EPH - International Journal of Biological & Pharmaceutical Science
ISSN (Online): 2208-2166
Volume 09 Issue 01 January 2023

DOI: https://doi.org/10.53555/eijbps.v9i1.49

PHYTO-REMEDIES FOR SOIL RESTORATION: A DEEP DIVE INTO BRASSICA'S PLANT CAPABILITIES IN CADMIUM REMOVAL

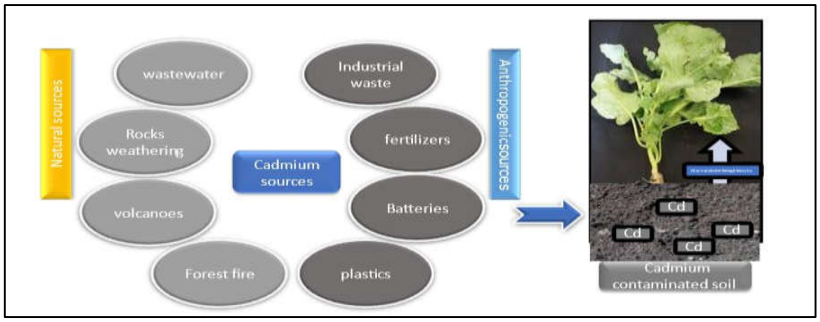
Muhammad Waseem[1], Muhammad Qamar Abbas[2], Khadija Ummer[3], Rida Fatima[4], Waseel Khan [5], Fatima Gulzar[6], Muhammad Qasim[7], Qudrat Ullah[8] , Irfan Haidri[9]
[1]Department of Environmental Science, Government College University Faisalabad 38000, Punjab Pakistan
mw6358673@gmail.com
[2]Department of Environmental Science, Government College University Faisalabad 38000, Punjab Pakistan
qamarabbasbashovi@gmail.com
[3]Institute of Soil and Environmental Sciences University of Agriculture Faisalabad 38000 Punjab Pakistan
khadijaumer68@gmail.com
[4]Center of Agricultural Biochemistry and Biotechnology, University of Agriculture Faisalabad 38000, Punjab Pakistan
ridufatima512@gmail.com
[5]Institute of Soil and Environmental Sciences University of Agriculture Faisalabad 38000 Punjab Pakistan
waseelkhan659@gmail.com
[6]Department of Chemistry, University of Agriculture Faisalabad 38000, Punjab Pakistan
fatimagulzar81@gmail.com
[7]Department of Environmental Science, Government College University Faisalabad 38000, Punjab Pakistan
qasim987khan@gmail.com
[8]Department of Environmental Science, Government College University Faisalabad 38000, Punjab Pakistan
qudratullahmpur2@gmail.com
[9]Department of Environmental Science, Government College University Faisalabad 38000, Punjab Pakistan
haidaryirfan807@gmail.com

***Corresponding Author:**
Email: haidaryirfan807@gmail.com

Abstract

One of the most critical environmental problems is heavy metal pollution, which is made worse by the impact of certain industries in certain nations. One of the primary hazardous heavy metals found in soil is cadmium (Cd). Soil cadmium pollution is a worldwide problem. All soils contain cadmium, a naturally occurring metal that comes from both geogenic and human sources. Cadmium has an impact on people, plants, and soil microorganisms. A disruption in the intake and translocation of mineral nutrients and a disruption in plant metabolism may cause Cd toxicity in crops, which can impede the growth and development of the plants. Some of the approaches used to remove heavy metal pollution from the air include physical, chemical, and biological. It is crucial to bear in mind that some of these have time or money limits. In situ, immobilization, phytoremediation, and natural approaches are the best ways to remove metal(loid) from the soil presently. Some of the remediation solutions included phytoremediation of Cd metal from Soil, highlighting the in-situ immobilization strategy as a particularly efficient way to remove Cd from soils. Heavy metals should not penetrate the atmosphere, established order, or exposure to people and animals as part of remediation activities at a contaminated site." All of these site-specific characteristics impact the treatment procedure applied at any particular site, including soil type, synthetic chemical type, and depth of contamination. In this study, we examine several molecular techniques for reducing Cd accumulation in grains and discuss new developments in the molecular processes of Cd accumulation in cereal crops.

Keywords: *Cd, sources of Cd, removal methods, Brassica rapa, Soil microbes, Phytoremediation, In situ immobilization, Environmental challenges, Remediation solutions*



Graphical abstract

1. INTRODUCTION

The biological system's soil is the most critical ecological component. Plants and animals, as well as humans, rely on soil for their existence and growth (Wang et al. 2011). Heavy metals from urban and metropolitan rubbish pollute soil and water, raising environmental issues. There may be a danger to people even at low concentrations of heavy metals that include more than four grams per cubic centimeter of thickness (Duruibe et al. 2007). In addition to the parent rock, human labor, and the soil's physical-substance qualities, heavy metal provides the energy source for the process. Ecological testing requires a full understanding of natural occurrences of heavy metals. For heavy metal aggregation and accessibility in soils, acidity, and organic matter are critical physical and chemical components (Ramos-Miras et al. 2011). A trace element called Cd has the potential to be hazardous to both plants and mammals. Cd is a dangerous heavy metal that belongs to the 12th group of the periodic table with an electronegativity of 1.69 and a specific density of 8 g/cm3. It also has an atomic number of 48. Even at low concentrations (0.001- 0.1 ppm), most aquatic life is adversely affected by cadmium (Chellaiah, 2018). Its introduction into the food chain poses serious health risks to people (Chaney, 2015; Shahid et al., 2017). The primary natural sources of Cd (100-500 tonnes year-1) include volcanic activity, and weathering, including erosion (15,000 tonnes per year), marine phosphates (15 mg kg^{-1}), and volcanic soil (4.5 mg kg-1). Primary human sources of cadmium include sewage sludge, the cement industry, fuel combustion, power plants, protective steel plating, polyvinyl chloride (PVC) stabilizers, phosphate fertilizers, plastics, glass as a pigment, nickel-cadmium battery electrode material, mining activities, smelting zinc into various alloys (Malyan et al., 2019; Sharaff et al., 2020; Singh et al., 2018). In addition to the platinum group metals, heavy metals include arsenic, cadmium, and cadmium-containing metals such as copper and iron are sources of cd. Nonmetallic and metallic qualities may be described using the term "metal(loid)s." No matter how they enter the environment, metals, and metalloids may be found in the soil, water, plants, and animals alike. Various amounts of metals may be found in Arctic soil, water, and plant materials (Szefer et al. 1997). With the reactivity, high mobility, and chemical similarity to that of the important element zinc (Zn), plants can absorb Cd even at lower concentrations of soil Cd levels (Rehman et al., 2017). In humans, cadmium causes lung inefficiency, liver damage, renal dysfunction, bone loss, hypercalciuria, hypertension, and neurological issues (Cabral Pinto et al., 2020).

Despite being poisonous and non-essential to plants, Cd can be absorbed by a variety of food plants and may accumulate in the eating sections. Plant Cd accumulation is influenced by the physio-chemical characteristics of soils (Li et al., 2019). Furthermore, a lot of studies have thoroughly described the poisonous effects of heavy metal toxicity, like Cd, on normal microbial activities in soil (Subrahmanyam et al., 2018). A variety of unique soil factors and plant traits have the highest impact on the amount of Cd that plants can absorb (Rizwan et al., 2016). The Cd poisons and bicoaumulatioin in the food change should be reduced to reduce its chronic effects in living organisms. The use of green techniques for the removal of chromium is necessary to decrease its versatility and movement is crucial for the safety of the ecosystem (Cojocaru et al., 2016). To remove dangerous toxins from the environment, bioremediation uses higher plants, naturally occurring bacteria, and genetically modified microorganisms (Gupta et al., 2020; Kumar et al., 2017). Higher green plants are employed in phytoremediation to remove Cd from soil. The capacity of different species of plants for the removal of heavy metals from soil using eco-friendly techniques has been adopted (Yadav et al., 2018). Phytoremediation involves some processes, including phytostabilization, phytovolatilization, phytodegradation, phytostimulation, and biodegradation (Yadav et al., 2018). Several different plant varieties, including sunflower (Rizwan et al., 2016b), sorghum (Feng et al., 2017), Brassica species, and maize, are regarded as accumulators because they can tolerate higher Cd concentrations in their above-ground parts (Rizwan et al., 2017c). Brassica species have great potential for the accumulation of cadmium in various parts without effects on its morphological and physiological health. The plans are also used for biofuel after cultivation when they absorb a amount of heavy metals (Cojocaru et al., 2016).

The current study provides a selected synopsis of the origins of lead contamination in some food plants, the toxicity of lead to plants and people, brassica spiking, and bioremediation techniques for removing lead from brassica. The majority of the elements of phytoremediation, microremediation, and other influencing variables for the removal of Cd have been gathered in this work. In the present study, heavy metal-like (Cd) contamination of the soil, and remediation approaches of Cd through brassica plants are examined.

1. Source of soil pollution

Metal emissions, both inorganic and organic, may be seen in the atmosphere. Pedogenic processes in the soil help to preserve parent rocks. Lead mining, purification, automobiles, and lead paints have all expanded over the last several years, contributing to an increase in lead emissions (Miralles et al. 2006). Lead and zinc manufacturing releases toxic heavy metals such as Hg and Cd into nature (Sumiahadi and Acar 2018). With leaded gas, this includes the usage of compost, animal waste, coal-burning, and the production of petrochemicals, which release heavy metals into the open air.

1.1. By Mining activities

Human activity is the primary source of heavy metal emissions from mining, and these metals persist in the atmosphere long after mining operations have ended (Nriagu 1989). Most of the time, mines pollute rivers and lakes with their waste products (INECAR 2000). Large amounts of heavy metals, both inorganic and naturally occurring, were released into the atmosphere. Hand-unloading mined materials in manual dressing procedures increases the toxicity of heavy-metal contamination (Huan et al. 2017).

1.2. By Fertilizers

Because of their early participation in gardening, humans were accepted by nature almost immediately. The availability of micro- and macronutrients is critical for development and the maintenance of the life cycle. Metals that are essential for plant development but depleted have been supplied through foliar and soil application. Farmers in wide and developing agriculture use large amounts of manure as a source of nitrogen, phosphate, and potassium for their crops (Dhaliwal et al. 2019). Utilizing composts high in phosphorus might unintentionally lead to soil contamination with potentially dangerous elements including fluoride, mercury, and lead (Duruibe et al. 2017).

1.3. By Pesticides

It used to be that some of the most common herbicides used in agriculture included heavy metals. Synthetic chemicals like Pb, Hg, Mn, Cu, and Zn may now be used in pesticides in the United Kingdom. It is possible to fight fungus by using copper-based insecticides such as the Bordeaux combination of copper oxychloride and copper sulfurate (Goswami & Das 2015). As a means of controlling parasites, lead arsenate has long been used in natural product crops. Several ways for preserving timber employ, Cr, and Cu metals. For agricultural reasons, the continual defiling of these regions is a major problem (Huang et al., 2016).

1.4. Biosolids and Manures

Biosolids are naturally resilient materials that may be put to use as a byproduct of wastewater treatment. Biosolids from urban populations may be used in horticulture in many nations because of the significant usage of bio-strong materials on horticulture land. The use of municipal biosolids such as sewage sludge, fertilizer, and compost may help reduce heavy metal pollution in the soil (Ghnaya et al. 2009). Poultry and pig weight management programmers use Cu and Zn in addition to compost as the main manure to improve growth, as well as address medical issues (Lianwen et al. 2018). According to official estimates, 5.6 million metric tons of sewage slime are deposited on agricultural land in the United States each year (Goswami and Das 2015).

1.5. By atmospheric deposition

The contamination of soils by heavy metals is a major consequence of modern activities such as burning coal and gasoline. There will be an increase in the long-term amounts of heavy metals such as niobium, zinc, lead, and copper (Boyd 2004). Concerns about environmental contamination have been expressed by current districts throughout the Northern Hemisphere (Shotyk et al. 2003). Lead and boron are two of the most prevalent anthropogenic impurities found in the environment and medical therapy (Mielke et al. 2005). Power plants, refineries, automotive pollution, volcanoes, aquifers, and other natural phenomena all increase the emission of lead into nature (Weiqing et al. 2016). More than 90 percent of the total quantity of boron in the atmosphere comes from the vapourous form, which accounts for between 0.2 and 300 parts per billion (Boyd 2004). Metals, like as arsenic, pb, and cd, are provided as unstable particles during the high-temperature treatment of these materials. These components were reduced to tiny fragments (Sun et al., 2023). Stack discharges may be removed from the vapor stream by distributing them across a vast region with the wind in dry or wet precipitation systems. Compared to urban regions, rural areas tend to have a lower rate of criminal discharges. Based on the kind of source and location, metals are categorized. Near sewage treatment plants and soils, the concentrations of Zn, Cd, and Pb are very high. Soil contamination in metropolitan areas and regions that connect to them is exacerbated by Pb emissions from burning petroleum. Zn and Cd are released from the tire and oil industries (Egwuonwu et al., 2023).

2. Pollution of soil by cadmium

In different crustal rocks such as granite, basalt, shale, sandstone, and limestone, Cd is distributed at concentrations of 0.15, 0.2, 1.4, 0.03, and 0.04 g/g, respectively (Cullen and Maldonado, 2013). Due to their harmful effects, extreme persistence, and inability to degrade, heavy metals present in the soil environment pose a potential threat to human health (Khan et al., 2016). Exchangeable, hydrous-oxide, carbonate, organic, and sulfide forms of Cd may exist in soils (Adriano, 2013). Expended nutrients and heavy metals (Zn, Cd, and P in wetlands) from hydrological and atmospheric sources are primarily absorbed by soils (Candeias et al., 2014; Jacob et al., 2013). However, non-ferrous metal mining, the production, and use of phosphate fertilizers, solid waste disposal, non-ferrous metallurgy, the use of sewage sludge, and wastewater irrigation practices also cause soil pollution (Khan et al., 2016).

3. Chemistry of Cd

The element cadmium is located at the end of the second column of transition elements. Its atomic weight is 112.4, atomic number is 48, density is 8.65 g cm^, melting point is 320.9°C, and boiling point is 765°C. Cd is one of the three main heavy metal poisons, along with Pb and Hg, and is not known to have any essential biological activities. In its compounds, cadmium appears as the divalent (cadmium Cd) (II) ion. Cadmium is situated just below zinc in the periodic table. Zinc is an essential mineral for both plants and animals. This might partially explain why Cd is so poisonous; because zinc is an essential trace element, substituting it with Cd could cause metabolic processes to malfunction (Campbell et al., 2006).

4. Cd sources in the environment

4.1. Natural sources of cadmium

Cadmium (Cd) is a rare metal that is mostly found in zinc deposits as a result of volcanic activity, forest fires, and weathering of cadmium-rich rocks (greenockite). Volcanic eruptions discharge between 100 and 500 tons of Cd into the atmosphere (Unsal et al., 2020: Saini et al., 2020). In addition, a significant natural source of Cd in aquatic bodies is volcanic activity in the deep sea. At the earth's crust, where it is abundant, Cd is present in concentrations of 0.1- 0.2 ppm. Although Cd can also be found in ocean water, it is mostly (approximately 500 ppm) found in sedimentary rocks, phosphorites, and marine phosphate (Saini et al., 2020). A significant natural source of air cadmium is thought to come from volcanic activity. The massive number of materials released and the Cd concentration in the volcanic aerosol have led to this predicament. Other naturally occurring sources of atmospheric Cd include forest fires, ocean sprays, and the emission of metal-enriched particles from terrestrial vegetation. Only in the case of release from vegetation are the quantities anticipated to be considerable on a global scale for these sources, which are difficult to assess. Although it rarely leads to any noticeable enrichment of the metal in the environment, weathering of crustal minerals plays a significant part in the natural cycle of Cd. One prominent exception is the presence of cadmium-enriched carboniferous shales in diverse places of the world. High quantities of Cd are also present in the soils created by these deposits and in the plant that grows there.

5.2 Anthropogenic source

The usage of synthetic phosphate fertilizers containing Cd as an impurity is one of the main causes of the rise in Cd levels in soil and groundwater (Kubier et al., 2019). Groundwater and soil cadmium toxicity is a worldwide problem (Chellaiah, 2018). Anthropogenic Cd is released into groundwater and soil via the metals industry, transportation, landfills, mining, accidents, combustion emissions, and sewage sludges (Bigalke et al., 2017). Australia, Britain, Canada, Denmark, Finland, Germany, New Zealand, Norway, Sweden, and the United States are just a few of the nations that have researched the process of groundwater intrusion (Taylor et al., 2016). Landfills, Cd-Ni batteries, and solid municipal trash are the main global sources of Cd contamination (Khan et al., 2017). The natural diversity of minerals and rocks in the nearby soils may contribute to an increase in Cd levels in the environment relative to human emissions and activities (Bigalke et al., 2017). The soil should be viewed as a significant temporary repository that can quickly change the concentration of Cd in groundwater over a range of timescales, including decadal (dry vs. wet years) and annual (rainy vs. dry season), given that Cd is easily activated (Sprynskyy et al., 2011). Rather than being a permanent sink for the metal. A product containing Cd may also comprise coatings, alloys, pigments, polyvinyl chloride stabilizers, and platings (Sprynskyy et al., 2011). A product containing Cd may also include coatings, alloys, pigments, polyvinyl chloride stabilizers, and platings. Furthermore, Cd concentrations in surface waters tend to increase when lake water pH decreases due to the enhanced geochemical mobility of Cd caused by acid rain and the ensuing acidification of soils and surface waters (Campbell et al., 2006). Cadmium is an inevitable byproduct of refining lead and potentially zinc (Hussain et al., 2024). The overall concentration of Cd in soils is increased by the use of agricultural inputs such as pesticides, fertilizers, and biosolids (sewage sludge), by the dumping of industrial wastes, and by the deposition of air pollutants. Whether plant Cd absorption happens to a large degree depends on the bioavailability of this Cd (Weggler et al., 2004).

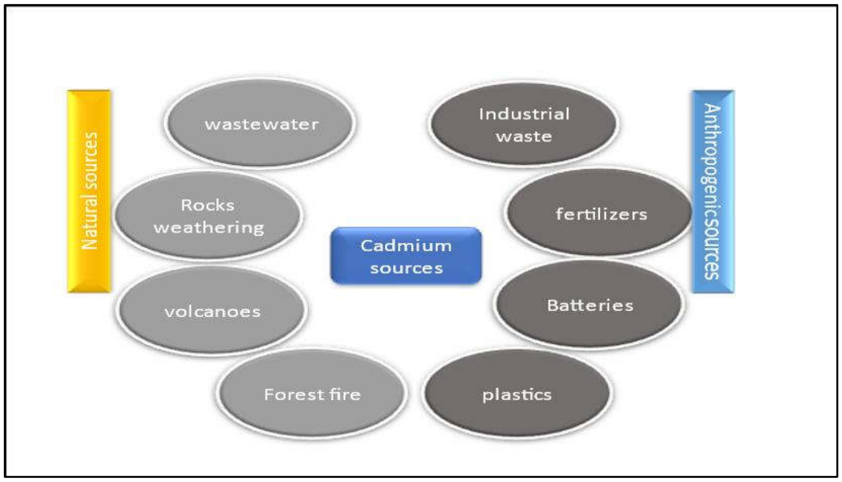


Fig. 1. Sources of Cd

Table 1. Concentration of Cd in some edible plants.

Edible plants	Edible parts	Cd Concentration	Reference
Orange	Fruit	0.005	(Sobukola et al., 2010)
Parsley	Leaf	0.98	(Ali and Al-Qahtani, 2012)
Sugar beet	Root	1.5	(Ramesh and Yogananda, 2012)
Tulsi	Leaf	0.11	(Inam, 2013)
Cinnamon	Bark	0.42	(Inam, 2013)
Potato	Stem	0.18	(Gebrekidan et al., 2013)
Brinjal	Fruit	0.9	(Labhade, 2013)
Black seed	seed	0.073	(Matloob, 2016)
Cardamom	Seed	0.156	(Matloob, 2016)
Turmeric	Rhizome	1.34	(Jawad, 2016)
Grapes	Fruit	0.15	(Ibraheen and Abed, 2017)
Rosemary	Leaf	0.008	(Mosleh et al., 2014)
Pumpkin	Fruit	0.01	(Islam and Hoque, 2014)
Radish leaf	Leaf	0.01	(Maleki et al., 2014)
Coriander	Leaf	2.4	(Sonawane, 2015)
Tomato	Fruit	0.2	(Mohod, 2015)
Brinjal	Fruit	1.8	(Sonawane, 2015)
Brinjal	Fruit	0.99	(Soloman et al., 2017)

5. Cadmium effects on the environment

Lead (Cd) can collect and linger in soil for extended periods. This may render the soil unfit for plant development, which might affect the ecosystem as a whole. Human health may also be negatively impacted by cadmium exposure. Following of the environmental toxic effects are discussed below.

5.1. Cd effects on soil

Heavy metal pollution not only negatively impacts several variables that determine the quality and production of plants, but it also modifies the size, composition, and activity of the microbial community (Yao and Huang, 2003). It is well-recognized that heavy metals negatively impact the chemical and biological properties of soil. The characteristics of the soil, such as its organic matter content, concentration of clay, and pH, have a significant effect on how much metals affect biological and biochemical properties (Speira et al., 1999). The activity of arylsulfatase, urease, protease, and alkaline phosphatase is adversely reduced by Cd contamination, but invertase is not much impacted (Chen et al., 2010).

5.2. Cd effects on plants

According to Gallego et al. (2012) and He et al. (2015), cadmium adversely affects nitrogen metabolism, protein expression, nutrition, hydration intake, stomata opening and closing, respiration, photosynthesis, and cell division. Excessive levels of Cd limit the development and production of plants because they negatively impact the enzymes that regulate the Calvin cycle and glucose metabolism (Javed et al. 2017). According to Sobrino-Plata et al. (2014), Cadmium stress in plants results in the generation of reactive oxygen species (ROS), which break peptide bonds, damage lipid and nucleic acid structures, and alter the way that carbohydrates are metabolized, ultimately leading to protein oxidation.

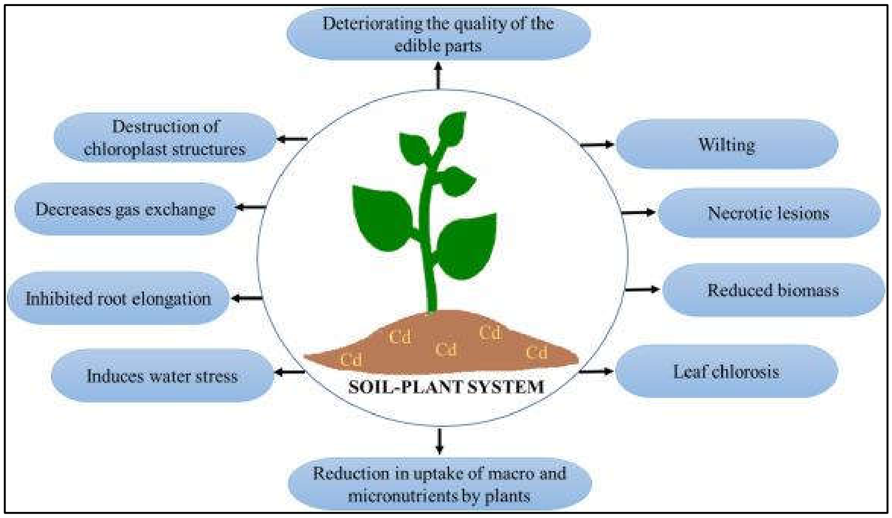


Fig 2. Cadmium effects in plants (Suhan et al., 2021)

Due to its occurrence in the environment from several anthropogenic causes and the threats it poses to the entire ecosystem, Cd is regarded as a hazardous and non-essential heavy metal (Zhou et al., 2019). Most Cd ions are taken by plant roots based on mobility, bioavailability, and concentration; however, the remaining amount can be absorbed directly from the atmosphere (Ismael et al., 2019). Cd has a deleterious effect on plant phenotype, cytotoxicity (e.g., lowering chlorophyll concentration and impeding photosynthetic effectiveness), and metabolic activities (e.g., chlorosis and cell damage) (Hayat et al., 2018). Additionally, Cd accumulates in the roots, shoots, and edible sections of plants after entering plant cells via different transporters such as Calcium (Ca) channels (Zhou et al., 2019). Cd in plants produces a variety of physiological and biochemical changes (Feng et al., 2010). Additionally, Cd buildup in plants has harmful effects like inhibiting various activities (minerals transportation, photosynthetic apparatus, and nutrient uptake). Additionally, it may prevent Fe from entering plant shoots (Schützendübel et al., 2002). According to Seregin et al. (2008), the xylem parenchyma is what allows heavy metals to move into conducting tissues, however, the amount of Cd that can move through the xylem is constrained (Haidri et al., 2023).

Soybean nodules exposed to Cd showed a reduction in primary ammonia absorption and nitrogen-fixing activity (Balestrasse et al. 2003). Hydrocharis dubia L. demonstrated that in the early stages of Hg poisoning, the chromatin condensed, the chloroplasts' thylakoids expanded, and the mitochondria's lumen widened (Hao et al. 2001). Garlic (Allium sativum) root tip cells showed an unusual deposit of electron-dense globules in the vacuoles (Liu et al. 2000). According to Yang et al. (2000), the organic and amino acids released by plant roots, such as citric acid, tartaric acid, oxalic acid, succinic acid, aspartic acid, and glutamic acid, combined with heavy metals to produce soluble complexes that increased the mobility of heavy metals like mercury, lead, and cadmium. According to Xu and Shi (2000), Nitrate reductase activity was lowered by Cd. The effects of Pb and Cd in soil on rice and cotton revealed that, under the same conditions, genetically modified cotton was more resistant to metal damage than regular cotton. At the same treatment level, rice leaves were less able to absorb Cd and Pb than cotton (Qin et al. 2000).

Table 2. CD effects on plants

Cadmium (Cd) level	Plant species	Effects on plants	Reference
200 µM $CdCl_2$	Mustard	Increased lipid peroxidation, cell death, and growth inhibition in plants.	Guan et al. (2009)
50 and 100 µM $CdCl_2$	Mouse-ear cress	Induced growth of plants, photosynthetic activity, and nutritional shortage.	Martínez-Penalver et al. (2012)
200 µM Cd	Black Nightshade	Reduced net photosynthesis and made plants more poisonous.	Deng et al. (2010)
1 mM $CdSO_4$	Sweet Potato	Decrease in plant growth and metabolic activity of cells.	Kim et al. (2010)
0.4 mM $CdCl_2$	Red Seaweed	Diminution of seedling growth.	Kumar et al. (2012)
50 and 250 µM	Wheat	Lipid oxidation, electrolyte leakage, and activated oxidative stress in the plant root.	Singh et al. (2008)
100 µM Cd $(NO3)_2$	Rice	Decrease in the expression of the genes involved in protein synthesis.	Zhao et al. (2012)

220 ppm $CdSO_2$	Tomato	Decreased plant growth, root elongation, and seed germination.	Baruah et al. (2019)
10 mg kg-1 $CdCl_2$	Alfalfa	Considerable decline in biomass, nitrogen absorption, elongation, and nodulation of the roots.	Liu et al. (2017)
6 mg kg- 1 $CdCl_2$	Maize	Reduced transpiration rate, fresh weight, height, and photosynthetic activity of the plant.	Liu et al. (2018)
220 ppm $CdSO_2$	Pea	Reduced chlorosis in leaves significantly and prevented plant germination.	Baruah et al. (2019)
2.86 mg kg-1 Cd	Wheat	Inhibited grain's high Cd content, shoot length, and root development.	Abbas et al. (2017)
100 mg kg-1 $CdCl_2$	Spinach	Plant growth and development were impeded by high levels of Cd in leaves.	Younis et al. (2016)

5.3. Cd effects on human health

Although cadmium cannot be metabolically broken down into less hazardous species and has very poor removal owing to the absence of efficient chelating agents, cadmium presents a major health concern even at lower concentrations in the body. The main ways that humans are exposed to cadmium are via food, cigarettes, and inhalation (Singh et al., 2020: Unsal., 2020). In Figure 3, the effect of Cd toxicity on the human body is shown. Additionally, cd alters the body's T cell population and functioning, which harms the immune system (Ebrahimi et al., 2020). Cd poisoning results in oxidative stress, which disrupts the body's antioxidant defense mechanism and produces ROS, impairing the immune system. ROS damages proteins, enzymes, and carbohydrates, which accelerates the lipid peroxidation of cell membranes. Moreover, causing DNA damage and mutation that may further contribute to the development of cancer (Singh et al., 2020: Unsal., 2020). Consuming acidic foods or drinks that were poorly stored in cadmium glaze containers can also cause CD poisoning (Ullah et al., 2024). The levels of ingested Cd cause the gastric epithelium to become irritated, resulting in tenesmus, vomiting, nausea, discomfort, stomach cramps, and diarrhea. Cd reaches the central nervous system (CNS) by modifying the blood-brain barrier's permeability during breathing. Superoxide dismutase and glutathione in particular are affected by Cd poisoning, which results in neurotoxicity and behavioral abnormalities (Malin and Wright. 2018: Saini and Dhania. 2020). Shortness of breath, lung edema, and the loss of mucous membranes are all symptoms of cadmium-induced pneumonitis, which is caused by inhaling cadmium-contaminated air (Seidal K et al.1993). Acute gastrointestinal symptoms, such as vomiting and diarrhea, have been linked to Cd contamination in food since 1942 (Nordberg 2004).

6.3.1 Kidney

Renal tubules may have experienced antagonistic reactions as a result of the present tolerance for low Cd concentrations. Those who are continuously exposed to CD have long been known to suffer from kidney impairment (Barbier et al. 2005). The kidneys get Cd in the form of cadmium-metallothionein, as previously stated (Cd-MT). The proximal tubules reabsorb Cd-MT after it is filtrated in the glomerulus. Cd accumulates in the tubule's cells, where it accounts for the majority of the body's cadmium burden. As a person ages, the quantity of Cd in the renal tubule cells rises an effect on phosphorus and calcium metabolism as a consequence of this phenomenon is being debated (Svartengren et al. 1986). Cd accumulation in the kidney has been linked to an increase in calcium excretion and, as a consequence, to an increased risk of kidney stones. It was shown that the concentration of Cd outcome in urine was directly linked to the extent of kidney damage caused by Cd. 4 percent renal tubular damage is indicated by 2.5 micrograms of Cd per gram creatinine excreted in the urine (Schwarz E 1993). For kidney injury, the urinary excretion of 2-microglobulin, NAG, and RBP serve as the key indicators (Bernard A 2004). Urinary 2-Microglobulin and RBP levels were found to be considerably greater in participants with elevated blood Cd concentrations in the China Cad study than in those with normal levels (Jin T et al.2002). Both glomerular and tubular damage was detected in the first group. Tubular damage has been debated as to whether or not it is reversible (Hotz P et al 1999). However, the widespread consensus today is that this is an irreversible process.

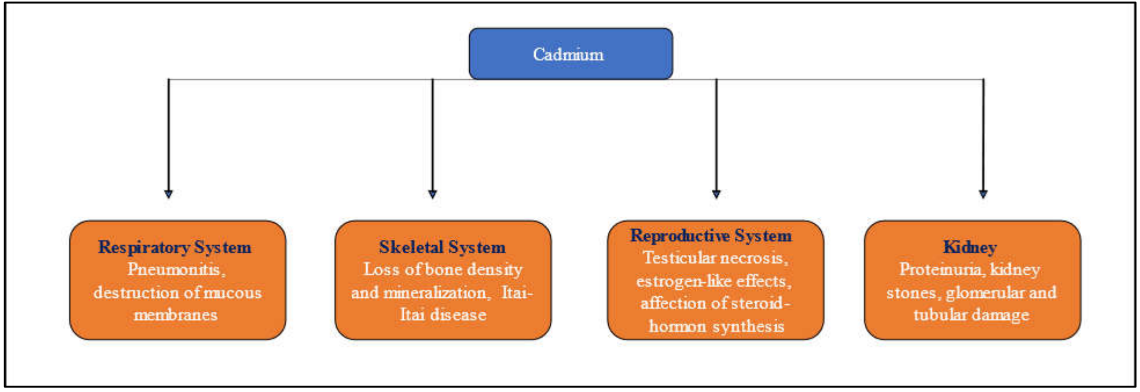


Figure .3. Cadmium effects on several human organs

6.3.2. Bone

Bone injury has been linked to Cd intoxication in workers due to cadmium exposure and dust in the 20th century (Kazantzis G 1979). Lower bone mass, decreased bone compactness, bone loss, an increase in bone fractures, and skeletal diseases are all effects of chronic exposure to Cd. Cd prevents the normal activation of vitamin D, inhibits the metabolism of magnesium, zinc, calcium, iron, and copper, and decreases the uptake of phosphate in bones (Unsal et al., 2020). Calcium absorption (from the stomach) and bone calcification are both significantly influenced by vitamin D. This results in severe bone pain, osteoporosis, osteomalacia, phosphaturia, bone demineralization, and other bone conditions (Ma et al., 2021).

When it comes to osteoporosis and other bone-related conditions, Cd causes to increased risk for fractures, osteoporosis itself, and excruciating pain in the bones itself. Patients who ate rice cultivated on fields irrigated with heavily cadmium-contaminated water were found to exhibit the classic symptoms in this investigation. Osteomalacia-related pseudo fractures and significant bone decalcification were also seen. This research was criticized since the bulk of the patients were women in their post-menopausal years (Nogawa et al.2004). Osteoporosis, which may have been exacerbated by Cd overdose, was considered the real cause of the symptoms seen. The year was (Kazantzis. 2004). Honda et al. 2003 uncovered more evidence that Cd overdose causes bone diseases. The STIFF index (an ultrasound measurement of bone density) and urine Cd content might be described as being inversely correlated (Frery N et al.1993). The OSCAR-Study, which included 1021 participants from southern Sweden, reached similar conclusions. In adults over the age of 60, Cd levels in the urine seem to have a strong negative connection with bone mineral density. Cd exposure has also been linked to an increased incidence of forearm fractures (Jarup L et al.1998). Participants in this research were either employed at the battery facility or lived in a nearby town. People who hadn't been exposed to the outside world were used as reference groups (Fatima et al., 2024).

5.4. Cd effect on brassica plants

One of the famous hazardous metals for plants is cadmium (Shahid et al., 2017; Sharmila et al., 2017). Brassica plants exhibit hazardous effects from excess Cd (Table 3). The length of time that a Cd stress is administered determines how it affects the development and biomass of Brassica species (Seth et al., 2008). In B. juncea leaves, Cd stress also decreased PSII efficiency and chlorophyll levels when compared to the control (Taamalli et al., 2014). B. oleracea's dry weight and leaf area were both reduced by cadmium toxicity (Jinadasa et al., 2016). Furthermore, genotoxicity was also generated by excess Cd in Brassica species. In the root tips of B. juncea, exposure to varying doses of Cd over 24 hours resulted in a considerable inhibition of the mitotic index, an increase in mitotic and chromosomal abnormalities, and the development of micronuclei (Seth et al., 2012).

Table 3. Cd effects in brassica plants Sp.

Experiment	Brassica Sp.	Cadium effects	Reference
Soil or pot	B. juncea	As the amount of Cd in the soil grew, plant growth and biomass decreased and Cd concentrations in roots and shoots increased.	Bauddh and Singh, 2012a
Hydroponic	----	There was a decrease in plant biomass, photosynthesis, and mineral absorption, and an increase in Cd uptake.	Mohamed et al., 2012
Hydroponic	----	In a dose-additive manner, the amount of chlorophyll was decreased and the absorption of Cd was enhanced.	Verma et al., 2013
Soil or pot	----	There was a reduction in leaf area, dry weights, and root and shoot lengths. The concentrations of Cd in shoots and roots rose.	Irfan et al., 2014
Field	----	Concentrations of Cd rose whereas gas exchange parameters and chlorophyll dropped. ----	Kapoor et al., 2014
Soil or pot	----	When exposed to lead, concentrations of lead rose, and the development of shoots, leaves, and roots reduced.	Goswami and Das, 2015
Sand or pot	----	The amount of fine roots, root surface area, root volume, and root length all affected how much CD a cultivar could absorb.	Xia et al., 2016
Soil or pot	----	Reduced plant dry weight and elevated plant Cd concentrations based on the kinds of soil and cultivars examined.	Khan et al., 2017
Hydroponic	B. chinensis	Reduction in plant N absorption and dry weight of the shoots and roots	Ma et al., 2017

6. Strategy to eliminate the soil Cd

Eliminate cadmium metals in soil by different methods like bioremediation, phytoremediation, etc. are given.

6.1. By physical methods

There is a broad spectrum of physical approaches for heavy metal cleanup in polluted soils for various waste products. Nearly all impurities can be removed using physical removal procedures. However, there are drawbacks as well. The pollutants removed by physical procedures typically need to be processed further and have a somewhat high application cost in comparison to other approaches. The majority of physical separation techniques are based on the pollution's particle size distribution. Below is a description of a few such physical treatments for soil polluted with heavy metals:

7.1.1 Replacement of contaminated soil

Contaminated soil can be removed and restored using the same techniques. The technique of incorporating or blending a sizable amount of clean soil with unclean soil is known as soil replacement. Soil removal is the process of removing contaminated soil and replacing it with fresh, uncontaminated soil. In a small region of heavily contaminated soil, this strategy is necessary. Nevertheless, soil isolation does not refer to the additional engineering procedures that must be carried out to remedy a situation (Zheng et al., 2002). It can therefore only be applied to a small area of soil.

7.1.2 By thermal treatment method

Calcination, sometimes referred to as thermal desorption, is the process of removing a volatile substance from a medium by heating it to a certain temperature. The main methods for soil heating include electrical resistive heating, radiofrequency heating, steam-based heating, and conductive heating (Song et al., 2017). To lessen the versatility and mobility of both Zn and Cu in polluted soils, Wang et al. (2018) examined thermal stabilization. The treated soil contains fixed metals. They discovered that as the temperature rose to 700 °C, the residual amounts in the studied soils declined. Desorbed volatile pollutants from the soil are collected using vacuum-negative pressure or carrier gas.

7.1.3 Utilizing vitrify method

The heating of soil to between 1400°C and 2000°C causes natural materials to dissolve or evaporate. The pyrolysis product is made from a fume gas generated by the treatment framework. Using anodes and plasma, as well as microwaves, anodes, and other direct heat transfer techniques, one may generate energy for ex-situ recovery. It is feasible to employ heat directly during in-situ remediation by placing anodes in the contaminated soil. Not only does this new method eliminate heavy metals, but it also works fairly well. As a result, only a small number of users can afford the high cost of combining these two technologies (Yang et al., 2023). Through the thermal process of vitrification, which involves cementing heavy metals and metalloids into vitreous material at temperatures above 1500 °C, the mobility of these compounds is decreased. The contaminated soil is heated throughout the process using high-voltage electricity. Melting the soil turns it into molten lava, which then cools to form a vitrified structure. The heavy metals and metalloids are contained inside this glassy matrix, while the other contaminants have been removed (Ballesteros et al., 2017).

7.2 Remediation by Chemical Strategies

The quantity of heavy metal accessible to plants may be reduced thanks to compound approaches. The soil pH may be altered to precipitate metals or generate insoluble metal structures as one method of achieving this aim.

7.2.1 Chemical leaching

Water, synthetic chemicals, or other liquids or gases may be used to remove the pollution from the soil (Shahi Khalaf Ansar et al., 2023). To get from the soil to the fluid, heavy metals have to go through many processes, including precipitation, particle exchange, chelation, and sorption. Surfactant, inorganic, and chelating specialists make up the bulk of the invading force. Hydrofluoric, sulfuric, phosphoric, and hydrochloric corrosives were the most effective ways to eliminate metals from soil polluted with erroneously positive findings, as proved by (Tokunaga and Hakuta 2002).

7.2.2 Through Chemical Fixation

To limit the spread of heavy metals into surrounding streams and other natural areas, soil remediation entails adding chemicals or other materials (Priya et al., 2023; Singhal et al., 2024). Metal transfer into a latent structure is part of the adjustment process, which is aided by a synthetic focus rather than a cleaning focus using bone meal ($Ca10(PO4,6H2O)$. Research has shown that it is capable of immobilizing metals and reducing the bioavailability of contaminated soils.

7.2.3 By electrokinetic remediation

Electric field inclinations are created on either side by using high voltage in electrokinetic cleanup (Luo et al. 2004). An electrophoresis, electro-osmotic stream, and electro-relocation cycle were employed to transport charged toxins from one post to another (Swartzbaugh et al. 1990). With poor penetrability soils, this strategy is both cost-efficient and successful in terms of establishment and activity, all while preserving the distinctive soil synthesis (Zhang and colleagues 2004) and preserving the ecotype. (Luo et al. 2004). Since it couldn't control the pH of the soil, this innovation's effectiveness in treating it was low (Fasani et al. 2017). Expanding the cushion response to manage soil pH or utilizing a particle layer that modulates dirt pH are two recent ways to improve mobility. Yeung and Gu (2011), contaminants that sorb to soil particle surfaces may reduce the efficiency of the EK. The use of electrokinetics in soil remediation is a novel and cost-effective approach. Soil pollutants may be transported to processing chambers on either side of an electrolytic tank by electromigration, electric seepage, or electrophoresis, minimizing contamination. Soils with low permeability are ideal for this technique (Hanson et al., 1992). For several experimental tests, the remediation efficiency varied from 14.7% to 95.1%, and the changes were primarily brought on by variations in the pH value (Sikka et al., 2024; Haidri et al., 2023).

7.3 Remediation through biological methods

7.3.1 Bioremediation

In the bioremediation process, poisonous wastes are converted by living organisms into harmless chemicals (Asha and Sandeep. 2013). The goal of bioremediation is to restore polluted places to their pre-polluted state with no additional adverse environmental effects (Adhikari et al., 2004). Actinomycetes, fungi, bacteria, and plants are examples of living organisms that have demonstrated the capacity to remediate soil that has been co-contaminated with heavy metals and pesticides.

7.3.2 Phytoremediation

Using plants to clean the damaged region and remove pollutants is known as phytoremediation. The fundamental idea behind phytoremediation is that pollutants are broken down by plant roots into less harmful components or they are accumulated in the parts of plants (Kaur et al. 2018). It could be possible to grow some plants in contaminated soil, depending on the kind. A tiny portion of these plants have the potential to hyper-accumulate contaminants from the soil, primarily in or around the roots. Due to heavy metal enrichment in contaminated soil, plants must be harvested, burned, and cured. An inventive new method for removing metals from the environment is to use plants and the microbes that coexist with them. To finish the process, we need facilities that can handle and store heavy metals. The majority of these plants belong to the Brassica family, which also contains Thlaspis and Alyssum. Recent research examined the capacity of the plant species Brassica rapa to thrive in mixed soil polluted with PAH and other metals, such as Cd, Cr, and Pb, under the effect of electric fields (Cameselle and Gouveia 2019). A greater ability to withstand cadmium ions has been determined by the effective absorption and assimilation of sulfate. Worldwide, there are more than 400 species of Brassica (Xing et al., 2003). Using a variety of plants, phytoremediation is an additional and alternative method to traditional physicochemical techniques for the in situ removal of metals like Cd from polluted soils. By using certain plants and the microorganism ecology they support in the rhizosphere, metals may be used to phytoremediation polluted soils by extracting, transferring, assimilating, transforming, and/or stabilizing pollutants. This process lowers the toxicity of the metals involved. Keller et al. (2005) showed that the Cd-contaminated plants treated with heat may make it possible to extract Cd evaporatively from plant leftovers. Thlaspi caerulescens, a Cd hyperaccumulator, and willow (S. viminalis) volatilized 90% to 100% of the Cd. Additionally, the effectiveness of phytoremediation on soil photoavailable Cd fraction stability was assessed (Wan et al., 2016).

7.3.3 Microbial remediation

"Microbial remediation" refers to the process of removing heavy metals from the soil by the use of microorganisms. According to Siegel et al (1986), fungi release organic acids, amino acids, and other metabolites that help dissolve heavy metals and the minerals that hold them. According to Fred et al. (2001), a fungus called Gomus intraradical has been shown to enhance the sunflower's ability to withstand and absorb Cr. In this field of research, biotechnology is being used to create microbes that can break down heavy metals (genetics, genetic engineering, and so on). Metals may be easily and successfully extracted from low-grade materials by microbial leaching (Galal et al. 2017). Bosecker (2001) Research has shown that microorganisms may also be used to remediate heavy metal-contaminated sediments and soils, detoxify sewage sludge, and treat industrial waste

7.3.4 Animal remediation

Heavy metals may be consumed by soil-dwelling creatures like maggots and earthworms. When soil copper concentrations are low, found that ryegrass may benefit from earthworm activity and secretion (Wang et al., 2007). According to the description, animal remediation involves some lesser animals adsorbing, decomposing, and migrating the heavy metals to remove and inhibit their toxicity. The investigations demonstrated that the treatment of earthworm-straw mulching combinations raised plant Cu concentration, and the quantity increased by it was less than the treatment with earthworms but more than the treatment with straw mulching (Wang et al., 2007). the measurement of soil Pb concentrations to determine the earthworm's Pb accumulation. The outcomes demonstrated that the earthworm was capable of efficiently accumulating Pd. The amount of buildup increased as the Pb concentrations rose (Kou et al., 2008).

7. Phytoremediation of soils utilizing plant species

Phytoremediation is a collection of techniques that uses various plant species to clean up polluted areas and immobilize, corrupt, and lessen anthropogenic ecological toxins (Mukhopadhyay and Maiti 2010). Metal removal from contaminated areas may be accomplished by a variety of phytoremediation procedures that use plants that are normally found in nature. There are many ways to improve chelating specialists, manure, natural revision, and pH to improve metal bioavailability and plant uptake. When it comes to cleaning up polluted soil, phytoremediation has recently received a lot of attention (Huang et al. 2016). Using plants to remove toxins from a polluted area is part of the phytoremediation process. Phytoremediation is based on the principle that plants may break down foreign substances into less dangerous components or assimilate impurities, and then store those impurities in the plant's stems and leaves (Kaur et al. 2018). As a result, removing or definitively reducing the number of harmful pollutants in the atmosphere should be made a voluntary process

(Yadav and Srivastava 2014). They are named hyper-gatherers because a few plant and animal species have shown the ability to accumulate enormous amounts of heavy metals and have been dubbed thus. When it came to ingesting metal essential for Phyto-extraction, these plants displayed a remarkable capability.

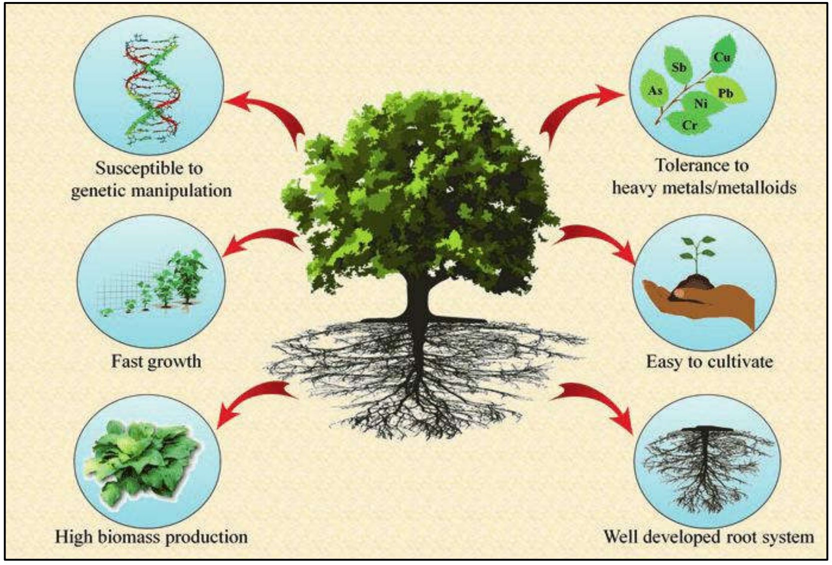


Figure .4. In phytoremediation, heavy metals from contaminated soil are removed using plants.

Even the susceptibility of plants to different amounts of heavy metal exposure varies. Plants may be susceptible to heavy metals, while others can withstand them fairly well. Even though many metals are needed for biological structures and should be easily accessible, there is evidence that they demonstrate damaging behavior by blocking or uprooting the necessary utilitarian groupings and atoms (Garbisu and Alkorta, 2003). Stotzky and Collins (1989) Brassicaceae species, such as Brassica napus, have a broad variety of typical breaking points for heavy metal poisoning and collection sizes. The phytotherapeutic innovation used in this study was effective in removing heavy metals from degraded soils.

8.1 Phyto-remediation through Brassica

Brassica rapa plants were recently tested to see whether they could grow and fill up deteriorating soil contaminated with PAH and other metals such as cadmium, chromium, and lead (Pb) (Cameselle and Gouveia 2019). Exchanging current was shown to be the most effective approach for commercial applications. It was possible to dispose of phenanthrene and anthracene mixtures using a 1 Volt/cm expected inclination around the B. rapa plant. Many types of terminals surrounding the plants may be employed to concentrate or transport poisons to the root zone, according to experts. Using Phragmites australis as a phytoremediator to remove nickel (Ni), lead (Pb), and cadmium (Cd) contamination from contaminated water took Bello et al. (2018) around 30 days to complete. P. australis shed 93% of its Cd, 95% of its Pb, and 16% of its Ni, according to the study's results (84 percent expulsion). Cd and Pb had 96 percent residuals (4 percent expulsion) in the controlled test, whereas Ni had 89% expulsion in the experiment (11 percent evacuation). Other species are less prone to producing aggregates of Fe, Zn, and Co than Lemna minor. It's (Amare et al., 2017). It has a high accumulation potential for Fe, Mn, Zn, and Cu but a lower potential for Cd. Co, Cr, and Ni have moderate accumulation potential while Cd has a significantly lower accumulation potential. Goswami and Das (2015), showed that Brassica juncea (Indian mustard) may be employed as a phytoremediation agent after being exposed to CdCl2 for 21 days at a research facility. Tumor and root/shoot length reduced despite strong Cd resistance (up to 400 mg/kg), whereas tissue carotenoid and chlorophyll content increased. The improvement coefficient and bud root mobility factor of Indian mustard demonstrated its ability to remove Cd from degraded soil. The unusually high concentration of Brassica spp. in the environment was explained by (Yadav and Srivastava 2014). The retention and absorption of sulfate may be responsible for the increased resistance to cadmium particles. This plant's ability to tolerate high levels of cadmium was revealed by Bhadkariya et al. (2014) in their research on Brassica juncea.

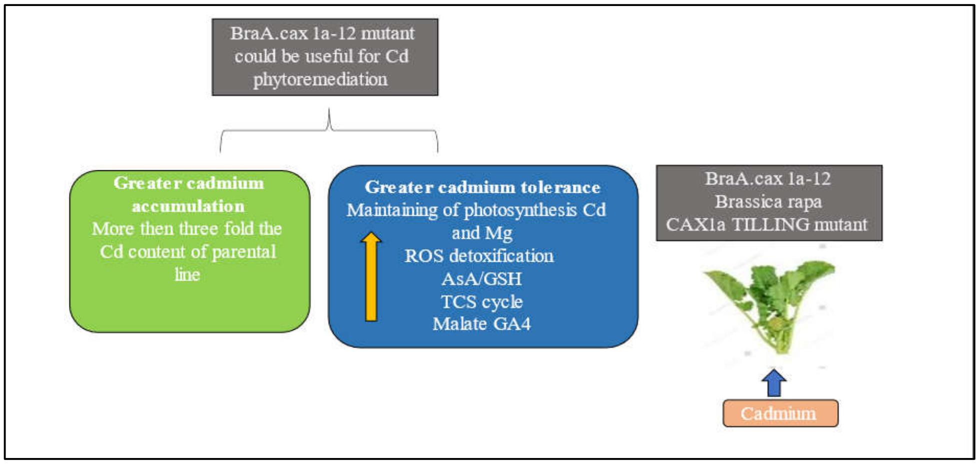


Figure .5. Cd removal via Brassica juncea (Navarro-León et al., 2020).

Cd was found in all parts of Brassica juncea, including the roots, stems, and leaves. The total Cd content in the plant was 89.90 mg kg1 during the 60-day improvement period. When Brassica juncea was studied further, it was discovered to be an excellent means of removing cadmium from soil. Cauliflower (Brassica juncea). According to Priya et al (2014), Brassica juncea (mustard) and Allium cepa (onion) have been used to cleanse wastewater. In this case, the onion plant. Compared to control samples, Cadmium in Brassica juncea and Allium cepa was decreased by more than 90 percent, from 0.17 to 0.009 g L1. To get a better understanding of Jaipur's wastewater treatment process, researchers used two plants from the phytoremediation system. Mustard should be grown in Sanganer and Jaipur's modern areas using wastewater from these regions. Brassica juncea (glycophyte) vs Cakile sea (halophyte) for phytoextraction of Cd were studied by (Taamalli and colleagues 2014). All Cd sections outside of the Cakile Sea showed a greater mobility factor for the Cakile Sea than Brassica juncea. Roots of Ricinus communis accumulated twice as much Cd as shoots of Brassica juncea when exposed to varying soil Cd levels. As a result of the increased ability of Ricinus communis to remove metal from soil, and also the better ability of Ricinus communis to remove metal from polluted soil, this was the case. Safflower, Brassica napus, and Wheat were all examined for their phytoremediation abilities. According to the findings, seed germination, and root and shoot length were lowered by expanding the focal point of the arrangement. The reasonableness of Brassica napus seed oil derived from diafiltrated regions. Almost half the heavy metal components were detected in the garbage after oil testing of the seed. Soil remediation will benefit from the Phyto-fixing potential of salt-sensitive plants like Atriplex halimus and Sesuvium portulacastrum (Moustakas et al. 2011; Hussain et al., 2024). Ishikawa et al., (2006) researched to investigate whether there were any limitations to the expansion of plant and animal species. According to the results, aquaculture-grown rice and sugar beet sprouts acquired more Cd than Brassica juncea, but this was also true of the plant's viability in soil growth. With Cd-depleted soils for rice and beet, Brassica juncea buds exhibited higher accumulations of heavy metals such as Cu, Fe, and Mn. Rice is more effective in the phytoextraction of Cd than Brassica juncea. Low metal grouping in deteriorated soil makes Brassica juncea phytoextraction more difficult. Cultivars of five different Brassica juncea L. species were also inhibited by Cadmium treatment (Bauddh and Singh 2009).

Table 5. Removal of cadmium through Brassica Sp

Experiment type	Brassica species	(Cd) Exposure mg kg^{-1}	Reference
Soil/pot	Brassica juncea	1.445	(Kathal et al., 2016)
Sand/pot	B. rapa	2.5, 5.	Khan et al., 2017
Soil/pot	B. chinensis	0-7.0	Shentu et al., 2008
Soil/pot	B. juncea	0-190	Jiang et al., 2004
Soil/pot	B. juncea	250, 300	John et al., 2009
Soil/pot	B. juncea	150	Bauddh and Singh, 2012a
Soil/pot	B. juncea	100	Irfan et al., 2014
Soil/pot	B. juncea	400	Goswami and Das, 2015
Soil/pot	B. juncea	100 mg kg^{-1}	Wong et al., 2004
Soil/pot	B. juncea	0.23	Bloem et al., 2017
Soil/pot	B. juncea	4	Lee and Sung, 2014
Soil/pot	B. juncea	186	Van Engelen et al., 2007
Soil	B. campestris	100	Anjum et al., 2014

The effects of lead and cadmium stress on plant growth, shade, biochemicals, and heavy metal intake. Cd and Pb lowered plant growth and chlorophyll content as well as carotenoids, although Cd was more detrimental than Pb. During the blooming stage, protein levels were reduced by 95% and 44% with the Cd and Pb treatments. At low Cd and Pb concentrations, proline content grows, but at higher concentrations, it decreases. Even when Cd concentrations were higher than Pb concentrations, the Cd absorption was hampered by the higher Pb concentrations. Cadmium was used to treat three species of Caryophyllales studied by (Watanabe et al. 2009). Brassica juncea was shown to have lower Cd accumulating limits in both water and soil than Amaranthus tricolor. Research shows that the rhizosphere Cd-gathering capacity of A. tricolor is superior to other species, despite its large growth and biomass. The Phyto-extraction of cadmium-contaminated fields could benefit from A. tricolor, therefore. Nickel and cadmium accumulation in Indian mustard was studied by (Tickoo et al. 2007), under controlled conditions. Dirt was broken down using a combination of a cadmium-acetic acid extraction and nickel sulfate under close observation. In Brassica juncea, the findings showed that nickel accumulated more efficiently than cadmium, which also showed that shoots gathered a greater number of heavy metals than roots. When Brassica napus was tested, it was shown to be ineffective in extracting metal from deteriorated soils. Radish has a limited potential for phytomedicine in soils with a high concentration of heavy metals. Low levels of zinc and cadmium have been found in certain Brassica animal species.

8. Conclusion

A plant's growth, decay, and recycling of dead biomass all depend on the quality of the soil in which it grows. Environmentalists are concerned about the deterioration of soil owing to resource evaporation. The recovery of regions affected by heavy metals has been recognized as one of the finest advances in soil remediation to date. Soil remediation operations are aimed at protecting humans and other living things from harmful synthetic substances by reducing soil pollution around hazardous waste sites. If the soil in a given area includes a wide range of synthetics or pollutants, several remediation methods may be necessary. Short and long-term sustainable treatments are necessary to achieve our goals. We also need to reduce impurity volume, decrease the amount of poisonousness in the product we produce, and increase its production capacity. Phytoremediation is the most cost-effective way of eradicating soil contamination. Depending on the scenario, there is a range of strategies for eliminating heavy metals from the soil. phytoremediation is the most cost-and cost-effective way to remove heavy metals from soil.

References

[1]. Abbas, T., Rizwan, M., Ali, S., Adrees, M., Zia-ur-Rehman, M., Qayyum, M.F., Ok, Y.S., Murtaza, G., 2017. Effect of biochar on alleviation of cadmium toxicity in wheat (Triticum aestivum L.) grown on Cd-contaminated saline soil. Environ. Sci. Pollut. Res. 25, 25668-25680.

[2]. Abshire, M.K.; Devor, D.E.; Diwan, B.A.; Shaughnessy, J.D., Jr.; Waalkes, M.P. *In vitro,* exposure to cadmium in rat L6 myoblasts can result in both enhancement and suppression of malignant progression *in vivo*. *Carcinogenesis* 1996, *17*, 1349-1356.

[3]. Acar, Y. B., Gale, R. J., Alshawabkeh, A. N., Marks, R. E., Puppala, S., Bricka, M., & Parker, R. (1995). Electrokinetic remediation: basics and technology status. *Journal of hazardous materials*, *40*(2), 117-137.

[4]. Adhikari, T., Manna, M. C., Singh, M. V., & Wanjari, R. H. (2004). Bioremediation measures to minimize heavy metals accumulation in soils and crops irrigated with city effluent. *Journal of Food Agriculture and Environment*, *2*, 266-270.

[5]. Anjum, N.A., Umar, S., Iqbal, M., 2014. Assessment of cadmium accumulation, toxicity, and tolerance in Brassicaceae and Fabaceae plants-implications for phytoremediation. Environ. Sci. Pollut. Res. 21, 10286-1029.

[6]. Antisari, L. V., Orsini, F., Marchetti, L., Vianello, G., & Gianquinto, G. (2015). Heavy metal accumulation in vegetables grown in urban gardens. *Agronomy for Sustainable Development, 35*, 1139-1147.

[7]. Asha. Latha. P, Sandeep. Reddy. S, Review on bioremediation potential tool for removing Environ. Pollut., Int. J. Basic Appl. Chem. Sci. (2013) 2277-2073.

[8]. Attanayake, C. P., Hettiarachchi, G. M., Harms, A., Presley, D., Martin, S., & Pierzynski, G. M. (2014). Field evaluations on the soil-plant transfer of lead from urban garden soil. *Journal of Environmental Quality, 43*, 475.

[9]. Aziz, N. A., Latiff, A. A., Lokman, M. Q., Hanafi, E., & Harun, S. W. (2017). Zinc oxide-based Q-switched erbium-doped fiber laser. *Chinese Physics Letters*, *34*(4), 044202.

[10]. Bai, J., Xiao, R., Cui, B., Zhang, K., Wang, Q., Liu, X., Gao, H., & Huang, L. (2011). Assessment of heavy metal pollution in wetland soils from the young and old reclaimed regions in the Pearl River Estuary, South China. *Environmental Pollution, 159*, 817-824.

[11]. Balestrasse KB, Benavides MP, Gallego SM, Tomaro ML (2003) Effect on cadmium stress on nitrogen metabolism in nodules and roots of soybean plants. Func Plant Biol 30:57-64.

[12]. Ballesteros, S.; Rincón, J.M.; Rincón-Mora, B.; Jordán, M.M. Vitrification of urban soil contamination by hexavalent chromium. *J. Geochem. Explore.* 2017, *174*, 132-139.

[13]. Barbier O, Jacquet G, Tauc M, Cougnon M, Poujeol P: Effect of heavy metals on, and handling by, the kidney. *Nephron Physiol* 2005,99(4):p105-10.

[14]. Baruah, N., Subham, C.M., Farooq, M., Gogoi, N., 2019. Influence of heavy metals on seed germination and seedling growth of wheat, pea, and tomato. Water Air Soil Pollut. 230, 273-288.

[15]. Bauddh, K., & Singh, R. P. (2012). Growth, tolerance efficiency, and phytoremediation potential of Ricinus communis (L.) and Brassica juncea (L.) in salinity and drought-affected cadmium contaminated soil. *Ecotoxicology and Environmental Safety*, *85*, 13-22.

[16]. Bauddh, K., Singh, R.P., 2012a. Cadmium tolerance and its phytoremediation by two oil-yielding plants Ricinus communis (L.) and Brassica juncea (L.) from the contaminated soil. Int. J. Phytorem. 14, 772-785.

[17]. Bello, B., Mattana, V., & Loi, M. (2017). The power of peers: A new look at the impact of creativity, social context, and self-efficacy on entrepreneurial intentions. *International Journal of Entrepreneurial Behavior & Research*.

[18]. Bernard A: Renal dysfunction induced by cadmium: biomarkers of critical effects. *Biometals* 2004,17(5):519-523.

[19]. Bhadkariya, R. K., Jain, V. K., Chak, G. P. S., & Gupta, S. K. (2014). Remediation of cadmium by Indian mustard (Brassica juncea L.) from cadmium contaminated soil: a phytoextraction study. *International Journal of Environment*, *3*(2), 229-237.

[20]. Bhardwaj JK, Panchal H, Saraf P: Cadmium as a testicular toxicant: a Review. J Appl Toxicol 2021, 41:105-117.

[21]. Bielecka, A., Ryłko, E., & Bojanowska, I. (2009). Zawartość pierwiastków metalicznych w glebach i warzywach z ogrodów działkowych Gdańska i okolic (Contents of metals in soils and vegetables from Gdansk and Straszyn allotments). *Environmental Protection and Natural Resources., 40*, 209-216 In Polish.

[22]. Bigalke, M., Ulrich, A., Rehmus, A., & Keller, A. (2017). Accumulation of cadmium and uranium in arable soils in Switzerland. *Environmental pollution*, *221*, 85-93.

[23]. Bilgin M, Tulun S (2016) Removal of heavy metals (Cu, cd, and Zn) from contaminated soils using EDTA and $FeCl_3$. Global NEST J 18:98-107.

[24]. Bilgin, M., & Tulun, S. (2016). Removal of heavy metals (Cu, Cd, and Zn) from contaminated soils using EDTA and FeCl3. *Global Nest J*, *18*, 98-107.

[25]. Bosecker K (2001) Microbial leaching in environmental clean-up programs. Hydrometallurgy 59:245-248.

[26]. Boyd, S., Boyd, S. P., & Vandenberghe, L. (2004). *Convex optimization*. Cambridge University Press.

[27]. Brown, S. L., Clausen, I., Chappell, M. A., Scheckel, K. G., Newville, M., & Hettiarachchi, G. M. (2012). High-iron biosolids compost–induced changes in lead and arsenic speciation and bioaccessibility in co-contaminated soils. *Journal of Environmental Quality, 41*, 1612.

[28]. Buekers, J. (2007). Fixation of cadmium, copper, nickel and zinc in soil: kinetics, mechanisms and its effect on metal bioavailability.

[29]. Cabral Pinto, M. M., Ordens, C. M., Condesso de Melo, M. T., Inácio, M., Almeida, A., Pinto, E., & Ferreira da Silva, E. A. (2020). An interdisciplinary approach to evaluate human health risks due to long-term exposure to contaminated groundwater near a chemical complex. *Exposure and Health*, *12*, 199-214.

[30]. Cameselle, C., & Gouveia, S. (2019). Phytoremediation of mixed contaminated soil enhanced with electric current. *Journal of Hazardous Materials*, *361*, 95-102.

[31]. Campbell, O. M., & Graham, W. J. (2006). Strategies for reducing maternal mortality: getting on with what works. *The Lancet*, *368*(9543), 1284-1299.

[32]. Candeias, C., Melo, R., Ávila, P. F., da Silva, E. F., Salgueiro, A. R., & Teixeira, J. P. (2014). Heavy metal pollution in mine soil–plant system in S. Francisco de Assis–Panasqueira mine (Portugal). *Applied Geochemistry*, *44*, 12-26.

[33]. Chaney, R. L. (2015). How does contamination of rice soils with Cd and Zn cause a high incidence of human Cd disease in subsistence rice farmers? *Current Pollution Reports*, *1*(1), 13-22.

[34]. Chellaiah, E. R. (2018). Cadmium (heavy metals) bioremediation by Pseudomonas aeruginosa: a minireview. *Applied water science*, *8*(6), 1-10.

[35]. Chen G.Q., Chen Y., Zeng G.M., Zhang J.C., Chen Y.N., Wang L. and Zhang W. J., Speciation of Cadmium and Changes in Bacterial Communities in Red Soil Following Application of Cadmium-Polluted Compost. Environmental Engineering Science, 27 (12), 1019- 1026 (2010).

[36]. Chen, Z. J., Sheng, X. F., He, L. Y., Huang, Z., & Zhang, W. H. (2013). Effects of root inoculation with bacteria on the growth, Cd uptake, and bacterial communities associated with rape grown in Cd-contaminated soil. *Journal of Hazardous Materials*, *244*, 709-717.

[37]. Cojocaru, P., Gusiatin, Z. M., & Cretescu, I. (2016). Phytoextraction of Cd and Zn as single or mixed pollutants from the soil by rape (Brassica napus). *Environmental Science and Pollution Research*, *23*(11), 10693-10701.

[38]. Collins, Y. E., & Stotzky, G. (1989). Factors affecting the toxicity of heavy metals to microbes. *Metal ions and bacteria*, *31*.

[39]. Cullen, J. T., & Maldonado, M. T. (2012). Biogeochemistry of cadmium and its release to the environment. *Cadmium: from toxicity to essentiality*, 31-62.

[40]. Defoe, P. P., Hettiarachchi, G. M., Benedict, C., & Martin, S. (2014). Safety of gardening on lead- and arsenic-contaminated urban brownfields. *Journal of Environmental Quality, 43*, 2064–2078.

[41]. Deng, X., Xia, Y., Hu, W., Zhang, H., Shen, Z., 2010. Cadmium-induced oxidative damage and protective effects of N-acetyl-L-cysteine against cadmium toxicity in Solanum nigrum L. J. Hazard. Mater. 180, 722-729.

[42]. Dhaliwal, R., Cahill, N., Lemieux, M., & Heyland, D. K. (2014). The Canadian critical care nutrition guidelines in 2013: an update on current recommendations and implementation strategies. *Nutrition in Clinical Practice*, *29*(1), 29-43.

[43]. Dhaliwal, S. S., & Welborn, T. A. (2009). Central obesity and multivariable cardiovascular risk as assessed by the Framingham prediction scores. *The American journal of cardiology*, *103*(10), 1403-1407.

[44]. Dhaliwal, S.S.; Singh, J.; Taneja, P.K.; Mandal, A. Remediation techniques for removal of heavy metals from the soil contaminated through different sources: A review. *Environ. Sci. Pollut. Res.* 2020, *27*, 1319-1333.

[45]. Durham, D.M.; Palmiter, R.D. Transcriptional regulation of the mouse metallothionein-I gene by heavy metals. *J. Biol. Chem.* 1981, *256*, 5712-5716.

[46]. Duruibe, J. O., Ogwuegbu, M. O. C., & Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences*, *2*(5), 112-118.

[47]. Ebrahimi M, Khalili Neda, Razi S, Keshavarz-Fathi M, Khalili Nastaran, Rezaei N: Effects of lead and cadmium on the immune system and cancer progression. J Environ Heal Sci Eng 2020, 18:335-343.

[48]. Egwuonwu, C. C., Arinze, R. U., & Chukwuma, E. C. (2023). Some physical and heavy metal analysis of waste tire derived oil produced by a locally fabricated reactor. Environmental Challenges, 11, 100711.

[49]. Fasani E, Manara A, Martini F, Furini A, Dal CG (2017) The potential of genetic engineering of plants for the remediation of soils contaminated with heavy metals. Plant Cell Environ 41:1201-1232.

[50]. Fasano, A., Canning, C. G., Hausdorff, J. M., Lord, S., & Rochester, L. (2017). Falls in Parkinson's disease: a complex and evolving picture. *Movement Disorders*, *32*(11), 1524-1536.

[51]. Fatima, R., Basharat, U., Safdar, A., Haidri, I., Fatima, A., Mahmood, A., Ullah, Q., Ummer, K., & Qasim, M. (2024). AVAILABILITY OF PHOSPHOROUS TO THE SOIL, THEIR SIGNIFICANCE FOR ROOTS OF PLANTS AND ENVIRONMENT. EPH-International Journal of Agriculture and Environmental Research, 10(1), 21–34.

[52]. Feng, J., Jia, W., Lv, S., Bao, H., Miao, F., Zhang, X., ... & Li, Y. (2018). Comparative transcriptome combined with morpho-physiological analyses revealed key factors for differential cadmium accumulation in two contrasting sweet sorghum genotypes. *Plant biotechnology journal*, *16*(2), 558-571.

[53]. Feng, J.; Shi, Q.; Wang, X.; Wei, M.; Yang, F.; Xu, H. Silicon supplementation ameliorated the inhibition of photosynthesis and nitrate metabolism by cadmium (Cd) toxicity in Cucumis sativus L. Sci. Hortic. (Amsterdam). 2010, 123, 521-530.

[54]. Finžgar, N., Kos, B., & Leštan, D. (2006). Bioavailability and mobility of Pb after soil treatment with different remediation methods. *Plant, Soil and Environment, 52*, 25-34.

[55]. Fitzmaurice, C., Allen, C., Barber, R. M., Barregard, L., Bhutta, Z. A., Brenner, H., ... & Satpathy, M. (2017). Global, regional, and national cancer incidence, mortality, years of life lost, years lived with disability, and disability-adjusted life-years for 32 cancer groups, 1990 to 2015: a systematic analysis for the global burden of disease study. *JAMA oncology*, *3*(4), 524-548.

[56]. Fred T, Davies J, Jeffrey DP, et al. 2001. Mycorrhizal fungi enhance the accumulation and tolerance of chromium in sunflowers (Helianthus annuus). Journal of Plant Physiology, 158: 777-786

[57]. Frery N, Nessmann C, Girard F, Lafond J, Moreau T, Blot P, Lellouch J, Huel G: Environmental exposure to cadmium and human birthweight. *Toxicology* 1993,79(2):109-118.

[58]. Galal TM, Gharib FA, Ghazi SM, Mansour KH (2017) Phytostabilization of heavy metals by the emergent macrophyte *Vossia cuspidata* (Roxb.) Griff.: a phytoremediation approach. Int J Phytoremed 19:992-999.

[59]. Gallego SM, Pena LB, Barcia RA, Azpilicueta CE, Iannone MF, Rosales EP, Zawoznik MS, Groppa MD, Benavides MP (2012) Unravelling cadmium toxicity and tolerance in plants: insight into regulatory mechanisms. Environ Exp Bot 83:33-46.

[60]. Garbisu, C., & Alkorta, I. (2003). Basic concepts on heavy metal soil bioremediation. *temp & ep (European Journal of Mineral Processing and Environmental Protection)*, *3*(1), 58-66.

[61]. Gebrekidan, A., Weldegebriel, Y., Hadera, A., Van der Bruggen, B., 2013. Toxicological assessment of heavy metals accumulated in vegetables and fruits grown in Ginfel river near Sheba Tannery, Tigray, Northern Ethiopia. Ecotoxicol. Environ. Saf. 95, 171-178.

[62]. Ghnaya, A. B., Charles, G., Hourmant, A., Hamida, J. B., & Branchard, M. (2009). Physiological behavior of four rapeseed cultivars (Brassica napus L.) submitted to mental stress. *Comptes Rendus Biologies*, *332*(4), 363-370.

[63]. Goswami, S., Aich, K., Das, S., Mukhopadhyay, C. D., Sarkar, D., & Mondal, T. K. (2015). A new visible-light-excitable ICT-CHEF-mediated fluorescence ‘turn-probe for the selective detection of Cd 2^{+} in a mixed aqueous system with live-cell imaging. *Dalton Transactions*, *44*(12), 5763-5770.

[64]. Goswami, S., Das, S., 2015. A study on cadmium phytoremediation potential of Indian mustard, Brassica juncea. Int. J. Phytorem. 17, 583-588.

[65]. Guan, Z., Chai, T., Zhang, Y., Xu, J., Wei, W., 2009. Enhancement of Cd tolerance in transgenic tobacco plants overexpressing a Cd-induced catalase cDNA. Chemosphere 76, 623-630.

[66]. Gupta, G., Yadav, G., Tiwari, S., 2020. Restoration of Wetland Ecosystem: A Trajectory towards a Sustainable Environment, Restoration of Wetland Ecosystem: A Trajectory towards a Sustainable Environment.

[67]. Haidri, I., Shahid, M., Hussain, S., Shahzad, T., Mahmood, F., Hassan, M. U., Al-Khayri, J. M., Aldaej, M. I., Sattar, M. N., & Rezk, A. A.-S. (2023). Efficacy of Biogenic Zinc Oxide Nanoparticles in Treating Wastewater for Sustainable Wheat Cultivation. Plants, 12(17), 3058.

[68]. Haidri, I., Shahid, M., Hussain, S., Shahzad, T., Mahmood, F., Hassan, M. U., Al-Khayri, J. M., Aldaej, M. I., Sattar, M. N., & Rezk, A. A.-S. (2023). Efficacy of Biogenic Zinc Oxide Nanoparticles in Treating Wastewater for Sustainable Wheat Cultivation. Plants, 12(17), 3058.

[69]. Hanson A, David T, Sabatin A. 1992. Transport and Remediation of Subsurface Contaminants. 108-120, American Chemical Society, Washington DC, USA

[70]. Hao H, Shi G, Du K, et al. (2001): Toxic effect of Hg 2§ on physiology and ultrastructure of Hydrochairs Dubai. J Lake Science 13 (2) 163-168.

[71]. Hayat, M.T.; Nauman, M.; Nazir, N.; Ali, S.; Bangash, N. Environmental Hazards of Cadmium: Past, Present, and Future. In Cadmium Toxicity and Tolerance in Plants: From Physiology to Remediation; Hasanuzzaman, M., Prasad, M.N.V., Fujita, M., Eds.; Academic Press: Cambridge, MA, USA, 2018; pp. 163-183.

[72]. Hengwei, F., Zifang, H., Qifei, W., Weiqing, T., Nali, D., Ping, Y., & Junlin, Y. (2016). Prevalence of idiopathic scoliosis in Chinese schoolchildren: a large, population-based study. *Spine*, *41*(3), 259-264.

[73]. Hu, B., Jia, X., Hu, J., Xu, D., Xia, F., & Li, Y. (2017). Assessment of heavy metal pollution and health risks in the soil-plant-human system in the Yangtze River Delta, China. *International Journal of Environmental Research and Public Health, 14*, 1042.

[74]. Huan L, Haixia Z, Longhua W, Anna L, Fang-Jie Z, Wenzhong X (2017) Heavy metal ATPase 3 (HMA3) confers cadmium hypertolerance on the cadmium/zinc hyperaccumulator *Sedum plumbizincicola*. New Phytol 15:687-698.

[75]. Huan, T. N., Ranjbar, N., Rousse, G., Sougrati, M., Zitolo, A., Mougel, V., ... & Fontecave, M. (2017). Electrochemical reduction of CO2 catalyzed by Fe-NC materials: A structure-selectivity study. *ACS catalysis*, *7*(3), 1520-1525.

[76]. Huang, Y. Q., Liang, C. H., He, L., Tian, J., Liang, C. S., Chen, X., ... & Liu, Z. Y. (2016). Development and validation of a radionics nomogram for preoperative prediction of lymph node metastasis in colorectal cancer. *Journal of Clinical Oncology*, *34*(18), 2157-2164.

[77]. Huang, Y., He, C., Shen, C., Guo, J., Mubeen, S., Yuan, J., & Yang, Z. (2017). Toxicity of cadmium and its health risks from leafy vegetable consumption. *Food & Function*, *8*(4), 1373-1401.

[78]. Hussain, S. R., Rashid, M. Z., Haidri, I., Shafqat, U., & Mahmood, F. (2024). Assessing global good agricultural practices standard adoption: insights from fruit and vegetable farmers in Pakistan. Italian Journal of Food Safety.

[79]. Hussain, S. R., Rashid, M. Z., Haidri, I., Shafqat, U., & Mahmood, F. (2024). Assessing global good agricultural practices standard adoption: insights from fruit and vegetable farmers in Pakistan. Italian Journal of Food Safety.

[80]. Hwua, Y.; Yang, J. Effect of 3-aminotriazole on anchorage independence and mutagenicity in cadmium- and lead-treated diploid human fibroblasts. *Carcinogenesis* 1998, *19*, 881-888.

[81]. Ibraheen, L.H., Abed, S.A., 2017. Accumulation detection of some heavy metals in some types of fruits in the local market of Al-Diwaniyah city, Iraq. Rasayan J. Chem. 10, 339-343.

[82]. Inam, F., 2013. Analysis of minerals and heavy metals in some spices collected from a local market. IOSR J. Pharm. Biol. Sci. 8, 40-43.

[83]. Irfan, M., Ahmad, A., Hayat, S., 2014. Effect of cadmium on the growth and antioxidant enzymes in two varieties of Brassica juncea. Saudi J. Biol. Sci. 21, 125-131.

[84]. Ishikawa, T., & Montello, D. R. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive psychology*, *52*(2), 93-129.

[85]. Islam, M.S., Hoque, M.F., 2014. Concentrations of heavy metals in vegetables around the industrial area of Dhaka city, Bangladesh, and health risk assessment. Int. Food Res. J. 21, 2121-2126.

[86]. Ismael, M.A.; Elyamine, A.M.; Moussa, M.G.; Cai, M.; Zhao, X.; Hu, C. Cadmium in plants: Uptake, toxicity, and its interactions with selenium fertilizers. Metallomics 2019, 11, 255-277.

[87]. Jacob, D. L., Yellick, A. H., La Toya, T. K., Asgary, A., Wijeyaratne, D. N., Saini-Eidukat, B., & Otte, M. L. (2013). Cadmium and associated metals in soils and sediments of wetlands across the Northern Plains, USA. *Environmental pollution*, *178*, 211-219.

[88]. Jarup L, Alfven T, Persson B, Toss G, Elinder CG: Cadmium may be a risk factor for osteoporosis. *Occup Environ Med* 1998,55(7):435-439.

[89]. Jarup L, Berglund M, Elinder CG, Nordberg G, Vahter M: Health effects of cadmium exposure-a review of the literature and a risk estimate. *Scand J Work Environ Health* 1998, 24 Suppl 1: 1-51.

[90]. Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin, 68*, 167-182.

[91]. Jawad, I., 2016. Determination of heavy metals in spices and medical herbs available in the Iraq Markets. Adv. Environ. Biol. 10, 66-69.

[92]. Jiang, X.J., Luo, Y.M., Liu, Q., Liu, S.L., Zhao, Q.G., 2004. Effects of cadmium on nutrient uptake and translocation by Indian mustard. Environ. Geochem. Health 26, 319-324.

[93]. Jin T, Nordberg M, Frech W, Dumont X, Bernard A, Ye TT, Kong Q, Wang Z, Li P, Lundstrom NG, Li Y, Nordberg GF: Cadmium biomonitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China (ChinaCad). *Biometals* 2002,15(4):397410.

[94]. Jinadasa, R. W., Zhou, Z., Vicente, M. G. H., & Smith, K. M. (2016). Syntheses and cellular investigations of di-aspartate and aspartate-lysine chlorin e 6 conjugates. *Organic & biomolecular chemistry*, *14*(3), 1049-1064.

[95]. John, R., Ahmad, P., Gadgil, K., Sharma, S., 2009. Cadmium and lead-induced changes in lipid peroxidation, antioxidative enzymes, and metal accumulation in Brassica juncea L. at three different growth stages. Arch. Agron. Soil Sci. 55, 395-405.

[96]. K. Weggler, M. J. McLaughlin, and R. D. Graham, "Effect of Chloride in Soil Solution on the Plant Availability of Biosolid-Borne Cadmium," Journal of Environmental Quality, vol. 33, no. 2, pp. 496-504, 2004.

[97]. Kabata-Pendias, A., & Pendias, H. (1999). *Biogeochemia pierwiastków śladowych*. Warsaw: PWN In polish.

[98]. Karami, N., Clemente, R., Moreno-Jiménez, E., Lepp, N. W., & Beesley, L. (2011). The efficiency of green waste compost and biochar soil amendments for reducing lead and copper mobility and uptake to ryegrass. *Journal of Hazardous Materials, 191*, 41-48.

[99]. Kathal, R., Malhotra, P., & Chaudhary, V. (2016). Phytoremediation of cadmium from polluted soil. *J. Bioremediation Biodegrad*, *7*, 376.

[100]. Kaur R, Bhatti SS, Singh S, Singh J, Singh S (2018) Phytoremediation of heavy metals using cotton plant: a field analysis. Bull Environ Contam Toxicol 101:637-643.

[101]. Kaur, K., & Rampersad, G. (2018). Trust in driverless cars: Investigating key factors influencing the adoption of driverless cars. *Journal of Engineering and Technology Management*, *48*, 87-96.

[102]. Kaur, R., Yadav, P., Thukral, A. K., Walia, A., & Bhardwaj, R. (2017). Co-application of 6-ketone type brassinosteroid and metal chelator alleviates cadmium toxicity in B. juncea L. *Environmental Science and Pollution Research*, *24*(1), 685-700.

[103]. Kazantzis G: Cadmium, osteoporosis, and calcium metabolism. *Biometals* 2004,17(5):493-498.

[104]. Kazantzis G: Renal tubular dysfunction and abnormalities of calcium metabolism in cadmium workers. *Environ Health Perspect* 1979, 28: 155-159.

[105]. Keller, C., Ludwig, C., Davoli, F., & Wochele, J. (2005). Thermal treatment of metal-enriched biomass produced from heavy metal phytoextraction. *Environmental science & technology*, *39*(9), 3359-3367.

[106]. Khan, K.Y., Ali, B., Cui, X., Feng, Y., Stoffella, P.J., Tang, L., Yang, X., 2017. Effect of a humic acid amendment on cadmium bioavailability and accumulation by pak choi (Brassica rapa ssp. chinensis L.) to alleviate dietary toxicity risk. Arch. Agron. Soil Sci.

[107]. Khan, M. A., Khan, S., Khan, A., & Alam, M. (2017). Soil contamination with cadmium, consequences, and remediation using organic amendments. *Science of the total environment*, *601*, 1591-1605.

[108]. Khan, M. U., Shahbaz, N., Waheed, S., Mahmood, A., Shinwari, Z. K., & Malik, R. N. (2016). Comparative health risk surveillance of heavy metals via dietary foodstuff consumption in different land-use types of Pakistan. *Human and Ecological Risk Assessment: An International Journal*, *22*(1), 168-186.

[109]. Kim, Y.-H., Lee, H.-S., Kwak, S.-S., 2010. Differential responses of sweet potato peroxidases to heavy metals. Chemosphere 81, 79-85.

[110]. Kou YG, Fu XY, Hou PQ, et al. The study of the lead accumulation of earthworms in lead pollution soil. Environmental Science and Management, 2008; 33(1): 62-4, 73.

[111]. Kuang, D., Hou, L., Wang, S., Yu, B., Lianwen, D., Lin, L., ... & Song, M. (2018). Enhanced electromagnetic wave absorption of Ni–C core-shell nanoparticles by HCP-Ni phase. *Materials Research Express*, *5*(9), 095013.

[112]. Kubier, A., Wilkin, R. T., & Pichler, T. (2019). Cadmium in soils and groundwater: a review. *Applied Geochemistry*, *108*, 104388.

[113]. Kumar, M., Bijo, A.J., Baghel, R.S., Reddy, C.R.K., Jha, B., 2012. Selenium and spermine alleviate cadmium-induced toxicity in the red seaweed Gracilaria dura by regulating antioxidants and DNA methylation. Plant Physiol. Biochem. 51, 129-138.

[114]. Kumar, N., Bauddh, K., Singh, R., Anand, K., Barman, S. C., & Singh, D. P. (2009). Phytotoxicity of trace metals (Cu & Cd) to gram (Cicer argentine) and mung (Phaseolus mungo). *Journal of Ecophysiology and Occupational Health*, *9*(1/2), 59.

[115]. Kumar, S.S., Kadier, A., Malyan, S.K., Ahmad, A., Bishnoi, N.R., 2017. Phytoremediation and Rhizoremediation: Uptake, Mobilization, and Sequestration of Heavy Metals by Plants, Plant-Microbe Interactions in Agro-Ecological Perspectives.

[116]. Labhade, K.R., 2013. Assessment of heavy metal contamination in vegetables grown in and around Nashik city, Maharashtra state, India. IOSR J. Appl. Chem. 5, 9-14.

[117]. Leitzmann, C. (2003). Nutrition ecology: the contribution of vegetarian diets. *The American Journal of Clinical Nutrition, 78*, 657S-659S.

[118]. Li, J., Liu, Y. R., Zhang, L. M., & He, J. Z. (2019). Sorption mechanism and distribution of cadmium by different microbial species. *Journal of Environmental Management*, *237*, 552-559.

[119]. Lim, M. P., & McBride, M. B. (2015). Arsenic and lead uptake by Brassicas grown on an old orchard site. *Journal of Hazardous Materials, 299*, 656-663.

[120]. Linshy, V. N., Saraswat, R., Kurtarkar, S. R., & Nigam, R. (2013). Experiment to decipher the effect of heavy metal cadmium on coastal benthic foraminifer Pararotalia nipponica (Asano).

[121]. Liu D, Jiang W, Li H, et al. (2000): Effects of cadmium on root growth and ultrastructural alterations in the root tip cells of garlic (Allium sativum L.). Acta Agriculture Boreli-Sinica 15 (3) 66-71.

[122]. Liu, L., Li, J.W., Yue, F.X., Yan, X.W., Wang, F.Y., Bloszies, S., Wang, Y.F., 2018. Effects of arbuscular mycorrhizal inoculation and biochar amendment on maize growth, cadmium uptake, and soil cadmium speciation in Cd-contaminated soil. Chemosphere 194, 495-503.

[123]. Liu, M., Sun, J., Li, Y., Xiao, Y., 2017. Nitrogen fertilizer enhances the growth and nutrient uptake of Medicago sativa inoculated with Glomus tortuosum grown in Cd-contaminated acidic soil. Chemosphere 167, 204.

[124]. Luo QS, Zhang XH, Wang H (2004) Mobilization of 2, 4-dichlorophenol in soils by non-uniform electrokinetics. Acta Sci Circumst 24:1104-1109.

[125]. Luo, Y., Su, B. O., Currie, W. S., Dukes, J. S., Finzi, A., Hartwig, U., ... & Field, C. B. (2004). Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. *Bioscience*, *54*(8), 731-739.

[126]. Ma Y, Ran D, Shi X, Zhao H, Liu Z: Cadmium toxicity: a role in bone cell function and teeth development. Sci Total Environ 2021:144646.

[127]. Maiti, S., Biswas, S., & Jana, U. (2010). Iron (III)-catalyzed four-component coupling reaction of 1, 3-dicarbonyl compounds, amines, aldehydes, and nitroalkanes: a simple and direct synthesis of functionalized pyrroles. *The Journal of Organic Chemistry*, *75*(5), 1674-1683.

[128]. Maleki, A., Amini, H., Nazmara, S., Zandi, S., Mahvi, A.H., 2014. Spatial distribution of heavy metals in soil, water, and vegetables of farms in Sanandaj, Kurdistan, Iran. J. Environ. Heal. Sci. Eng. 12, 1-10.

[129]. Malin AJ, Wright RO: The developmental neurotoxicity of cadmium. In Handbook of Developmental Neurotoxicology. Elsevier; 2018:407-412.

[130]. Malyan, S. K., Singh, R., Rawat, M., Kumar, M., Pugazhendhi, A., Kumar, A., ... & Kumar, S. S. (2019). An overview of carcinogenic pollutants in groundwater of India. *Biocatalysis and Agricultural Biotechnology*, *21*, 101288.

[131]. Marchiol, L., Assolari, S., Sacco, P., & Zerbi, G. (2004). Phytoextraction of heavy metals by canola (Brassica napus) and radish (Raphanus sativus) grown on multi-contaminated soil. *Environmental Pollution*, *132*(1), 21-27.

[132]. Martínez-Penalver, ˜ A., Grana, ˜ E., Reigosa, M.J., Sanchez-Moreiras, ´ A.M., 2012. The early response of Arabidopsis thaliana to cadmium- and copper-induced stress. Environ. Exp. Bot. 78, 1-9.

[133]. Matloob, M.H., 2016. Using stripping voltammetry to determine heavy metals in cooking spices used in Iraq. Pol. J. Environ. Stud. 25, 2057-2070.

[134]. McBride, M. B., Shayler, H. A., Russell-Anelli, J. M., Spliethoff, H. M., & Marquez-Bravo, L. G. (2015). Arsenic and lead uptake by vegetable crops grown on an old orchard site amended with compost. *Water, Air, & Soil Pollution, 226*, 265-279.

[135]. McBride, M.B., Shayler, H.A., Spliethoff, H.M., Mitchell, R.G., Marquez-Bravo, L.G., Ferenz, G.S., Russell-Anelli, J.M., Casey, L., Bachman, S. (2014). Concentrations of lead, cadmium, and barium in urban garden-grown vegetables: the impact of soil variables. Environmental Pollution, 194, 254-261.

[136]. McGrath, R. G. (2001). Exploratory learning, innovative capacity, and managerial oversight. *Academy of management journal*, *44*(1), 118-131.

[137]. Memon, A. R., & Schröder, P. (2009). Implications of metal accumulation mechanisms to phytoremediation. *Environmental Science and Pollution Research*, *16*(2), 162-175.

[138]. Memon, N., & Wong, P. W. (2001). A buyer-seller watermarking protocol. *IEEE Transactions on image processing*, *10*(4), 643-649.

[139]. Miralles, O., Sánchez, J., Palou, A., & Picó, C. (2006). A physiological role of breast milk leptin in body weight control in developing infants. *Obesity*, *14*(8), 1371-1377.

[140]. Mohod, C.V., 2015. A review of the concentration of heavy metals in vegetable samples like spinach and tomato grown near the area of amba nalla of Amravati city. Int. J. Innov. Res. Sci. Eng. Technol. 4, 2788-2792.

[141]. Moosavi, A., Haghighi, A., Mojarad, E. N., Zayeri, F., Alebouyeh, M., Khazan, H., ... & Zali, M. R. (2012). Genetic variability of Blastocystis sp. isolated from symptomatic and asymptomatic individuals in Iran. *Parasitology Research*, *111*(6), 2311-2315.

[142]. Mosleh, Y.Y., Mofeed, J., Almaghrabi, O., Kadasa, N.M.S., Alzahrani, H., Fuller, M.P., 2014. Residues of heavy metals, PCDDs, PCDFs, and DL-PCBs on some medicinal plants were collected randomly from the jeddah, central market. Life Sci. J. 11, 1-8.

[143]. Moustakas, M., Sperdouli, I., Kouna, T., Antonopoulou, C. I., & Therios, I. (2011). Exogenous proline induces soluble sugar accumulation and alleviates drought stress effects on photosystem II functioning of Arabidopsis thaliana leaves. *Plant Growth Regulation*, *65*(2), 315-325.

[144]. Murray, H., Pinchin, T. A., & Macfie, S. M. (2011). Compost application affects metal uptake in plants grown in urban garden soils and potential human health risks. *Journal of Soils and Sediments, 11*, 815-829.

[145]. Navarro-León, E., Ruiz, J. M., Albacete, A., & Blasco, B. (2020). Tolerance to cadmium toxicity and phytoremediation potential of three Brassica rapa CAX1a TILLING mutants. *Ecotoxicology and environmental safety*, *189*, 109961.

[146]. Nogawa K, Kobayashi E, Okubo Y, Suwazono Y: Environmental cadmium exposure, adverse effects and preventive measures in Japan. *Biometals* 2004,17(5):581-587.

[147]. Nordberg GF: Cadmium and health in the 21st century-historical remarks and trends for the future. *Biometals* 2004,17(5):485-489.

[148]. Nriagu, J. O. (1989). A global assessment of natural sources of atmospheric trace metals. *Nature*, *338*(6210), 47-49.

[149]. Ojuederie, O.B., Babalola, O.O., 2017. Microbial and plant-assisted bioremediation of heavy metal polluted environments: a review. Int. J. Environ. Res. Publ. Health 14, 1504.

[150]. P. G. C. Campbell, “Cadmium-A priority pollutant,” Environmental Chemistry, vol. 3, no. 6, pp. 387-388, 2006.

[151]. Paltseva, A., Cheng, Z., Deeb, M., Groffman, P. M., Shaw, R. K., & Maddaloni, M. (2018). Accumulation of arsenic and lead in garden-grown vegetables: factors and mitigation strategies. *The Science of the Total Environment, 640-641*, 273-283.

[152]. Pope, E. C., Bird, D. K., & Arnórsson, S. (2013). Evolution of low-18O Icelandic crust. *Earth and Planetary Science Letters*, *374*, 47-59.

[153]. Pourahmad, J.; O'Brien, P.J.; Jokar, F.; Daraei, B. Carcinogenimetal induced sites of reactive oxygen species formation in hepatocytes. *Toxicol. In vitro* 2003, *17*, 803-810.

[154]. Priya, A. K., Muruganandam, M., Ali, S. S., & Kornaros, M. (2023). Clean-Up of Heavy Metals from Contaminated Soil by Phytoremediation: A Multidisciplinary and Eco-Friendly Approach. Toxics, 11(5), 422.

[155]. Priya, B., Gupta, V. K., Pathania, D., & Singha, A. S. (2014). Synthesis, characterization, and antibacterial activity of biodegradable starch/PVA composite films reinforced with cellulosic fiber. *Carbohydrate polymers*, *109*, 171-179.

[156]. Qayyum, M. F., ur Rehman, M. Z., Ali, S., Rizwan, M., Naeem, A., Maqsood, M. A., ... & Ok, Y. S. (2017). Residual effects of mono ammonium phosphate, gypsum, and elemental sulfur on cadmium phytoavailability and translocation from soil to wheat in an effluent irrigated field. *Chemosphere*, *174*, 515-523.

[157]. Qin P, Tie B, Zhou X, et al. (2000): Effects of Cadmium and Lead in Soil on the Germination and Growth of Rice and Cotton. Journal of Hunan Agricultural University 26 (3) 205-207.

[158]. Ramos-Miras, J. J., Roca-Perez, L., Guzmán-Palomino, M., Boluda, R., & Gil, C. (2011). Background levels and baseline values of available heavy metals in Mediterranean greenhouse soils (Spain). *Journal of Geochemical Exploration*, *110*(2), 186-192.

[159]. Randolph, J. Molecular mechanisms of transformation of CH3/10T1/2 C1 8 mouse embryo cells and diploid human fibroblasts by carcinogenic metal compounds. *Environ. Health Perspect.* 1994, *102*, 119-125.

[160]. Rehman, M. Z., Khalid, H., Akmal, F., Ali, S., Rizwan, M., Qayyum, M. F., ... & Azhar, M. (2017). Effect of limestone, lignite, and biochar applied alone and combined on cadmium uptake in wheat and rice under rotation in an effluent irrigated field. *Environmental Pollution*, *227*, 560-568.

[161]. Rizwan, M., Ali, S., Abbas, T., Zia-ur-Rehman, M., Hannan, F., Keller, C., ... & Ok, Y. S. (2016). Cadmium minimization in wheat: a critical review. *Ecotoxicology and environmental safety*, *130*, 43-53.

[162]. Rizwan, M., Ali, S., Hussain, A., Ali, Q., Shakoor, M. B., Zia-ur-Rehman, M., ... & Asma, M. (2017). Effect of zinc-lysine on growth, yield and cadmium uptake in wheat (Triticum aestivum L.) and health risk assessment. *Chemosphere*, *187*, 35-42.

[163]. Rizwan, M., Ali, S., Rizvi, H., Rinklebe, J., Tsang, D. C., Meers, E., ... & Ishaque, W. (2016). Photo management of heavy metals in contaminated soils using sunflower: a review. *Critical Reviews in Environmental Science and Technology*, *46*(18), 1498-1528.

[164]. Rizwan, M., Meunier, J. D., Davidian, J. C., Pokrovsky, O. S., Bovet, N., & Keller, C. (2016). Silicon alleviates Cd stress of wheat seedlings (Triticum turgidum L. cv. Claudio) grown in hydroponics. *Environmental Science and Pollution Research*, *23*, 1414-1427.

[165]. Rose, J., West, C., & Clifford, D. (2000). Group interventions for anger in people with intellectual disabilities. *Research in developmental disabilities*, *21*(3), 171-181.

[166]. Saini S, Dhania G: Cadmium as an environmental pollutant: ecotoxicological effects, health hazards, and bioremediation approach for its detoxification from contaminated sites. In Bioremediation of industrial waste for environmental safety. Springer; 2020:357-387.

[167]. Sankhla, M. S., Kumari, M., Nandan, M., Kumar, R., & Agrawal, P. (2016). Heavy metals contamination in water and their hazardous effect on human health-a review. *Int. J. Curr. Microbiol. App. Sci (2016)*, *5*(10), 759-766.

[168]. Scheckel, K. G., Diamond, G. L., Burgess, M. F., Klotzbach, J. M., Maddaloni, M., Miller, B. W., Partridge, C. R., & Serda, S. M. (2013). Amending soils with phosphate as means to mitigate soil lead hazard: a critical review of the state of the science. *Journal of Toxicology and Environmental Health, Part B: Critical Reviews, 16*, 337-380.

[169]. Schützendübel, A.; Nikolova, P.; Rudolf, C.; Polle, A. Cadmium and H2O2-induced oxidative stress in Populus x canescens roots. Plant Physiol. Biochem. 2002, 40, 577-584.

[170]. Seidal K, Jorgensen N, Elinder CG, Sjogren B, Vahter M: Fatal cadmium-induced pneumonitis. *Scand J Work Environ Health* 1993,19(6):429-431.

[171]. Seregin, I.V.; Kozhevnikova, A.D. Roles of root and shoot tissues in transport and accumulation of cadmium, lead, nickel, and strontium. Russ. J. Plant Physiol. 2008, 55, 1-22.

[172]. Shaheen, S. M., & Rinklebe, J. (2015). Phytoextraction of potentially toxic elements by Indian mustard, rapeseed, and sunflower from contaminated riparian soil. *Environmental geochemistry and health*, *37*(6), 953-967.

[173]. Shahi Khalaf Ansar, B., Kavusi, E., Dehghanian, Z., Pandey, J., Asgari Lajayer, B., Price, G. W., & Astatkie, T. (2023). Removal of organic and inorganic contaminants from the air, soil, and water by algae. Environmental Science and Pollution Research, 30(55), 116538–116566.

[174]. Shahid, M., Shamshad, S., Rafiq, M., Khalid, S., Bibi, I., Niazi, N. K., ... & Rashid, M. I. (2017). Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: A review. *Chemosphere*, *178*, 513-533.

[175]. Sharaff, M. M., Subrahmanyam, G., Kumar, A., & Yadav, A. N. (2020). Mechanistic understanding of the root microbiome interaction for sustainable agriculture in polluted soils. In *New and Future Developments in Microbial Biotechnology and Bioengineering* (pp. 61-84).

[176]. Shentu, J.L., He, Z.L., Yang, X.E., Li, T.Q., 2008. Accumulation properties of cadmium in a selected vegetable rotation system of southeastern China. J. Agric. Food Chem. 56, 6382-6388.

[177]. Shotyk, W., Goodsite, M. E., Roos-Barraclough, F., Frei, R., Heinemeier, J., Asmund, G., ... & Hansen, T. S. (2003). Anthropogenic contributions to atmospheric Hg, Pb, and As accumulation recorded by peat cores from southern Greenland and Denmark dated using the 14C "bomb pulse curve". *Geochimica et Cosmochimica Acta*, *67*(21), 3991-4011.

[178]. Siegel SM, Keller P, et al. 1986. Metal Speciation. Kluwer Academic Publishers, Chicago USA

[179]. Sikka, R., Sahni, T., Verma, D., Chaitra, P., & Singh, A. (2024). Phytoremediation of Cadmium-Contaminated Soil. In Cadmium Toxicity Mitigation (pp. 327–347). Springer.

[180]. Šimonová, E., Henselová, M., Masarovičová, E., & Kohanová, J. (2007). Comparison of tolerance of Brassica juncea and Vigna radiata to cadmium. *Biologia Plantarum*, *51*(3), 488-492.

[181]. Singh P, Mitra P, Goyal T, Sharma S, Sharma P: Blood lead and cadmium levels in occupationally exposed workers and their effect on markers of DNA damage and repair. Environ Geochem Health 2020:1-9.

[182]. Singh, H.P., Batish, D.R., Kaur, G., Arora, K., Kohli, R.K., 2008. Nitric oxide (as sodium nitroprusside) supplementation ameliorates Cd toxicity in hydroponically grown wheat roots. Environ. Exp. Bot. 63, 158-167.

[183]. Singh, K., Singh, R., Malyan, S. K., Rawat, M., Kumar, P., Kumar, S., ... & Pandey, G. (2018). Health risk assessment of drinking water in Bathinda district, Punjab, India.

[184]. Singhal, A., Parihar, A., Khare, V., Tripathi, G. K., & Khan, R. (2024). Chemical Approaches to Remediate Heavy Metals. Remediation of Heavy Metals: Sustainable Technologies and Recent Advances, 123–147.

[185]. Soloman, P.E., Jain, S., Chauhan, S.S., 2017. Bio Accretion of Heavy Metals by Okra and Eggplant Grown in Polluted Areas of Jaipur 428-434.

[186]. Sonawane, V.Y., 2015. Analysis of Heavy metals in vegetables collected from the selected area around Dhulia, North Maharashtra, Maharashtra, India. Int. J. Chem Tech Res. 8, 1935-1939.

[187]. Song, B.; Zeng, G.; Gong, J.; Liang, J.; Xu, P.; Liu, Z.; Zhang, Y.; Zhang, C.; Cheng, M.; Liu, Y.; et al. Evaluation methods for assessing the effectiveness of in situ remediation of soil and sediment contaminated with organic pollutants and heavy metals. *Environ. Int.* 2017, *105*, 43-55.

[188]. Speira T.W., Kettlesb H.A., Percivalc H.J., and Parshotam A., is soil acidification the cause of biochemical responses when soils are amended with heavy metal salts? Soil Biology and Biochemistry, 31, 1953-1961 (1999).

[189]. Sprynskyy, M., Kowalkowski, T., Tutu, H., Cozmuta, L. M., Cukrowska, E. M., & Buszewski, B. (2011). The adsorption properties of agricultural and forest soils towards heavy metal ions (Ni, Cu, Zn, and Cd). *Soil and Sediment Contamination*, *20*(1), 12-29.

[190]. Sprynskyy, M., Kowalkowski, T., Tutu, H., Cukrowska, E. M., & Buszewski, B. (2011). Adsorption performance of talc for uranium removal from aqueous solution. *Chemical Engineering Journal*, *171*(3), 1185-1193.

[191]. Subrahmanyam, G., Sharma, R. K., Kumar, G. N., & Archana, G. (2018). Vigna radiata var. GM4 plant growth enhancement and root colonization by a multi-metal-resistant plant growth-promoting bacterium Enterobacter sp. C1D in Cr (VI)-amended soils. *Pedosphere*, *28*(1), 144-156.

[192]. Suhani, I., Sahab, S., Srivastava, V., & Singh, R. P. (2021). Impact of cadmium pollution on food safety and human health. *Current Opinion in Toxicology*, *27*, 1-7.

[193]. Sumiahadi, A., & Acar, R. (2018, March). A review of phytoremediation technology: heavy metals uptake by plants. In *IOP conference series: earth and environmental science* (Vol. 142, No. 1, p. 012023). IOP Publishing.

[194]. Sun, Q., Yang, H., Feng, X., Liang, Y., Gao, P., & Song, Y. (2023). A novel iron-based composite modified by refinery sludge for fixing Pb, Zn, Cu, Cd, and As in heavy metal polluted soil: Preparation, remediation process and feasibility analysis. Journal of Environmental Chemical Engineering, 11(6), 111233.

[195]. Svartengren M, Elinder CG, Friberg L, Lind B: Distribution and concentration of cadmium in human kidney. *Environ Res* 1986,39(1):1-7. 10.1016/S0013-9351(86)80002-0

[196]. Szefer, P., Geł, J., Ali, A. A., Bawazir, A., & Sad, M. (1997). Distribution and association of trace metals in soft tissue and byssus of mollusc Perna perna from the Gulf of Aden, Yemen. *Environment International*, *23*(1), 53-61.

[197]. Taylor, K. Y. (2016). *From# BlackLivesMatter to black liberation*. Haymarket Books.

[198]. Taylor, M., Kim, N., Smidt, G., Busby, C., McNally, S., Robinson, B., ... & Schnug, E. (2016). Trace element contaminants and radioactivity from phosphate fertilizer. In *Phosphorus in agriculture: 100% zero* (pp. 231-266). Springer, Dordrecht.

[199]. Tickoo, S. K., Alden, D., Olgac, S., Fine, S. W., Russo, P., Kondagunta, G. V., ... & Reuter, V. E. (2007). Immunohistochemical expression of hypoxia-inducible factor-1α and its downstream molecules in sarcomatoid renal cell carcinoma. *The Journal of urology*, *177*(4), 1258-1263.

[200]. Tokunaga, S., & Hakuta, T. (2002). Acid washing and stabilization of artificial arsenic-contaminated soil. *Chemosphere*, *46*(1), 31-38.

[201]. Traore, A.; Ruiz, S.; Baudrimont, I.; Sanni, A.; Dano, S.D.; Guarigues, P.; Narbonne, J.F.; Creppy, E.E. Combined effects of okadaic acid and cadmium on lipid peroxidation and DNA bases modifications (m5dC and 8-(OH)-dG) in Caco-2 cells. *Arch. Toxicol.* 2000, *74*, 79-84.

[202]. Ullah, Q., Qasim, M., Abaidullah, A., Afzal, R., Mahmood, A., Fatima, A., & Haidri, I. (2024). EXPLORING THE INFLUENCE OF NANOPARTICLES AND PGPRS ON THE PHYSICO-CHEMICAL CHARACTERISTICS OF WHEAT PLANTS: A REVIEW. EPH-International Journal of Agriculture and Environmental Research, 10(1), 1–9.

[203]. Unsal, V., Dalkıran, T., Çiçek, M., & Kölükçü, E. (2020). The role of natural antioxidants against reactive oxygen species produced by cadmium toxicity: a review. *Advanced pharmaceutical bulletin*, *10*(2), 184.

[204]. Van Engelen, D.L., Sharpe-Pedler, R.C., Moorhead, K.K., 2007. Effect of chelating agents and solubility of cadmium complexes on uptake from soil by Brassica juncea. Chemosphere 68, 401-408.

[205]. Virkutyte, J. (2002). Electrokinetic treatment overview 2002, the science of the total environment. *Science of the Total Environment*, *289*, 97-121.

[206]. Virkutyte, J., Sillanpää, M., & Latostenmaa, P. (2002). Electrokinetic soil remediation—critical overview. *Science of the total environment*, *289*(1-3), 97-121.

[207]. Wan, X., Lei, M., & Chen, T. (2016).Cost–benefit calculation of phytoremediation technology for heavy-metal-contaminated soil. *Science of the total environment*, *563*, 796-802.

[208]. Wang DD, Li HX, Hu F, et al. Role of earthworm-straw interactions on phytoremediation of Cu contaminated soil by ryegrass. Acta Ecologica Sinica, 2007; 27(4): 1292-98.

[209]. Wang, J. (2011). *The end of the revolution: China and the limits of modernity* (Vol. 40, No. 5, pp. 631-633). Sage CA: Los Angeles, CA: SAGE Publications.

[210]. Wang, P.; Hu, X.; He, Q.; Waigi, M.G.; Wang, J.; Ling, W. Using Calcination Remediation to Stabilize Heavy Metals and Simultaneously Remove Polycyclic Aromatic Hydrocarbons in Soil. *Int. J. Environ. Res. Public Health* 2018, *15*, 1731.

[211]. Watanabe, T., Nobusawa, S., Kleihues, P., & Ohgaki, H. (2009). IDH1 mutations are early events in the development of astrocytomas and oligodendrogliomas. *The American journal of pathology*, *174*(4), 1149-1153.

[212]. Wen, T. H., Gasic, M., Mrksic, N., Su, P. H., Vandyke, D., & Young, S. (2015). Semantically conditioned lstm-based natural language generation for spoken dialogue systems. *arXiv preprint arXiv:1508.01745*.

[213]. Wiseman, C. L., Zereini, S. F., & Püttmann, W. (2015). Metal and metalloid accumulation in cultivated urban soils: a medium-term study of trends in Toronto, Canada. *The Science of the Total Environment, 15*, 564-572.

[214]. Właśniewski, S., & Hajduk, E. (2012). Akumulacja kadmu w glebach i wybranych warzywach uprawianych w ogrodach działkowych Rzeszowa. *Roczniki Gleboznawcze – Soil Science Annual, 48*, 55-60. In polish.

[215]. Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *ISRN Ecology*, 1-20.

[216]. Xin QG, Pan WB, Zhang TP. 2003. On phytoremediation of heavy metal contaminated soils. Ecologic Science, 22(3): 275-279.

[217]. Xu Q, Shi G (2000): The toxic effects of single Cd and interaction of Cd with Zn on some physiological index of [Oenanthe javanica (Blume) DC]. J Nanjing Normal University (Natural Science) 23 (4) 97-100.

[218]. Xu, J., Plaxco, K. W., & Allen, S. J. (2006). Probing the collective vibrational dynamics of a protein in liquid water by terahertz absorption spectroscopy. *protein Science*, *15*(5), 1175-1181.

[219]. Yadav S, Srivastava J (2014) Phytoremediation of cadmium toxicity by *Brassica spp*: a review. Int J Biol Sci 3:47-52.

[220]. Yadav, K.K., Gupta, N., Kumar, A., Reece, L.M., Singh, N., Rezania, S., Ahmad Khan, S., 2018. Mechanistic understanding and holistic approach of phytoremediation: a review on application and future prospects. Ecol. Eng. 120, 274-298.

[221]. Yadav, R. K., Sangwan, R. S., Sabir, F., Srivastava, A. K., & Sangwan, N. S. (2014). Effect of prolonged water stress on specialized secondary metabolites, peltate glandular trichomes, and pathway gene expression in Artemisia annua L. *Plant physiology and biochemistry*, *74*, 70-83.

[222]. Yang R, Zeng Q, Zhou X, et al. (2000): The activated impact of plant root exudates on heavy metals in soils contaminated by tailing of lead-zinc ore. Agro-environmental Protection 19 (3) 152-155.

[223]. Yang Z, Rui-lin M, Wang-dong N, Hui W (2010) Selective leaching of base metals from copper smelter slag. Hydrometallurgy 103:25-29.

[224]. Yang, Y., Li, B., Li, T., Liu, P., Zhang, B., & Che, L. (2023). A review of treatment technologies for acid mine drainage and sustainability assessment. Journal of Water Process Engineering, 55, 104213.

[225]. Yang, Y., Zhang, N., Xue, M., & Tao, S. (2010). Impact of soil organic matter on the distribution of polycyclic aromatic hydrocarbons (PAHs) in soils. *Environmental Pollution*, *158*(6), 2170-2174.

[226]. Yao H., Xu J., and Huang C., Substrate utilization pattern, biomass and activity of microbial communities in a sequence of heavy metal polluted paddy soils. Geoderma, 115, 139-148 (2003).

[227]. Ye, X., Xiao, W., Zhang, Y., Zhao, S., Wang, G., Zhang, Q., & Wang, Q. (2015). Assessment of heavy metal pollution in vegetables and relationships with soil heavy metal distribution in Zhejiang province, China. *Environmental Monitoring and Assessment, 187*, 378.

[228]. Yeung, A. T., & Gu, Y. Y. (2011). A review of techniques to enhance electrochemical remediation of contaminated soils. *Journal of hazardous materials*, *195*, 11-29.

[229]. Yiin, S.J.; Chern, C.L.; Sheu, J.Y.; Lin, L.H. Cadmium-induced liver, heart, and spleen lipid peroxidation in rats and protection by selenium. *Biol. Trace Elem. Res.* 2000, *78*, 219-230.

[230]. Younis, U., Malik, S.A., Rizwan, M., Qayyum, M.F., Ok, Y.S., Shah, M.H.R., Rehman, R. A., Ahmad, N., 2016. Biochar enhances the cadmium tolerance in spinach (Spinacia oleracea) through modification of Cd uptake and physiological and biochemical attributes. Environ. Sci. Pollut. Res. 23, 21385-21394.

[231]. Zhang, H., Dang, Z., Zheng, L. C., & Yi, X. Y. (2009). Remediation of soil co-contaminated with pyrene and cadmium by growing maize (Zea mays L.). *International Journal of Environmental Science & Technology*, *6*(2), 249-258.

[232]. Zhang, Z., Yan, K., Zhang, L., Wang, Q., Guo, R., Yan, Z., Chen, J., 2019. A novel cadmium-containing wastewater treatment method: Bio-immobilization by microalgae cell and their mechanism. J. Hazard. Mater. 374, 420-427.

[233]. Zhao, F.Y., Han, M.M., Zhang, S.Y., Wang, K., Zhang, C.R., Liu, T., 2012. Hydrogen peroxide-mediated growth of the root system occurs via auxin signaling modification and variations in the expression of cell-cycle genes in rice seedlings exposed to cadmium stress. J. Integr. Plant Biol. 54, 991-1006.

[234]. Zheng XS, LU AH, Gao X, et al. 2002. Contamination of heavy metals in soil present situation and method. Soils and Environmental Sciences, 11(l): 79-54.

[235]. Zhou, C.; Ge, N.; Guo, J.; Zhu, L.; Ma, Z.; Cheng, S.; Wang, J. Enterobacter asburiae Reduces Cadmium Toxicity in Maize Plants by Repressing Iron Uptake-Associated Pathways. J. Agric. Food Chem. 2019, 67, 10126-10136.

[236]. Zhou, H., Yang, W. T., Zhou, X., Liu, L., Gu, J. F., Wang, W. L., Zou, J. L., Tian, T., Peng, P. Q., & Liao, B. H. (2016). Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. *International Journal of Environmental Research and Public Health, 13*, 289.