ISSN: 0973-4929, Vol. 19, No. (1) 2024, Pg. 425-435

Current World Environment

www.cwejournal.org

Heavy Metal Phytoremediation by Crop Species at Hebbal Industrial Area, Mysuru, India

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Abstract
Heavy metals are frequently added to the soil in the area of study as a result of industrialization. Removing this heavy metal from the soil is a difficult procedure, and phytoremediation is an essential and effective method for remediation. Heavy metals present in the study area include Fe, Cu, Cd, Pb, and Zn. Two plants namely *Brassica juncea L*. and *Rapanus sativus L*. were successfully grown on the polluted areas soil samples for phytoremediation. *Brassica juncea L* remediates the heavy metals Cu, Zn, Pb, and Cd, while *Rapanus sativus L* remediates Cd, Cu, Pb, and Fe. These two plants can uptake metal from roots to shoots, which means metal concentration is transferred from roots to shoots of the plant, indirectly decreasing concentration in the soil. *Brassica juncea L* was remediated for heavy metals Cd, Cu, Pb, and Zn at a rate of 25.47%, 38.74%, 31.60%, and 26.75%, respectively. The remediation percentages for *Rapanus sativus L* of Cd, Cu, Pb, and Fe were 21.01%, 37.08%, 23.77%, and 47.19%, respectively. *Brassica juncea L* remediate in the order of Cu>Pb>Zn>Cd, and *Rapanus sativus L* Fe>Cu>Pb>Cd were in decreasing order. Shoots of *Brassica juncea L* had a higher bioconcentration than the roots of *Rapanus sativus L*, which clearly explains the metal uptake capacity of the plant. This paper investigated the uptake of heavy metals from roots to shoots, as well as their bioconcentration.

Article History
Received: 30 October 2023
Accepted: 08 May 2024

Keywords
Brassica juncea L;
Bioconcentration;
Heavy Metals;
Rapanus sativus L.

Introduction

International bodies like the World Health Organization regularly evaluate and conduct extensive research on the effects of heavy metals on human health.[1] Heavy metals are major contributors to environmental contamination as a result of human activities, particularly industrialization. Heavy metals are one of the primary abiotic stresses that have led to contamination of the environment in recent decades.[2] This type of pollution has the potential to affect humans, animals, and plants in various ways. The introduction of heavy metals into soils through

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Doi: http://dx.doi.org/10.12944/CWE.19.1.36

industrial wastewater should raise serious worries since these metals are persistent in the environment and can cause cancer in humans.[3,4] Removing these metal pollutants is critical to decreasing the damage to our natural environment and all living things. Solvent extraction, ion exchange, reverse osmosis, chemical precipitation, and adsorption are some of the technologies and processes used for removing heavy metals (HMs) from the environment.[5,6] However, these methods are typically not sustainable and require a large amount of maintenance costs and functions. Heavy metals are among the numerous pollutants discharged into soils by industrial activities such as transmitting waste and raw materials used for alkaline storage batteries, pharmaceuticals, artificial organic substances, etc.[7,8]

Phytoremediation is an economical and feasible method for addressing toxic metal pollution and cleaning up HM-contaminated places, which is one of the environmentally friendly methods available.[9] Phytoremediation is the technique of using green plants to remove environmental contaminants. Few plant species, or cultivars within a species, possess the capacity to absorb, stabilize, or decompose specific contaminants.[10] Only a few plant species can take up and degrade certain contaminants. Specific plant species and varieties can be used for phytoremediation; some plants successfully degrade organics, while others degrade heavy metals[11,12] After phytoremediation is finished, the area can be used as farmland or for other agricultural purposes.[13]

The main source of the anticarcinogenic 3-butenyl glucosinolate is Indian mustard (*Brassica juncea*).[16] The total concentration of Pb and Cd in areas above ground determines how well phytoremediation performed overall. There are notable variations in the levels of Pb and Cd in the shoots of genotypes of *Brassica juncea L.*[14-16] grown on soil contaminated with heavy metal.[17] Similar amounts of Cu were taken up by this species from the external solution, but there was a slight root-to-shoot translocation that indicated a higher potential for phytoremediation.[18] Research demonstrates that essential heavy metals Zn, Pb, Cu, and Cd, accumulate, are tolerated, toxic, translocated, and accumulate at the cellular level in Indian mustard (*Brassica juncea*).[19]

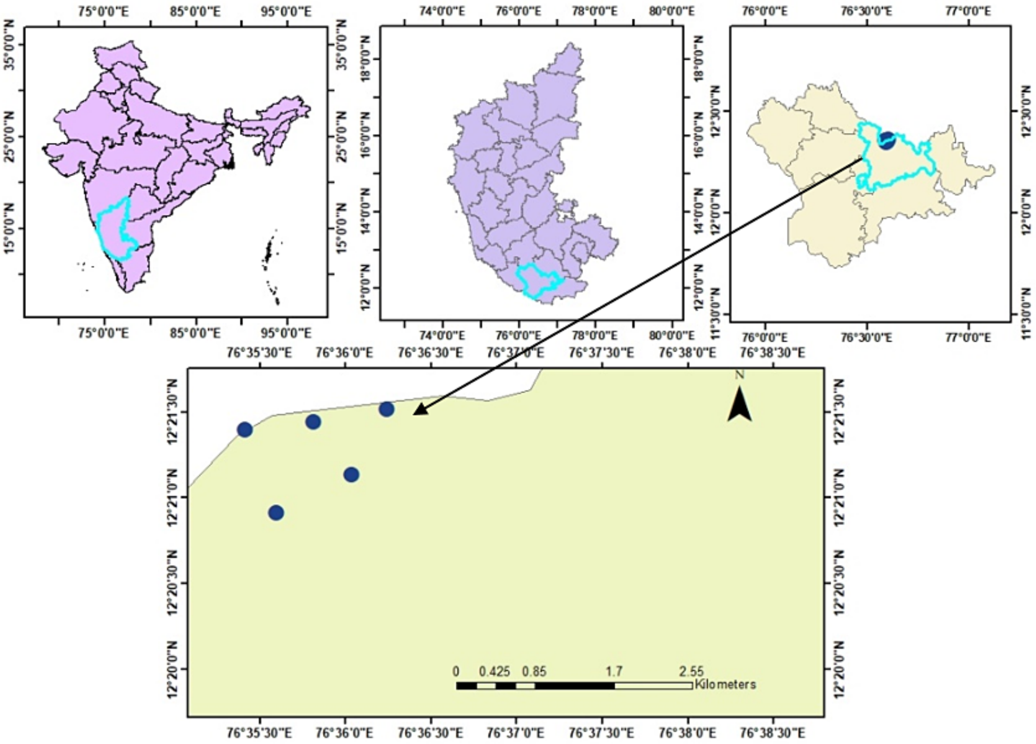

Fig. 2.1: Map showing the sampling locations in the research area.

In traditional Chinese medicine (TCM), the Raphanus sativus L. dried seed also referred to as radish seed or Raphani Semen, is used to treat hypertension, chronic tracheitis, and constipation. Raphani Semen's primary active ingredients are flavonoids, brassinosteroids, glucosinolates, and alkaloids.[20] The phytoremediation potential of Raphanus sativus L. was responsible for monitoring heavy metals such as Pb, Cd, Fe, and Cu.[21]

This study examined the movement of metals from soil into the root and shoot systems of *Brassica juncea L*. and *Rapanus sativus L*. to assess their potential for phytoremediation of contaminated sites, as well as the growth criteria.

Materials and Methods

The study area is located in Hebbal Industrial Area, Ilavala Hobli, Karnataka, India. The crops are irrigated by wastewater contaminated by industries. Between latitudes 12°21'14.60"N and longitudes 76°36'2.59"E is where the chosen area is situated. This area contains most of the industries which are contagious to the water body situated near the industries and the same water may also contaminate the soil with heavy metals. Soil samples were collected in five locations in the Hebbal industrial area which is shown in Figure 2.1. The purpose of the sampling collection in this particular area is to examine the heavy metal concentration and apply the phytoremediation technique to degrade the metal concentration, as well as to understand the bioaccumulation factor of the heavy metal in the selected species. This soil is heavily contaminated by industrial water. To understand the benefits of phytoremediation, it is necessary to collect soil samples in this region.[22,23]

***Brassica juncea L* and *Rapanus Sativus L* Cultivation**

The experiment's genotypes of *rapanus sativus L* and *brassica juncea L* seeds were purchased from the local seed market in Mysuru, Karnataka. The heavy metals in the soil contaminated by wastewater released by industries, the control soil, and the control crops were gathered in a typical Mysuru city irrigated area. Ten sections, each measuring 4 × 5 meters, were created in the cultivation land. Plant seeds were buried 30 cm below the surface with 30 cm apart of the soil and allowed to grow for 80 days then samples were taken at the harvesting stage. Fresh weight measurements were made as soon as the plants were harvested, and dry weight measurements were made after the plants were dried at 50 ˚C in an oven for two days.

Sample Collection and Preparation for Analysis

In the field, the number and weight of yielding plants for every treatment were recorded per square meter. 10 plant samples were analyzed by being taken carefully, thoroughly cleaned of all dirt and debris, rinsed in distilled water, divided into shoots and roots, and then stored in bags. Three duplicates of all plant samples were used to represent it. Three duplicates of each soil sample were taken, and the samples were taken between 0 and 30 cm down. Soil samples were allowed to air dry, then gently crushed, and 2mm sieved through before the analysis. One gram of all plant samples was powdered for analysis.[24] The plant samples underwent pH analysis and were digested using a tri-acid mixture. After the digested sample was preserved, 2 milliliters of aqua regia were added, and the samples were then stored in a 100-milliliter distilled container. The amount of heavy metals in the digested sample was measured using (ICPAES) Inductively Coupled Plasma Atomic Emission Spectroscopy methods.[24]

Calculation Formulas

Remediated metal fraction (mg/kg) is the difference between the initial and final metal concentrations in the soil before and after the plant cultivation.

Remediation (%) =Remedial metal fraction/initial concentration of metals in the soil before planting × 100.[25]

Bioconcentration Factor of Shoots or roots (BCF) = Concentration of metal in parts of the plant (shoots or roots) / metal concentration in soil.[26]]

Results and Discussion

The five samples were collected from the site-grown plant *Brassica juncea L* and five samples were collected from the plant *rapanus sativus L*. The minimum, maximum, and Mean of all samples were discussed. The control soil was collected from the outside of the polluted area which showed lesser values of heavy minerals in all heavy metals concentration.

Analysis of Heavy Metal by *Brassica Juncea L*

Cadmium

A viable crop species for phytoremediation of soils with mild to moderate levels of lead and mercury pollution is *Brassica juncea L*. There exists a noteworthy positive association among dry weights, and heavy metal absorption, and it seems that given their robust growth response to Cd stress and lack of adverse effects, It was discovered that Indian mustard was resistant to Cd at soil Cd concentrations of 1.44 and 123 mg/kg. The values of shoots and roots were nearer to the earlier work done by many researchers.[27]

Table 3.1: Total milligrams per kilogram Cd content in parts of the plant in soil (*Brassica juncea L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	0.28	2.64	6.28	4.98	1.3	20.70	0.05	0.53
Maximum	0.98	2.78	6.28	4.68	1.6	25.47	0.27	0.78
Mean	0.68	1.69	6.28	4.73	1.54	24.58	0.15	0.39
Control	0.10	0.98	3.25	2.71	0.54	16.61	0.03	0.32

Referring to Table 3.1, the Cd concentrations in the samples of shoots and roots varied from 0.28 to 0.98 (mean of 0.79 mg/kg) and 2.64 to 2.78 (mean of 0.79 mg/kg), respectively. After *Brassica juncea L*, the Cd concentrations in the soil samples were significantly lower, with a mean of 4.73 mg/kg, within the 4.68–4.98 range. The Cd-remediated fraction represented varied from 1.3 to 1.6 with a mean of 1.54. The remediation percentage ranged from 20.70% to 43.31 % a mean 28.15 %. The bioconcentration factor varied between 0.05-0.27 (mean 0.15 mg/kg) in shoots and between 0.53-0.78 (mean 0.39 mg/kg) in roots.

Copper

This plant tested well in highly polluted soil (150 mg Cu/kg), showing no signs of copper poisoning. The typical copper content in plants is between 5 and 25 mg/kg. Even in the presence of high soil copper, plant copper concentrations are regulated within a very small range, with concentrations exceeding 100 mg/kg being extremely uncommon.[28] The data obtained by this research of shoots to root were almost in the range of 5 mg/kg.

Table 3.2: Total milligrams per kilogram Cu content in parts of the plant in soil (*Brassica juncea L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	0.21	4.09	19.28	11.96	7.32	37.96	0.01	0.34
Maximum	1.24	6.39	19.28	11.81	7.47	38.74	0.10	0.74
Mean	0.76	4.43	19.28	12.43	6.84	35.51	0.06	0.55
Control	0.05	0.78	10.21	8.11	2.10	20.56	0.006	0.096

Cu concentrations in shoot samples varied from 0.21 to 1.24 (mean 0.76 mg/kg), and in root varied between 4.09 and 6.39 (mean of 4.43 mg/kg), as shown in Table 3.2. After *Brassica juncea L*, the Cu concentrations in the soil were significantly lower, with a mean of 12.43 mg/kg, within the 11.81–11.96 range. The Cu-remediated fraction represented varied from 7.32 to 7.47, with a mean of 6.84. The remediation percentage ranged from 37.96% to 38.74%, with a mean of 35.51%. The bioconcentration factor in shoots varied between 0.01-0.10 (mean 0.06 mg/kg) and in roots between 0.34-0.74 (mean 0.55 mg/kg).[29]

Lead

Root shape, soil properties, and plant subcellular distribution all affect this genotype-dependent variance. In addition to the soil's physical and chemical properties, one of the factors influencing differences in heavy metal absorption across genotypes of Indian mustard is biomass. Positive correlation results between biomass Pb uptake and this were verified. The results of shoot and roots are nearly within the range of the research conducted in 2019 by Gurajala.[30]

Table 3.3: Total milligrams per kilogram Pb content in parts of the plant in soil (*Brassica juncea L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	0.58	1.86	7.15	6.12	1.03	14.40	0.09	0.30
Maximum	1.12	2.32	7.15	4.89	2.26	31.60	0.22	0.47
Mean	0.84	2.49	7.15	5.81	1.34	18.74	0.14	0.43
control	0.10	1.11	3.24	2.89	0.35	10.80	0.03	0.38

Pb concentrations in shoot samples varied from 0.58 to 1.12 (mean 0.84 mg/kg), and in the root samples, they varied from 1.86 to 2.32 (mean 2.49 mg/kg), according to Table 3.3. After *Brassica juncea L*, the Pb concentrations in the soil samples were significantly lower, with a mean of 5.81 mg/kg, within the range of 4.89–6.12. The Pb-remediated fraction represented varied from 1.03 to 2.26, with a mean of 1.34. The remediation percentage ranged from 14.40% to 31.60% (mean of 18.74%). The bioconcentration factor varied between 0.09 and 0.22 (mean 0.14 mg/kg) in shoots and between 0.30-0.47 (mean 0.43 mg/kg) in roots.

Zinc

A plant's ability to develop normally is affected if the concentration of metals it absorbs is above a certain threshold. It is well known that *Brassica juncea* can absorb significant concentrations of heavy metals (Zn, Cu, Au, and Cd) from polluted areas. Higher quantities of heavy metals can be harmful to plants because they can stunt their growth and, in more extreme cases, inflict structural and physiological harm.[28,31] *Brassica juncea* exhibited a remarkable ability to acquire zinc in greater quantities from polluted locations. Plant development is affected by an increase in zinc content beyond the typical range of 100 mg/L, as measured by dry weight and length. The biomass of the roots and stems reduced as the quantity of zinc increased, according to the data.[29] In this research, we have not increased the zinc content with ant acids to increase concentration in plants so the values were lesser than the actual range and it was real plant ability range.

Table 3.4: Total milligrams per kilogram Zn content present in parts of the plant in soil (*Brassica juncea L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	8.41	29.09	140.56	132.25	8.31	5.91	0.06	0.21
Maximum	9.44	31.39	140.56	102.96	37.6	26.75	0.09	0.30
Mean	8.96	29.43	140.56	117.58	22.97	16.34	0.07	0.25
control	4.95	10.21	98.78	54.25	7.55	7.64	0.09	0.18

Zn concentrations in shoot samples varied from 8.41 to 9.44 (mean 8.96 mg/kg), and in the root samples, they varied from 29.09 to 31.39 (mean 29.43 mg/kg), as shown in Table 3.4. After *Brassica juncea L*, the concentrations of Zn in the soil samples were significantly lower, with a mean of 117.58 mg/kg, within the 102.96–132.25 range. The Pb-remediated fraction represented varied from 8.31 to 37.6, with a mean of 22.97. The remediation percentage ranged from 5.91% to 26.75%, with a mean of 16.34%. The bioconcentration factor varied between 0.06-0.09 (mean 0.07 mg/kg) in shoots and between 0.21-0.30 (mean 0.25 mg/kg) in roots.

Analysis of Heavy Metal by *Rapanus Sativus L*

Cadmium

Among the test plants, R. sativus exhibited the highest Rf but the lowest Cd accumulation. For R. sativus, the mean Cd Rf was 1.61%. Consequently, the test plants were not Cd hyperaccumulators.[32] As per our data, the remediated percentage ranged from 16% to 21% so the plant was a better accumulator.

Table 3.5: Total milligrams per kilogram Cd content present in parts of the plant in soil (*Rapanus sativus L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	0.15	1.38	6.28	5.23	1.05	16.71	0.02	0.26
Maximum	0.85	1.46	6.28	4.96	1.32	21.01	0.17	0.29
Mean	0.55	1.07	6.28	4.17	0.93	14.80	0.11	0.25
Control	0.25	0.60	3.25	2.75	0.50	15.38	0.09	0.21

In Table 3.5, the Cd concentrations were found in the root samples (range of 1.38 to 1.46, mean 1.07 mg/kg) and the shoot samples (ranging from 0.15 to 0.85, mean 0.55 mg/kg). After *rapanus sativus L*, the concentrations of Cd in the soil samples were significantly lower, with a mean of 4.17 mg/kg, within the 4.96–5.23 range. The Cd-remediated fraction represented varied from 1.05 to 1.32 (mean of 0.93). The remediation percentage varied between 16.71% and 21.09% (mean 14.80%). The bioconcentration factor varied between 0.02-0.17 (mean 0.11 mg/kg) in shoots and between 0.26-0.29 (mean 0.25 mg/kg) in roots.[33]

Lead

According to the findings, R. sativus can be used to remediate Pb with favorable outcomes if its Rf is more than 10%. R. sativus was likewise shown to have a moderate Pb accumulation. In highly polluted soils, this plant's capacity to collect hazardous chemicals would be reduced. The test plant's Rf of 11.03–12.92% qualified it for phytoremediation of Pb-contaminated soils, even if the Pb level of the soils was not high.[34] In this research we obtained the Rf percentage from 7% to 23% which was a better result to the plant is a good accumulator.

Table 3.6: Total milligrams per kilogram Pb content present in parts of the plant in soil (*Rapanus sativus L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	0.43	1.41	7.15	6.58	0.57	7.97	0.06	0.21
Maximum	0.97	1.87	7.15	5.45	1.70	23.77	0.17	0.34
Mean	0.69	2.04	7.15	5.96	1.18	16.58	0.11	0.34
Control	0.02	0.78	3.24	2.95	0.29	8.95	0.02	0.26

Pb concentrations in shoot samples varied from 0.43 to 0.97 (mean 0.69 mg/kg), and in the root samples, they varied from 1.41 to 1.87 (mean 2.04 mg/kg), as shown in Table 3.6. After *rapanus sativus L*, the concentrations of Pb in the soil samples were significantly lower, with a mean of 5.96 mg/kg, within the 5.45–6.58 range. The Pb-remediated fraction represented varied between 0.57 and 1.70 (mean of 1.18). The remediation percentage ranged from 7.97% to 23.77% (mean 16.58%). The bioconcentration factor varied between 0.06-0.17 (mean 0.11 mg/kg) in shoots and between 0.21-0.34 (mean 0.34 mg/kg) in roots.[35]

Copper

It was determined that radish plants qualify as high accumulator plants for copper. In every CuSo4 solution, the radish plant showed the highest bioaccumulation coefficient. On the other hand, a significant rate of accumulation was noted in roots. It has been noted that plants could take metal from the soil up to a particular concentration; beyond that, as metal concentration increased, plant bioaccumulation rate decreased.[36] The plant accumulation was very similar to the above-mentioned research paper.

Table 3.7: Total milligrams per kilogram Cu content present in parts of the plant in soil (*Rapanus sativus L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	0.15	3.17	19.28	15.12	4.16	21.57	0.009	0.20
Maximum	1.17	5.47	19.28	12.13	7.15	37.08	0.096	0.45
Mean	0.68	3.51	19.28	13.20	6.07	31.50	0.05	0.27
Control	0.09	0.52	10.21	8.18	2.03	19.88	0.001	0.06

Cu concentrations in shoot samples varied from 0.15 to 1.17 (mean 0.68 mg/kg) and in root samples varied between 3.17 and 5.47 (mean 3.51 mg/kg), as shown in Table 3.7. After *rapanus sativus L*, the Cu concentrations in the soil samples were significantly lower, with a mean of 13.20 mg/kg, within the 12.13–15.12 range. The Cu-remediated fraction represented varied from 4.16 to 7.15, with a mean of 6.07. The remediation percentage ranged from 21.57% to 37.08%, with a mean of 31.50%. The bioconcentration factor varied between 0.009 and 0.096 (mean 0.05 mg/kg) in shoots and between 0.20-0.45 (mean 0.27 mg/kg) in roots.[35]

Iron

The control treatment's Rf (remediation faction) for Fe was shown to be greater. This is because iron (Fe) is a necessary element for plants and the water treatment system did not include any other heavy metals, indicating that there was no elemental interaction. As a result, control plants discovered that the soil provided the right conditions for them to absorb iron. L. sativa had a noticeably higher Rf.[22] The control soil which was mentioned in the above research Rf values was almost similar to our research iron Rf value.[37]

Table 3.8: Total milligrams per kilogram Fe content present in parts of the plant in soil (*Rapanus sativus L*)

Sample	Shoot	Root	Initial value of soil	Soil value after planting	Remediated fraction	Remediation Percentage	BCF of shoot	BCF of root
Minimum	117.36	458.36	1708.69	1352.63	356.06	20.83	0.08	0.33
Maximum	160.36	486.30	1708.69	902.23	806.46	47.19	0.17	0.53
Mean	130.002	458.05	1708.69	1209.65	499.03	29.20	0.11	0.38
Control	98.25	210.25	1102.56	895.26	207.30	18.80	0.09	0.10

In Table 3.8, the concentrations of Fe were discovered in root samples (mean 458.05 mg/kg) and in shoot samples with a range of 117.36 to 160.36 (mean 13.002 mg/kg). After *rapanus sativus L*, the Fe concentrations in the soil samples were significantly lower, with a mean of 1209.65 mg/kg, within the 902.23–1352.63 range. The Fe-remediated fraction represented varied from 356.06 to 806.46, with a mean of 499.03. The remediation percentage varied between 20.83% and 47.19% (mean 29.20%). The bioconcentration factor varied between 0.08 and 0.17 (mean 0.11 mg/kg) in shoots and between 0.33 and 0.53 (mean 0.38 mg/kg) in roots.[38]

BCF Comparison

This element determines how well a plant accumulates heavy metals. It may be possible to determine that two plants are hyperaccumulating species if the plant exhibits a BCF value in its shoots and roots.[39] The two plants grown for 80 days on contaminated soil found the resulting BCF values. When comparing the *Brassica juncea L* plant to the *Rapanus sativus L* plant, the cadmium BCF value of greater accumulation of cadmium content in *Brassica juncea L*. When comparing the *Brassica juncea L* plant to the *Rapanus sativus L* plant, the copper and lead BCF values also accumulate in *Brassica juncea L*. The results make it clear that *Brassica juncea L* plants had better accumulations of the heavy metals cd, cu, and pb than *Rapanus sativus L* plants.[40]

Table 3.9: Heavy metal Bioconcentration in factor in plant body (mg/kg) by *Brassica juncea L* and *rapanus sativus L*.

Heavy Metal	Plant Name	Shoots	Roots
Cd	*Brassica juncea L*	0.27	0.53
	Rapanus sativus L	0.17	0.29
Cu	*Brassica juncea L*	0.10	0.74
	Rapanus sativus L	0.09	0.45
Pb	*Brassica juncea L*	0.22	0.47
	Rapanus sativus L	0.17	0.34
Zn	*Brassica juncea L*	0.09	0.3
Fe	*Rapanus sativus L*	0.17	0.53

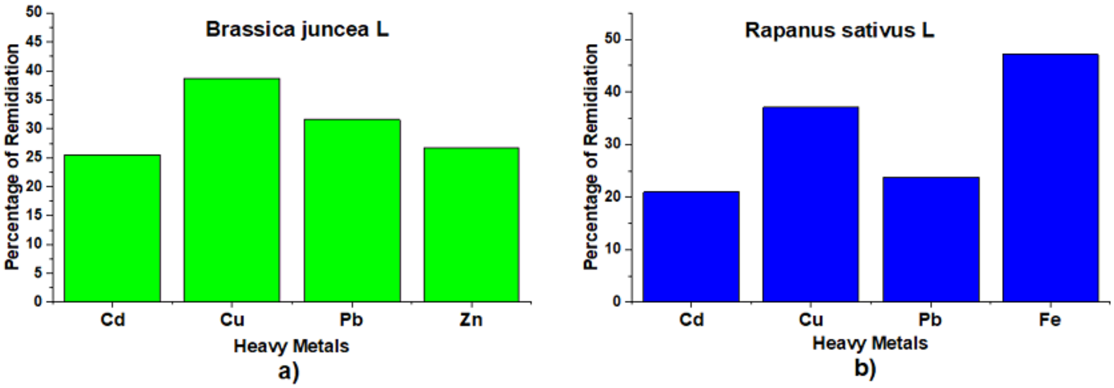

Fig. 3.1: Percentage of Remediation in a) *Brassica juncea L* and b) *Rapanus sativus L*.

The Shoots bio-concentraion of *Brassica juncea L* was higher than the *Rapanus sativus L* plants indicating that *Brassica juncea L* Plant is more efficient in concentration. Only maximum values were tabulated in tableted in table 3.9. All the root's concentration values are higher than the shoot's concentration which means the plant is efficient in transferring some amount of element concentration to the shoots.[41]

Remediation Percentage

The percentage of Cd, Cu, Pb, and Zn was 25.47%, 38.74%, 31.60%, and 26.75% respectively in the *Brassica juncea L* Figure 3.1 a). The maximum percentage of Cd, Cu, Pb, and Fe was 21.01%, 37.08%, 23.77%, and 47.19% respectively in the *Rapanus sativus L* plant Figure 3.1 b. When comparing the *Brassica juncea L* plant to the *Rapanus sativus L* plant, the cadmium, copper, and lead remediation percentage of greater accumulation of cadmium content in *Brassica juncea L*.

Conclusion

Industrial water should not be reused for irrigation to fill up the shortfall in available water, particularly in the current study area. The study's goal was to determine the potential for metal accumulation in plants growing on contaminated land. *Brassica juncea L* and *Rapanus sativus L* were grown for 80 days. *Brassica juncea L* is more effective at removing Cd, Cu, and Pb from the soil than *Rapanus sativus L*. *Brassica juncea L*'s remediation percentage for heavy metals is Cu>Pb>Zn>Cd. At the same time, *Rapanus sativus L*'s is Fe>Cu>Pb>Cd. These two crops are effective at removing heavy metals from low to moderately contaminated soil. The cultivation of these crops may help to remove the heavy metal toxicity in soils and helpful. Growing these plants will help to minimize the heavy metal pollution in the soil and removing the strategy is very costly as well as difficult. The main finding of this research was the bioaccumulation factor, which was higher in *Brassica juncea L* than *Rapanus sativus L* compared with cu, pb, and cd heavy metals. These plants can't transfer 100 % of heavy metal concentration from roots and then transfer to the shoots. The plants can't absorb the soil's heavy metals concentration completely. The condition and soil type should be beneficial to grow plants to degrade metal.

Acknowledgement

The author would like to thank the Environmental Science Department for granting Ph.D. research. The work and analysis were conducted in IOE, Vijnana Bhavana, University of Mysore, Mysuru.

Funding

There is no funding or financial support for this research work.

Conflict of Interest

There was no potential conflict of interest by the author.

Authors' Contribution

All study completed by the author at the University of Mysore 39;s Vijnana Bhavana Department of Environmental Science and IOE with assistance from the corresponding author.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

Ethics Approval Statement

This study did not involve any human or animal participants.

References

1. Rehman, K., *et al*., *Prevalence of exposure of heavy metals and their impact on health consequences.* Journal of cellular biochemistry, 2018. 119(1): p. 157-184.
2. Sarwar, N., *et al*., *Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives.* Chemosphere, 2017. 171: p. 710-721.
3. Duruibe, J.O., M. Ogwuegbu, and J. Egwurugwu, *Heavy metal pollution and human biotoxic effects.* International Journal of physical sciences, 2007. 2(5): p. 112-118.
4. Briffa, J., E. Sinagra, and R. Blundell, *Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon,* 2020. 6(9).
5. Ayangbenro, A.S. and O.O. Babalola, *A new strategy for heavy metal polluted environments: a review of microbial biosorbents.* International journal of environmental research and public health, 2017. 14(1): p. 94.

6. Malik, L.A., *et al*., *Detection and removal of heavy metal ions: a review.* Environmental Chemistry Letters, 2019. 17: p. 1495-1521.
7. Kemp, R., J. Schot, and R. Hoogma, *Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management.* Technology analysis & strategic management, 1998. 10(2): p. 175-198.
8. Naja, G.M. and B. Volesky, *Toxicity and sources of Pb, Cd, Hg, Cr, As, and radionuclides in the environment*, in *Handbook of advanced industrial and hazardous wastes management.* 2017, Crc Press. p. 855-903.
9. Suman, J., *et al*., *Phytoextraction of heavy metals: a promising tool for clean-up of polluted environment?* Frontiers in plant science, 2018. 9: p. 392782.
10. Ghosh, M. and S. Singh, *A review on phytoremediation of heavy metals and utilization of it's by products.* Asian J Energy Environ, 2005. 6(4): p. 18.
11. Susarla, S., V.F. Medina, and S.C. McCutcheon, *Phytoremediation: an ecological solution to organic chemical contamination.* Ecological engineering, 2002. 18(5): p. 647-658.
12. Wong, M.H., *Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils.* Chemosphere, 2003. 50(6): p. 775-780.
13. Wan, X., M. Lei, and T. Chen, *Cost–benefit calculation of phytoremediation technology for heavy-metal-contaminated soil.* Science of the total environment, 2016. 563: p. 796-802.
14. Tian, Y. and F. Deng, *Phytochemistry and biological activity of mustard (Brassica juncea): a review.* Cyta-journal of Food, 2020. 18(1): p. 704-718.
15. Yoon, J., *et al*., *Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site.* Science of the total environment, 2006. 368(2-3): p. 456-464.
16. Qadir, S., *et al*., *Genotypic variation in phytoremediation potential of Brassica juncea cultivars exposed to Cd stress.* Plant Science, 2004. 167(5): p. 1171-1181.
17. Chen, H., *et al*., *Chemical methods and phytoremediation of soil contaminated with heavy metals.* Chemosphere, 2000. 41(1-2): p. 229-234.
18. McGrath, S., F. Zhao, and E. Lombi, *Plant and rhizosphere processes involved in phytoremediation of metal-contaminated soils. Plant and soil,* 2001. 232: p. 207-214.
19. Seth, C.S., P.K. Chaturvedi, and V. Misra, *The role of phytochelatins and antioxidants in tolerance to Cd accumulation in Brassica juncea L*. Ecotoxicology and Environmental Safety, 2008. 71(1): p. 76-85.
20. Sham, T.-T., *et al*., *A review of the phytochemistry and pharmacological activities of raphani semen.* Evidence-based complementary and alternative medicine, 2013. 2013.
21. Turan, M. and A. Esringu, *Phytoremediation based on canola (Brassica napus L.) and Indian mustard (Brassica juncea L.) planted on spiked soil by aliquot amount of Cd, Cu, Pb, and Zn.* Plant Soil and Environment, 2007. 53(1): p. 7.
22. Vardhan, K.H., P.S. Kumar, and R.C. Panda, *A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives.* Journal of Molecular Liquids, 2019. 290: p. 111197.
23. Rai, P.K., *Heavy metal pollution in aquatic ecosystems and its phytoremediation using wetland plants: an ecosustainable approach.* International journal of phytoremediation, 2008. 10(2): p. 133-160.
24. Zhao, F., S. McGrath, and A. Crosland, *Comparison of three wet digestion methods for the determination of plant sulphur by inductively coupled plasma atomic emission spectroscopy (ICP-AES).* Communications in soil science and plant analysis, 1994. 25(3-4): p. 407-418.
25. Mulligan, C., R. Yong, and B. Gibbs, *Remediation technologies for metal-contaminated soils and groundwater: an evaluation.* Engineering geology, 2001. 60(1-4): p. 193-207.
26. Zacchini, M., *et al*., *Metal tolerance, accumulation and translocation in poplar and willow clones treated with cadmium in hydroponics.* Water, Air, and Soil Pollution, 2009. 197: p. 23-34.
27. Liu, Z., *et al*., *A review on phytoremediation of mercury contaminated soils.* Journal of Hazardous Materials, 2020. 400: p. 123138.
28. Nagajyoti, P.C., K.D. Lee, and T. Sreekanth,

Heavy metals, occurrence and toxicity for plants: a review. Environmental chemistry letters, 2010. 8: p. 199-216.

29. Clemente, R., D.J. Walker, and M.P. Bernal, *Uptake of heavy metals and As by Brassica juncea grown in a contaminated soil in Aznalcóllar (Spain)*: the effect of soil amendments. Environmental pollution, 2005. 138(1): p. 46-58.
30. Qiu, Q., *et al*., *Effects of phosphorus supplied in soil on subcellular distribution and chemical forms of cadmium in two Chinese flowering cabbage (Brassica parachinensis L.) cultivars differing in cadmium accumulation.* Food and Chemical Toxicology, 2011. 49(9): p. 2260-2267.
31. Tangahu, B.V., *et al*., *A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation.* International journal of chemical engineering, 2011. 2011.
32. Hladun, K.R., D.R. Parker, and J.T. Trumble, *Cadmium, copper, and lead accumulation and bioconcentration in the vegetative and reproductive organs of Raphanus sativus: implications for plant performance and pollination.* Journal of Chemical Ecology, 2015. 41: p. 386-395.
33. Khan, S., *et al*., *Effects of Cd and Pb on soil microbial community structure and activities.* Environmental Science and Pollution Research, 2010. 17: p. 288-296.
34. Malar, S., *et al*., *Lead heavy metal toxicity induced changes on growth and antioxidative enzymes level in water hyacinths [Eichhornia crassipes (Mart.)].* Botanical studies, 2016. 55: p. 1-11.
35. Marchiol, L., *et al*., *Phytoextraction of heavy metals by canola (Brassica napus) and radish (Raphanus sativus) grown on multicontaminated soil.* Environmental pollution, 2004. 132(1): p. 21-27.
36. Bauddh, K. and R.P. Singh, *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, 2012. 85: p. 13-22.
37. Su, C. and R.W. Puls, *Nitrate reduction by zerovalent iron: effects of formate, oxalate, citrate, chloride, sulfate, borate, and phosphate.* Environmental science & technology, 2004. 38(9): p. 2715-2720.
38. Jayakumar, K., C.A. Jaleel, and P. Vijayarengan, *Changes in growth, biochemical constituents, and antioxidant potentials in radish (Raphanus sativus L.) under cobalt stress.* Turkish Journal of Biology, 2007. 31(3): p. 127-136.
39. Malik, R.N., S.Z. Husain, and I. Nazir, *Heavy metal contamination and accumulation in soil and wild plant species from industrial area of Islamabad, Pakistan.* Pak J Bot, 2010. 42(1): p. 291-301.
40. Mourato, M.P., *et al*., *Effect of heavy metals in plants of the genus Brassica.* International journal of molecular sciences, 2015. 16(8): p. 17975-17998.
41. Uraguchi, S., *et al*., *Root-to-shoot Cd translocation via the xylem is the major process determining shoot and grain cadmium accumulation in rice.* Journal of experimental botany, 2009. 60(9): p. 2677-2688.