *Dalbergia sissoo* [40] have been reported to accumulate and remove significant quantities of Cd and other metals from soil.

Phytoremediation potential of woody tree species

Woody tree species are used for phytoextraction due to several advantages over other species as these species can produce a very high amount of biomass when compared to herbs and shrubs, which facilitate the accumulation of high levels of heavy metals in their aboveground biomass. They have a deep root system, which can effectively reduce soil erosion and prevent the dispersal of contaminated soil to the surrounding environment. In addition, trees are preferred over crop plants for phytoremediation due to their non-edible characteristics, which means there is a lower probability of heavy metals entering the food chain via trees [13, 89]. The phytoremediation potential of Willow tree species has been explored by many scientists in the past. A characteristic of willow, which makes it a very suitable tree for use in phytoremediation, is that it can be frequently harvested by coppicing, has high biomass, effective nutrient uptake, high evapotranspiration rate, and a pronounced clone-specific capacity for heavy metal uptake [70]. Various clones of Salix species were tested by many researchers for their tolerance to different heavy metals. [45] elucidated that some clones of Salix under study were found to be tolerant to Cd and Zn, further tolerant clones had a relatively high or low net uptake of metal, with the net transport to the shoots varying between 1% and 72% of the total metal uptake. Other species of Salix namely, *Salix viminalis* [21] and *Salix phiphilodendron* [72] had the highest metal-accumulating ability and are suitable for removing significant quantities of Cd and other metals from soil. Some Salix species in a pot experiment were compared for their capacity to extract and accumulate Cd, Zn, Cu, Ni, Pb, and Cr among which *Salix schwerinii* "Christina", *S. dasyclados* "Loden" and *S. fragilis* "Belgisch Rood" showed the highest Cd and Zn accumulation and therefore considered good candidates for remediation [57]. [12] suggested the use of willow to remove Cd from moderately contaminated soil as the most immediate practical application of phytoremediation after considering the potential of willow to take up large amounts of Cd from contaminated soils. The better genotypes of willow under study had a capacity of about five times higher than the hyperaccumulators *Thalapsi caerulescens* and *Alyssum murale* plants due to their high biomass production and transport of Cd to the shoot [26]. Three woody, fast-growing species namely, *Jatropha curcas*, *Acacia mangium,* and *Hopea odorata* were tested by [55] for their phytoremediation potential for Cu contamination soil. The highest Cu concentration was observed in the roots of all the studied species. Among all species, *J. curcas* showed the highest BCF in T1 (20% sludge). *Jatropha curcas* and *A. mangium* showed high TF and low BCF in soil with higher Cu concentrations.

Concentrations of EDTA extractable Cd, Cu, Ni, and Zn in sewage sludge-treated soils were higher under *Salix burrata* than in unplanted areas [71]. On the other hand, [96] found evidence for depletion of extractable metals due to biomass willow growth, when compared to concentrations in adjacent unplanted areas. As per [19], *Salix mucronata* had the highest survival percentage in the presence of $CdCl_2$, $CuCl_2$, and Pb acetate. Based on BCF, TF%, and TIb data this species was found to be suitable as a photo stabilizer for Cd and Cu and as a phytoextractor for Pb-contaminated soil.

Other timber tree species like *Hopea odorata* and *Intsia palembanica* demonstrated their phytoextraction potential in the sequestration of Cd and were recorded to have a greater concentration of Cd in the woody tissues than the soils. *Acacia mangium* had significantly accumulated a greater total amount of Pb than *Swietenia macrophylla* cause of their relatively faster growth and thus having greater oven-dry biomass [7]. The toxicity effects of lead and cadmium on germination, root length, and dry biomass of *Thespesia populneoides*, *Leucaena leucocephala,* and *Delonex regia* were also evaluated. Exposure to high concentration (125ppm) of Cd decreased the root size of *L. leucocephala*, *T. populneoides,* and *D. regia* by 89.79, 71.8 and 62.26% respectively. Furthermore, the percent phytotoxicity and tolerance index represented *D. regia* as the most tolerant species whereas; *T. populneoides* and *L. leucocephala* were moderately tolerant and less tolerant species respectively against the Pb and Cd treatment [32]. Pot culture experiments with *Acacia saligna*, *Eucalyptus rostrata,* and *Conocarpus erectus* showed the highest levels of Pb and Cd caused a significant reduction in vegetative growth parameters and photosynthetic pigment. Both these metal contents in plant organs increased with increasing Pb or Cd levels in the soil till a certain level. Further *A. saligna* was found as the most tolerant species to lead and cadmium pollution followed by *E. rostrara* [6]. In some reports, the most satisfactory accumulators of heavy metals were *Alnus acuminata* subsp. *acuminate* (Cr, Pb), *Populus alba* (Cd, Pb), and Salix species (Cd, Zn) [100, 31, 36].

Fourteen tree species from 14 genera of 13 families were collected and investigated by [37] out of which *Platanus × acerola*, *Broussonetia papyrifera*, *Ligutrum lucidum*, *Viburnum awabuki*, *Firmiana simplex*, *Robina pseudoacacia, Melia azedarach* and *Osmanthus fragrans* exhibited high accumulated capacity and strong tolerance to heavy metals. Therefore, *Viburnum awabuki*, *Firmiana simplex*, *Robina pseudoacacia,* and *Melia azedarach* are suitable trees for Cd-contaminated areas. Cadmium phytoextraction potential of four multipurpose tree species viz. eucalyptus (*Eucalyptus tereticornis*), subadult (*Leucaena leucocephala*), Shrek (*Melia azedarach* L.) and shishamo (*Dalbergia sissoo* Roxb.) was presented by [40]. Among these Subabul showed the highest and eucalyptus showed the lowest total dry matter production at all levels of Cd. Subabul had the significantly highest uptake of Cd at various levels due to its higher biomass whereas shisham had the lowest. Also, Dhrek was more tolerant to Cd but subabul had the greatest potential for phytoextraction of Cd from the soil. [52] determined the chemical composition of leaves and flower buds of *Eucalyptus camaldulensis* in seven affected areas of mine-spill and found this species to be appropriate for the phytostabilization of Cd contaminated, As and Pb; given the relatively low levels of accumulation of these elements recorded in the aboveground biomass. In contrast, *Salix purpurea* accumulated high concentrations of foliar Cd and Zn. Pot experiment on Zinc accumulation in seedlings of six afforestation species was studied by [95]. Maximum height and high biomass were observed in *Betula alnoides* than the rest of the species under study. *Alnus nepalensis* showed the highest translocation and bioconcentration factor values for Pb, whereas, *Pinus yunnanensis* had higher translocation and bioconcentration factor values for Zn. Studies showed that *Alnus nepalensis* is the best candidate species for phytoremediation of Pb/Zn in mine tailing areas.

Acer platanoides L., *Acer pseudoplatanus* L., *Betula pendula* Roth, *Quercus robur* L., *Tilia cordata* Miller, *Ulmus laevis* Pall. cultivated on mining sludge were also studied for phytoremediation potential for As, Cd, Cu, Pb, Tl, and Zn. Out of which *A. platanoides* was reported to have effective phytoextraction of As, Cu, Pb, Tl, and Zn [60]. [82] explored the effect of salinity on the cadmium tolerance and phytoremediation potential of *Acacia nilotica* and showed that shoot and root growth, biomass, tissue water content, and chlorophyll contents decreased more in response to salinity and combination of Cd C salinity compared to Cd alone.

Shoot and root Cd concentrations, bioconcentration factor, and translocation factor increased with increasing soil Cd and Cd C salinity levels and due to Cd tolerance, high shoot biomass and shoot Cd uptake, *Acacia nilotica* has some potential for phytoremediation of Cd from the metal contaminated saline and non-saline soils.

While working on *Taxtodium distishum*, [66] showed a decreased concentration of heavy metal Cd, Pb, and Zn in the contaminated soil at the end of the experiment which suggested that these tree species act as a potential phytoremediator to improve soil properties, increasing fuel and timber production economic. Other woody species named *Fraxinus ornus* showed the ability to phytoextract Ca, *Populus nigra* for Zn, Ca and Cd, while *Salix alba* and *Salix caprea* have the capacity to phytoextract Zn and Ca [11].

Phytoremediation potential of trees belonging to the family Meliaceae

The potential of tree species belonging to the family Meliaceae namely, Dhrek (*Melia azedarach* L.) and Malabar neem (*Melia dubia*) for tolerance and accumulation of Cd in soils contaminated with graded levels of cadmium were reported by many workers. In two years of pot experiment, [41] investigated *Melia azedarach* is tolerant to Cd-contaminated soils without showing any toxicity symptoms. Accumulation of Cd in was observed higher in roots as compared to leaves and stem, thus considered as suitable phytoremediator for Cd-contaminated soils. Kang et al. 2016 reported high accumulated capacity and strong tolerance to heavy metals like Cd and Pb in *Melia azedarach*. Cadmium phytoextraction potential of Shrek (*Melia azedarach* L.) along with three other timber trees for the period of eighteen months was investigated. In which the upper critical level of available Cd in the soil at 20% reduction in dry matter was found to be highest for Dhrek and the lowest for eucalyptus, suggesting tolerance of Dhrek towards Cd [40]. *Melia dubia* Cav. FRI/MD/232-Varsha and FRI/MD/349-Shashi were well adapted, tolerant, and efficiently remediated the Cd from the soil when compared with the control. The concentration factor, tolerance index, and remediation factor were found to be more than 1 except the translocation factor which was less than 1 indicating bioaccumulation of heavy metals in the root system and reduced translocation from root to shoot system [25]. In a chromium salt-producing factory wasteland [99] proclaimed that the maximum accumulation of Cd (15.61 mg $kg^{-}1$) and Cr (925.07 mg $kg^{-}1$) was found in *Melia azedarach* L. Seedlings were exposed to different concentrations of Cd, Cr and Cd+ Cr in nutrient solutions which showed maximum survival rate of seedlings under heavy metal stress. *Melia azedarach* L. showed a BCF greater than 147.56 for Cd and 36.76 for Cr. The highest bioaccumulation was reported in root tissues. Another tree species, *Khaya senegalensis* belongs to the family Meliaceae showed the highest levels of Cd, Cr, Pb, Ni and Zn accumulation in the roots, whereas the highest Cu concentrations were observed in the shoot. The roots of *Khaya senegalensis* were found to be suitable for the phytostabilization of heavy metals in both the tannery effluent and borehole water irrigated media [104].

Effect of different doses of cadmium on growth parameters of tree species

The reduction in growth and abscission of leaves were observed in Willow Tangio (*S. mastodon × S. alba*) when grown in soil containing cadmium [78]. Additionally, the total leaf area of Willow clones was affected by Cd sulfate concentration of 38.5 mg $L^{-}1$ [103].

A tropical tree, *Dendropanax cuneatum* showed a considerable total accumulation of 697 µg kg-1 Cd with 63% of the total accumulated in the stem of plants in cadmium-contaminated dark red soils. The high accumulation of Cd in the stem of *D. cuneatum* showed the potential of this species in Cd phytoremediation and reduction of Cd secondary soil contamination from leaf accumulation [86]. [58] investigated five tree species (*Acer pseudoplatanus* L., *Alnus glutinosa* L. Gaertn., *Fraxinus excelsior* L., *Populus alba* L. and *Robinia pseudoacacia* L.) and found that *R. pseudoacacia* and *P. alba* had the highest growth rates, *F. excelsior, A. pseudoplatanus* and *A. glutinosa* had the highest survival rates (90%), but having stunted growth. *Salix dasyclados* showed a potential phytoremediation when grown in a pot containing soil moderately contaminated with Cd (5.46 mg kg-1). The species showed pronounced growth, besides accumulating high levels of Cd in leaves and branches (57.5 and 28.7 mg kg-1, respectively) without showing symptoms of Cd toxicity [22]. Also, *Populus eurphratica* and *Populus canescens* could grow in treated soil with Cd [69]. [20] observed a significant decrease in the values of the growth traits of *Populus nigra* in comparison to the control. The negative impact was higher with increasing heavy metal concentrations. Meanwhile, the reduction in root length was 27.62, 30.73 and 31.03% at the higher level of each heavy metal.

The highest level of Pb and Cd concentrations in soils caused a significant reduction in vegetative growth parameters and photosynthetic pigments. *Acacia saligna* appeared as the most tolerant species to lead and cadmium followed by *Eucalyptus rostrata* while *Conocarpus erectus* showed a low level of tolerance to these heavy metals [6]. *Populus maximowiczi* × *Populus nigra* could grow in 7.3 mg Cd, 1368 mg Pb, and 218 mg Zn /kg soil in spite of the inhibition effects on the growth parameters that correlated with higher levels of Cd, Pb, and Cu in the soil [43]. Fresh and dry root weights of *Alternanthera bettzickiana* significantly decreased at concentrations of 0.225 $mgL^{-}1$ of Cd and 0.414 $mgL^{-}1$ Pb doses [90]. Trees species belonging to the family Lythraceae named *Lagerstroemia indica* showed high growth compared to *Lagerstroemia fauriei*, when grown on different doses of Cd. The translocation factor of *L. indica* was high at all concentrations of Cd which further represented this species as a good candidate [95]. Two clones of the family Salicaceae were tested for Cd phytoremediation. *Populus deltoides* (clone B-81) presented high total biomass, root mass, leaf mass, and leaf area and *Populus trichocarpa* showed high tolerance to Cd toxicity as it didn't show significant differences in total biomass [65]. At a concentration of 27 mg kg-1, *Populus trichocarpa* was found to be highly tolerant to Cd toxicity [16].

[76] inferred the reduction in dry root biomass of *Populus nigra* 'Italica' when treated with 50 mg Cd and 1200 mg Pb kg^{-1} soil and observed 100% survival. Four tree species were subjected to five concentrations of Cd under greenhouse conditions, out of which *Leucaena leucocephala* showed great phytoremediation potential due to growth gains and large accumulation of Cd in shoots as a function of Cd concentrations applied to the vessel. In addition, chemical analysis of soil after harvesting the Leucaena plants showed a reduction in Cd levels, compared to analysis of soil prior to planting [40]. Salix species showed a decrease in the leaf area and vegetative fresh and dry weight with increasing heavy metal concentrations. Further, the values of root lengths, root fresh and dry weights, and greenness degrees were significantly reduced for all Cd, Cu, and Pb levels.

Salix mucronata tolerated $CdCl_2$, $CuCl_2$, and Pb acetate up to 80, 200, and 850 mg·kg^{-}1, respectively with 100% survival [19]. *Eucalyptus* seedlings have a good ability to accumulate Cd in their shoot, on the basis of translocation factor values (which is greater than one) as well as for BAC, BCF, and CI which further confirmed the ability of seedlings to accumulate and transfer elements from soil to root and shoot, and that seedlings have a good ability to absorb and accumulate Pb in their roots, when increasing the concentration of Pb in the soil, whether alone or in the presence of Cd [5].

Partitioning of cadmium in different parts of tree species

Trees differ in their ability to translocate heavy metals from the roots to shoots. Some species show the ability to tolerate and accumulate heavy metals [50]. Accumulation of cadmium varies in plant structures (i.e., root, stem, branches, and leaves) which are depicted in Table 1.

Table 1 List of tree species that have shown potential for phytoremediation and preferred accumulation of cadmium in their different parts.

Sr. No.	Tree species	Plant part where cadmium is accumulated	Results/ Remarks	References
1	*Picea abies* and *Pinus contorta*	Branches and stembark	No correlations were found between quantities of elements (Cd and Pb) in the trees and element pools in the soil.	[4]
2	*Salix sp.*	Stem	Stem Cd concentrations were found up to an order of magnitude greater than soil concentrations.	[71]
3	*Salix discolor*, *Salix eriocephala*, *Salix exigua*, *Salix nigra*, and *Salix lucida*	Roots	In a greenhouse hydroponics experiment, cadmium concentration in roots ranged from 75.9-577.3 µg g-1 in different treatments, with the most found in *S. lucida* at 25-µM treatments.	[44]
4	*Populus alba*	Leaves	The concentration of Cd was 8.0 mg kg^{-}1 in leaves.	[58]
5	*Salix viminalis*	Roots	Higher average Cd concentrations ranged from 4.4-12.2 mg.kg^{-}1.	[56]
6	*Salix dasyclados* and *Salix smithiana*	Leaves	The largest metal concentrations in leaves were detected in *Salix dasyclados* (315 mg Cd kg(-1) d.m.) and *Salix smithiana* clone (3180 mg Zn kg(-1) d.m.).Both the species showed low metal tolerance.	[92]
7	*Salix smithiana*	Leaves	Cd concentration in leaves was 250 mg /Kg-1 The bioaccumulation factor for Cd is 27	[97]
8	*Salix smithiana* (Clone S-218, S-150), *Salix viminalis* (S-519), *Salix alba* (S-464), *Salix* 'Pyramidalis' S-141, *Salix dasyclados* (S-406), *Salix rubens* (S-391)	Leaves	*S. smithiana* (S-150) and *S. rubens* (S-391) demonstrated the highest phytoextraction effect for Cd and Zn.The highest Cd content in leaves was approximately 20-fold higher than the minimum content in leaves.	[91]
9	*Salix sp.*	Leaves	The higher cadmium content in willow leaves was 1.73 mg/kg	[34]
10	*Rhapis excelsa*	Roots	At 50 mg kg^{-}1 Cd concentration, the content of Cd in the roots of *Rhapis excelsa* was the highest amongst all the tested species and 7.05 times higher than at 10 mg kg^{-}1 Cd concentration.	[107]
11	*Hopea odorata and Intsia palembanica*	Stem	Cd extracted by the two species was small and ranged only from 0.1 to 0.4 g Cd ha-1.	[7]
12	*Populus alba*	Green leaves and fallen leaves	In *P. alba,* fallen leaves showed higher concentrations of Cd and Cr [Cd (13.97 mg/kg at level 80) and Cr (15.39 mg/kg at level 240]	[73]
13	*Acacia mangium*	Stem	*A. mangium* depicted the high translocation factor and low bioconcentration factor values.	[54]
14	*Melia azadrek* and *Populus alba*	Roots	The highest uptake of Cd was recorded for roots, stem and leaves in decreasing order in both the species.	[41]
15	*Acacia saligna* and *Eucalyptus rostrata*	Roots	In *Acacia saligna* roots concentrations of Cd was 62 mg/kg -1 and in *Eucalyptus rostrata* roots the concentration of Cd was 52 mg/kg -1.	[6]
16	*Conocarpus erectus*	Shoots	The concentration of Cd was 35 mg.kg-1dwt in shoots.	[6]
17	*Salix Sp.* and *Populus sp.*	Leaves	The highest average amount of Cd and Zn was in willow leaves (from 5.16 to 8.18 mg Cd.kg^{-}1 and from 748 to 1050 mg Zn.kg^{-}1).	[35]
18	*Eucalyptus tereticornis*, *Leucaena leucocephala*, *Melia azedarach* and *Dalbergia sissoo*	Leaves	The total uptake at different levels of applied Cd was higher in *Leucaena leucocephala* (0.05–71.4 mg pot-1) than the other tree species, which may be due to higher total biomass. Cd uptake at various levels was the lowest by *Dalbergia sissoo* (0.05–28.2 mg pot-1) due to its lower biomass.	[40]
19	*Quercus robur*	Roots	268 ± 57 mg kg^{-}1 (Cadmium concentration in roots)	[60]
	Acer platanoides	Stem	30.2 ± 2.1 mg kg^{-}1 (Cadmium concentration in stem)	
	Ulmus laevis	Leaves	34.2 ± 3.6 mg kg^{-}1 (Cadmium concentration in leaves)	
20	*Salix purpuare*	Leaves	The concentration of Cd in leaves of *S. purpurea* (mean of 7 mg kg-1) was about 15 times higher than *in E. camaldulensis*, and above the phytotoxicity threshold (5 mg kg-1).	[52]
	Eucalyptus camaldulensis	Leaves and flowers		

21	*Populus deltoides*	Roots	The 58.0 and 46.7% of the total Cd content was accumulated in the roots of *P. × euramericana* and *P. deltoides*, respectively, with the remainder in the stems (18.2 and 39.9%) and leaves (23.8 and 13.4%).	[65]
22	*Cinnamomum camphora*	Stem and Leaves	Cd was mainly distributed in the shoots. The maximum Cd content in stems and leaves were 12.5 and 10.71 mg·kg^{-1}	[105]
23	*Tamarix nilotica*	Leaves	Bio-concentration Factor (BCF) of Cd in leaves was 1.31.	[18]
24	*Cassia alata*	Roots	The BCF in the roots was higher at concentrations of 132 μM Cd, while the BCF in leaves decreased with increases in Cd concentrations in solution	[85]
25	*Salix mucronate*	Roots	Estimated BCF indicated that the majority of Cd, Cu, and Pb accumulations in plant organs were considered medium (BCF = 1–0.1). In general, BCF values were higher in roots, followed by leaves and stems, in Cd-contaminated soils.	[19]
26	*Ailanthus altissima*	Leaves	Accumulation of higher percentage Ni, Cu, and Cd in leaves by virtue of wider leaf surface area of the species under study.	[30]
27	*Populus deltoides* (clone 'Bora') and *Salix viminalis* L.	Leaves	Cd and Zn were mostly accumulated in the leaves of both Poplar and Willow trees. In contrast, other metals (e.g., Cr, Ni, Pb, Cu) were mostly phytostabilized in the roots.	[68]
28	*Populus nigra*	Roots	The bioconcentration factor was <1, and thetranslocation factors (TF) of Cd and Cu were <1 under various concentrations of each heavy metal.	[20]
29	*Melia dubia*	Roots	Concentration factor, tolerance index, and remediation factor were found to be more than 1 except translocation factor which was less than 1 indicating bioaccumulation of heavy metals in root system and reduced translocation from root to shoot system.	[25]
30	*Eucalyptus spp.*	Roots	Translocation factor, biological accumulation coefficient, bioconcentration factor, and concentration index for Cd ranged between (0.611-4.239), (1.333-28.790), (0.383-16.840), and (1-490.812) respectively.	[5]
31	*Khaya senegalensis*	Roots	*Khaya senegalensis* had concentrations of metals showing TF values of (1.17, 1.50 and 1.67) for Cd and (1.60, 1.00 and 1.00) for Cu which are all greater than one in growth media irrigated with tannery waste water, borehole water (groundwater) and control respectively.	[104]
32	*Betula spp.*	Wood and leaves	The SRMAR (Shoot-to-root metal allocation ratio) values found for Cd in the deciduous tree group were the highest (7.8) recorded for all target metals in the contaminated soil under study.	[27]

Conclusions: Efficient and economical remediation of Cd-contaminated urban and agricultural lands by chemical, physical, and biological faces limitations due to mechanical limitations, logistical problems, time, and cost. Whereas, Phytoremediation often called green remediation is considered an eco-friendly remediation of soil which includes the use of specific plant and tree species belonging to different families to remediate heavy metals from the contaminated soils. Some of them are identified as excluder species whereas, some are designated as accumulators as well as hyperaccumulators. Trees are preferred to annual/ biennial crops due to their capacity to produce large biomass, extensive deep root system, and ability to accumulate toxic metals in a form that is not biologically hazardous. In addition, tree species provide several beneficial attributes such as cost-effectiveness, aesthetic advantage, long-term applicability, and site stability. Many woody species like *Melia azedarach, Populus alba*, *Salix discolor*, *Salix eriocephala*, *Eucalyptus camaldulensis*, *Leucaena leucocephala,* and *Dalbergia sissoo* were noticed to accumulate and remove significant quantities of Cd and other metal from soil.

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