

# HEAVY METALS AND CADMIUM TOXICITY IN SOIL AND PLANTS

## **Abstract:**

Primarily in areas with high levels of human activity, heavy metals like cadmium, copper, lead, chromium, and mercury are significant environmental hazards. Deposition of heavy metals in soils is a problem in agricultural output because it has a negative impact on food safety and consumer appeal, growth of crops due to phytotoxicity, and soil organisms' environmental health. Through soil, water, and air pollution, plants and their metabolic processes affect the geological and ecological redistribution of heavy metals. This review article addresses the toxicity of heavy metals, particularly Cd, on plants. Plants are greatly impacted by toxicity, which consequently affects the environment in which plants are crucial. Plants cultivated in metal-polluted environments exhibit metal accumulation, reduced growth, altered metabolism, and lower biomass output. Many plant physiological and biochemical functions are impacted by metals.

**Keywords:** Heavy Metals, Contamination, Cadmium toxicity.

**Introduction:** Extensive development and rapid economic growth have mostly contributed to environmental contamination. Environmental contamination has been caused by a variety of sources, including radioactive isotopes, organic and organometallic compounds, gaseous pollutants, inorganic pollutants (including heavy metals), and the toxicity of certain nanoparticles. Because of its catastrophic long-term effects, pollution has become a major issue to solve despite global efforts to reduce it. One of the main causes of pain and death in the world today is environmental degradation. Inorganic heavy metal pollution has received significant attention due to their widespread presence and hazardous effects (Al-Khayri et al., 2023).

Heavy metals are a diverse set of elements that primarily belong to the transition element in the periodic table and vary in their chemical characteristics and functions. The elements classified as heavy metals have a specific weight greater than 5 g cm<sup>3</sup>. Heavy metals are described as those that are at least five times denser than water. These metals can be either

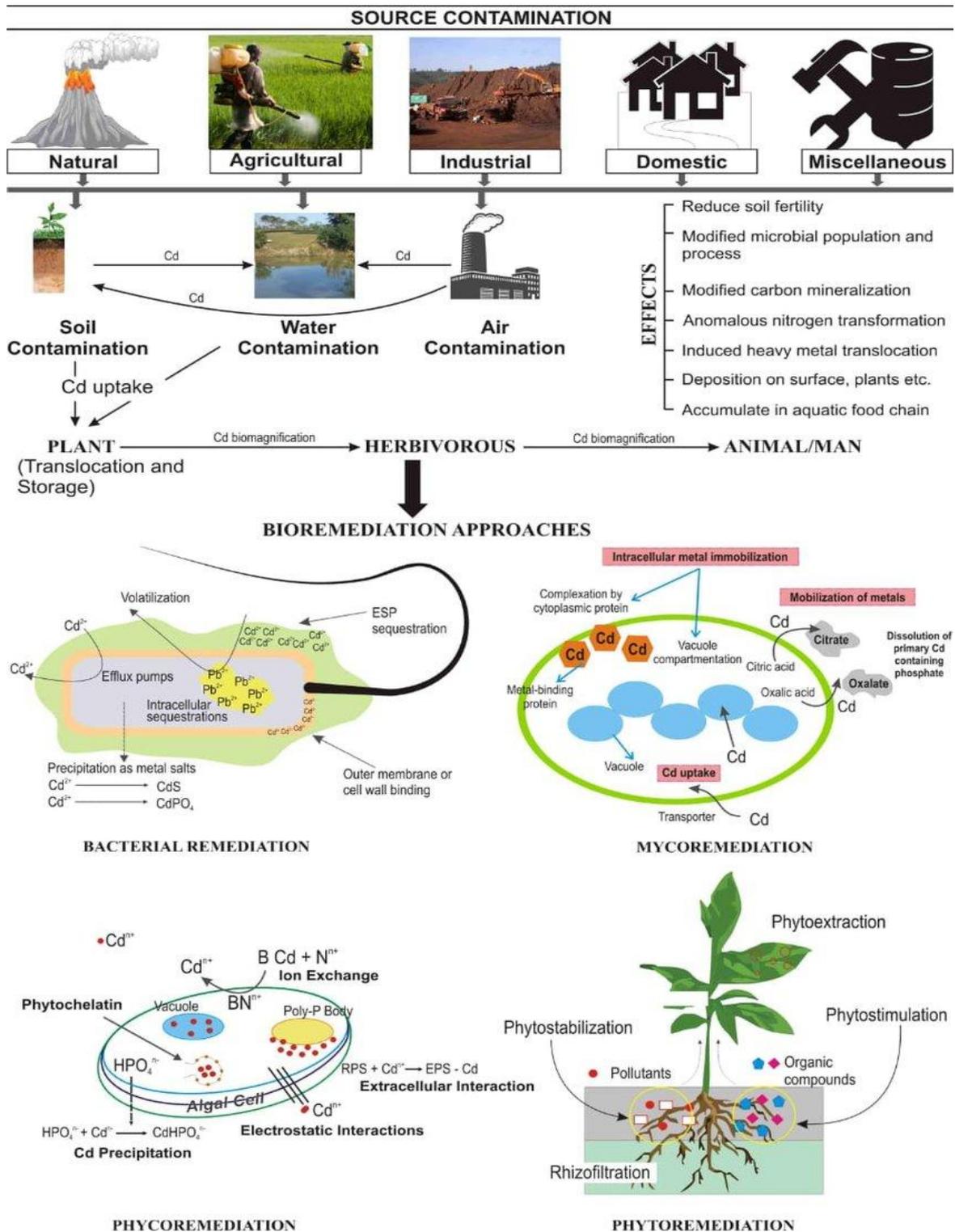
33 essential (such as Mo, Mn, Cu, Ni, Fe, and Zn) or non-essential (such as Cd, Ni, As, Hg, and  
34 Pb)(**Kiran et al., 2022**).

35 Cadmium (Cd) had the highest ecological risk index of all the heavy metals. The current  
36 investigation shows that the soil in the metropolitan region of Rohtak has greater levels of  
37 cadmium. Plants, animals, and humans are at risk from cadmium (Cd), a heavy metal that  
38 occurs naturally in soil. Soil and groundwater contamination by cadmium is a worldwide  
39 issue(**Soni et al., 2024**). Manure, sewage sludge, excessive use of phosphatic fertilizers, and  
40 airborne deposition are the primary causes of Cd pollution in soil. Long-term application of  
41 sewage sludge, industrial effluents, sewage, contaminated river water, and municipal solid  
42 waste results in a high concentrations of metal contamination in soil (**Golui et al., 2021**).

43 **Cadmium toxicity in soil:** A worldwide issue is the contamination of soils and groundwater  
44 with cadmium (**Soni et al., 2024**). In plants, the heavy metal cadmium (Cd) serves no  
45 biological use(**Riaz et al., 2021**). Among the top 20, it is the eighth most hazardous metal and  
46 is classified as a group 1 carcinogen (**Lu et al., 2019**). According to **Singh et al. (2020)**, it is  
47 one of the most hazardous metals because of its high level of toxicity and widespread  
48 bioaccumulation. It is therefore readily absorbed by plants. After being absorbed, Cd is  
49 moved and accumulates in different edible plant parts (**Adil et al., 2020**). Both natural  
50 resources like mines and volcanoes, as well as human activities like fertilization, waste  
51 discharges, and industrial effluents, cause cadmium to build up in soil (**Bouida et al., 2022**).  
52 Because of its lengthy half-life (10–33 years), cadmium persists in soil for a long  
53 time. According to **Soni et al. (2024)**, the levels of Cd in vegetables and cereal grains  
54 cultivated in soil contaminated with the metal range from 0.008 mg kg<sup>-1</sup> to 0.062 mg kg<sup>-1</sup>.  
55 Phosphate fertilizers, sewage sludge, industrial effluents, municipal garbage, and airborne  
56 deposition are among the anthropogenic activities that cause cadmium to infiltrate the soil  
57 (**Golui et al., 2021**). Cd is a persistent hazard to the environment, particularly soil and  
58 groundwater, because of its lengthy half-life and persistence. This contamination comes from  
59 both natural (such as mineral weathering and volcanic activity) and man-made (such as  
60 fertilizer use and industrial discharge) sources (**Bouida et al., 2022**). Cadmium interferes with  
61 microbial diversity, enzymatic activity, and nutrient cycling in soil. It leads to reduced  
62 decomposition rates, impaired nitrogen fixation, and changes in the soil microbial  
63 biomass. Plants absorb Cd mainly through their roots via cation transporters that are also  
64 responsible for uptake of essential metals like Zn and Fe. Following absorption, Cd is moved  
65 to the plant's aerial sections, especially the leaves and fruits, where it builds up. This uptake is

66 non-selective and varies depending on plant species, genotype, and environmental  
67 conditions. Some plants develop tolerance to Cd through binding Cd with phytochelatins and  
68 metallothioneins, sequestering Cd in vacuoles, root exudation to limit Cd availability and  
69 activation of antioxidant systems. Plants such as Amaranthus and Vetiver grass are used to  
70 remediate Cd-contaminated soil. Techniques include phytoextraction, phytostabilization, and  
71 rhizofiltration. Cd enters the food chain through plant consumption and bioaccumulates in  
72 human tissues, especially the kidneys and liver. Chronic exposure causes renal dysfunction,  
73 skeletal damage, and cancer. Cd bioaccumulates in the kidney cortex and liver, causing renal  
74 tubular dysfunction, osteoporosis, and cancers. Long-term exposure leads to itai-itai disease,  
75 hypertension, and reproductive toxicity. A reasonable monthly dose of 25 µg/kg body weight  
76 is advised by WHO (WHO, 2023). **Soni et al. (2024)** reported Cd levels exceeding WHO  
77 limits in Rohtak's peri-urban agricultural soils. Sources included wastewater irrigation,  
78 industrial discharges, and phosphate fertilizer overuse. Vegetable crops grown in this area  
79 showed elevated Cd content, raising food safety concern.

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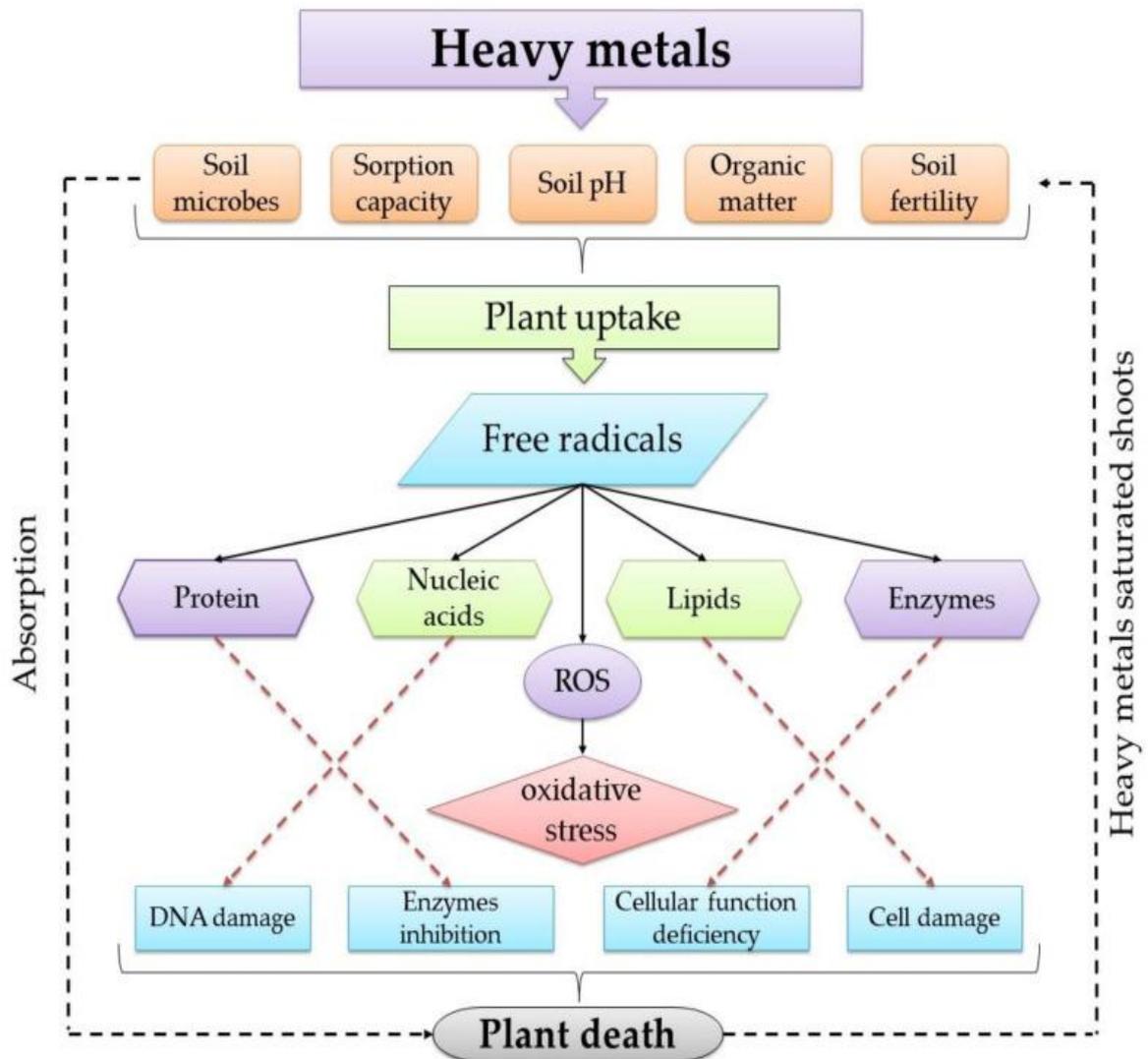
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82 **Fig.1: Overview of Cadmium toxicity (Kumar et al.,2020).**

83 **Major impact on plants:** Certain plant species exhibit toxin resistance by containing  
 84 accumulated metals in their roots or by tolerating elevated amounts of heavy metals in their  
 85 tissue (Davis and Beckett, 1978). According to Boggess et al. (1978), plants' propensity to  
 86 accumulate metal in their shoots can be linked to their sensitivity to metal toxicity. Hewitt

87 (1966) postulated that elements with comparable physical and chemical characteristics would  
 88 behave antagonistically in biological interactions. Reactive enzymatic and receptor proteins  
 89 are displaced by elements of similar types, which also compete for the same transport and  
 90 storage places in the cell. Copper toxicity may be inhibited by Cd, whereas selenium may  
 91 work in concert with it. It can impact morphological, physicochemical, and structural  
 92 alterations in plants, such as stomatal density, chlorosis, and suppression of lateral roots  
 93 (Huybrechts et al., 2020). For instance, whereas Cd may inhibit the absorption of copper,  
 94 selenium may work in concert with it. Cd toxicity often results in altered ion homeostasis,  
 95 enhanced reactive oxygen species (ROS) generation, disruption of enzymatic activity,  
 96 structural damage to mitochondria and chloroplasts and reduced crop yield and biomass.

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99 **Fig. 1:** Heavy metals and their effects in plants (Alengebawy et al.,2021).

**Table 1: Effects observed in plants due to heavy metals.**

S.No.	Metal studied	Plant studied	Effects Observed	References
1	Cd	Spinach, soybeans, lettuce, and curlycress	Leafy vegetables accumulated toxic levels of cadmium at low soil concentrations, while grains and fruit crops showed greater tolerance and lower Cd uptake.	<b>Bingham et al.,1975</b>
2	Cd	Maize, sorghum, pearl millet, clusterbean, green gram and cowpea	Reduction in rice yield	<b>Sarkunan et al.,1998</b>
3	Cd, Pb, Zn, Cu, Cr and Ni	Wheat	Protein content decreased	<b>Athar and Ahmad 2000</b>
4	Cd (II), Cr (VI) and Cu (II)	<i>Convolvulus arvensis</i>	Reduction in root elongation but shoot is suitable for phytoremediation	<b>Torresdey et al.,2004</b>
5	Cd, Zn, Cu, Cr and Pb	Chickpea	Depletion of plant growth, chlorophyll, nodulation and nitrogen concentration in roots and shoots	<b>Wani et al.,2007</b>
6	Cd	Rice ( <i>Oryza sativa</i> L.)	Predominance of photosynthetic rates, chlorophyll content, fluorescence efficiency and reduced nitrate reductase activity	<b>Hussain et al.,2008</b>
7	Cd and Pb	Mango	Predominance of photosynthetic rates, chlorophyll content, fluorescence efficiency and reduced nitrate reductase activity	<b>Yang et al.,2010</b>
8	Cd and Pb	Corn ( <i>Zea mays</i> )	Phytoremediation	<b>Mojiri,2011</b>
9	Cd	Amaranthus, fenugreek and buckwheat	Reduction in dry matter yield	<b>Joshi et al.,2011</b>
10	Cd	Spinach	Decrease in dry matter	<b>Dalir et al.,2013</b>
11	Cd, Pb, Cr, Zn	Maize	-	<b>Nacke et al.,2013</b>
12	Cd	Bana grass, vetiver grass	No significant effect on chlorophyll content and photosynthetic rates but water content and leaf transpiration rate increased	<b>Zhang et al.,2014</b>
13	Cd	-	Altered mitochondrial function as a result of redox regulation being upset and more ROS being produced,	<b>Gallego et al., 2012; Chen et al., 2018a, 2018b, 2018c;</b>

			which interferes with plant metabolism and damages membrane lipid	<b>Huybrechts et al., 2020</b>
14	Cd	Rice	Delays in plant growth and decreased yield	<b>Mitra et al., 2018b</b>
15	Cd	-	Plant physicochemical, morphological, and structural alterations, such as stomatal density, chlorosis, and lateral root inhibition	<b>Bari et al., 2019; Huybrechts et al., 2020</b>
16	Cd	Rice	variation in ion homeostasis through reduced water and mineral uptake, changed nitrogen metabolism, and restricted absorption of basic ions such as iron and magnesium	<b>Afzal et al., 2019; Huybrechts et al., 2020</b>
17	Cd	<i>Phaseolus lunatus</i> , Castor ( <i>Ricinus communis</i> )	Effects on water transport, nutrition intake, enzyme activity, and photosynthesis	<b>Ahmad et al., 2021a, Ahmad et al., 2021b; Rahul and Sharma, 2022</b>
18	Cd	-	Effects on growth inhibition, wilting, chlorosis, leaf necrosis, decreased biomass, and yield	<b>Shaari et al., 2022</b>
19	Cd	Brassica	Plant death, reduced biomass output, and decreased plant growth	<b>Li et al., 2023</b>
20	Cd	Wheat	Compared to water control, enzyme activity were lower at low concentrations (100 µM) of cadmium but increased in roots treated with high doses (500 µM).	<b>Ghosh et al., 2023</b>

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102 This table elaborated experimental design, metal concentration used, and specific plant  
103 responses, including physiological, morphological, and yield data. **Cd – Spinach, soybeans,**  
104 **lettuce, and curlycress:** Bingham et al. (1975) found general toxicity but didn't elaborate on  
105 mechanisms. Symptoms included reduced biomass and chlorosis. **Cd – Maize, sorghum,**  
106 **pearl millet, clusterbean, green gram, cowpea:** Sarkunan et al. (1998) observed significant  
107 yield reduction. This correlates with photosynthetic inhibition and impaired nutrient  
108 transport. **Cd, Pb, Zn, Cu, Cr, Ni – Wheat:** Athar and Ahmad (2000) reported decreased  
109 protein content. This is linked to disrupted nitrogen metabolism and enzyme  
110 inhibition. **Cd(II), Cr(VI), Cu(II) – Convolvulus arvensis:** Torresdey et al. (2004) found  
111 reduced root growth, but the species showed good phytoremediation potential, indicating

112 adaptive mechanisms.**Cd, Zn, Cu, Cr, Pb – Chickpea:** Wani et al. (2007) noted reduced  
113 growth and chlorophyll. Heavy metals interfere with nodulation, affecting nitrogen  
114 fixation.**Cd – General:** Hussain et al. (2008) described reduced photosynthetic rate and  
115 enzyme activity.**Cd and Pb – Mango:** Yang et al. (2010) didn't specify exact symptoms but  
116 highlighted fruit contamination risk.**Cd and Pb – Corn (Zea mays):** Mojiri (2011) focused  
117 on its suitability for phytoremediation.**Cd – Amaranthus, fenugreek, buckwheat:** Joshi et  
118 al. (2011) observed reduced dry matter, indicating overall metabolic stress.**Cd – Spinach:**  
119 Dalir et al. (2013) also confirmed dry weight decline, echoing broader observations.**Cd, Pb,**  
120 **Cr, Zn – Maize:** Nacke et al. (2013) noted unspecified symptoms, implying general stress.**Cd**  
121 **– Bana grass, vetiver grass:** Zhang et al. (2014) found high tolerance; good for  
122 remediation.**Cd – General:** Gallego et al. (2012), Chen et al. (2018) showed mitochondrial  
123 damage and ROS production.**Cd – General:** Mitra et al. (2018b) described delayed growth  
124 and yield decline.**Cd – General:** Bari et al. (2019) observed structural changes like chlorosis  
125 and stomatal shifts.**Cd – General:** Afzal et al. (2019) noted disrupted ion homeostasis.**Cd –**  
126 **General:** Ahmad et al. (2021) found disrupted photosynthesis and water/nutrient transport.**Cd**  
127 **– General:** Shaari et al. (2022) reported growth inhibition, necrosis, and yield loss.**Cd –**  
128 **General:** Li et al. (2023) observed biomass decline and death at high concentrations.**Cd –**  
129 **Wheat:** Ghosh et al. (2023) found enzymatic changes: stimulated at high Cd, suppressed at  
130 low.

131 **Conclusion:** This review focused on the hazardous effects of heavy metals three key  
132 ecosystem components: soil, plants, and humans. The dangers of heavy metals especially  
133 Cadmium were thoroughly highlighted. In addition, their effects on human health were  
134 observed and several research studied related to restrict nitrogen metabolism, increasing and  
135 lowering the activity of particular enzymes due to toxicity. The presence of Cd in agricultural  
136 soil not only impacts plant physiology and crop productivity but also poses significant risks to  
137 human health through bioaccumulation in edible plants. Understanding the mechanisms of Cd  
138 uptake, accumulation, and phytotoxicity is essential for developing effective strategies for  
139 phytoremediation, soil management, and pollution control. Further interdisciplinary research  
140 is vital for mitigating heavy metal pollution and ensuring ecological and agricultural  
141 sustainability. There is an urgent need for long-term monitoring of soil and food  
142 crops, development of Cd-resistant crop varieties, use of biofertilizers, development of low-Cd-  
143 accumulating crop genotypes, application of biochar and organic amendments to immobilize  
144 Cd. Integrated monitoring systems for agroecosystems and Policies limiting Cd emissions and

145 promoting sustainable agriculture and mycorrhizal inoculants and strict enforcement of  
146 effluent discharge standards.

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