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Original Research Article

Phytoremediation of Heavy Metals Contaminated Soils

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A B S T R A C T

Human activities such as mining, transport, agriculture, waste disposal and military actions frequently release these inorganic pollutants in high and toxic concentrations. Heavy metal pollution causes potential ecological risk. Metals like Cadmium (Cd), Lead (Pb), Zinc (Zn) and Chromium (Cr) when present in high concentrations in soil exert potential toxic effects on overall growth and metabolism of plants and bioaccumulation of such toxic metals in the plant poses a risk to human and animal health. Phytoremediation is a technology that exploits a plant's ability to remove contaminants from the environment or render toxic compounds harmless. Phytoremediation has been attracting attention as a rapidly developing, inexpensive plant-based remediation technology. This technology exploits the natural ability of a green plant to accumulate a variety of chemical elements and transport them from the substrate to above ground parts. At sites contaminated with metals, plants can be used to either stabilize or remove the metals from the soil and groundwater through three mechanisms, Phytoextraction, Phytomining, Rhizofiltration, and Phytostabilization. In the present study a pot experiment was conducted using *Acalypha indica*, *Abutilon indicum* and *Physalis minima* weed plant species for their ability to absorb the heavy metals (Lead, Nickel, Cadmium and Chromium) from the contaminated soil. The final results shows that *A. indica* was good accumulator of lead, nickel and chromium, *Abutilon indicum* was good accumulator of chromium and *Physalis minima* was good accumulator of lead and chromium. Finally these weed plant species was recommended for the remediation of specific heavy metal contaminated soils.

Keywords

Heavy metal, Pollution, Phytore-mediation

Introduction

Phytoremediation involves diverse use of plants for treatment of metal contaminated soils, sediments, water and air. It is best applied at sites with shallow contamination of metals. Plants possess some characteristic features which enable them to absorb heavy metals and other minerals which are essential for their growth and development. The heavy metals include iron (Fe), lead (Pb), zinc (Zn), nickel (Ni), cadmium (Cd) manganese (Mn), chromium (Cr), copper (Cu), molybdenum (Mo), etc. Plants accumulate toxic metals which may not have any biological function, these include: silver (Ag), cadmium (Cd), chromium (Cr), cobalt (Co), mercury (Hg), lead (Pb) selenium (Se), etc. Phytoremediation, the use of plants to extract, sequester or detoxify pollutants, has been reported to be an effective, non-intrusive, inexpensive, aesthetically pleasing, socially accepted technology to remediate polluted soils (Alkorta and Garbisu, 2001; Weber *et al.*, 2001; Garbisu *et al.*, 2002). The basic idea that plants can be used for environmental remediation is quite old. The aquatic or semi-aquatic vascular plants also used for phytoremediation such as, water hyacinth *(Eichhornia crassipes)*, pennyworth *(Hydrocotyle umbellata)*, duckweed *(Lemna minor)*, and water velvet *(Azolla pinnata*), can take up Pb, Cu, Cd, Fe and Hg from contaminated media existed for a long time (Chen *et al.*, 2003; Fitz and Wenzel, 2002; Karenlampi *et al.*, 2000; Lanza and Flathman, 2001; Lasat, 2002; Madrid *et al.*, 2003; McGrath and Zhao, 2003; McGrath *et al.*, 2001; Meagher, 2000; Palmer *et al.*, 2001; Prasad, 2003).

Application of phytoremediation for the cleanup of industrial waste dump sites contaminated with toxic metals is another important area that has blossomed in recent years. Certain plants translocate metals at high concentrations from their surroundings and accumulate them in their above ground parts. Thus, they can be harvested and removed from the site (Prasad *et al.*, 2001). During phytoextraction heavy metal contaminants are taken up from the soil by plant roots and translocated to shoots. A plant for this purpose is expected to (i) be heavy-metal tolerant; (ii) grow rapidly with a high biomass yield per hectare; (iii) have high metal accumulating ability in the shoot; (iv) have a profuse root system and (v) a high bioaccumulation factor (Scragg, 2006; Jadia and Fulekar, 2008).

Reeves and Baker, (2000) reported that 45 plant families are known to contain metal-accumulating species. Such plants can accumulate As, Cu, Co, Cd, Mn, Ni, Se, Pb or Zn up to levels that are 100 to 1,000 times of those normally accumulated by plants grown under the same conditions (Baker *et al.,* 2000; Brooks, 1998). Over 500 plant species comprising of 101 families have been reported, including members of the Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Violaceae and Euphobiaceae. Metal hyperaccumulation occurs in approximately 0.2% of all angiosperms and is particularly well represented in the Brassicaceae (Kramar, 2010). Wei *et al.,* (2004) have reported that *S. nigrum* as hyper-accumulator of Cd. Based on results the plant species were found to have the potential for Phytostabilization and Phytoextraction. *B. reptans*, *S. nigrum P. oleracea* and *X. stromarium* had very high BCF values and could be useful for Phytostabilization of soils contaminated with Cu and Pb. *Canna indica* effectively translocate lead and chromium to aerial parts while the roots retain high quantities of cadmium, nickel and zinc. The total absorption was high for zinc followed by chromium (Subhashini *et al.,* 2014).

Materials and Methods

The experimental plants seedlings were grown in pots filled with garden soil. The seedlings were collected from the uncontaminated soils. All the selected seedlings were of uniform size and free of any disease symptoms. The heavy metals selected for the study was lead, nickel, cadmium and chromium, the metal uptake was estimated in root, stem and leaves for every 20 days for a total period of 60 days. In addition a control set of experimental pots was also maintained. The heavy metal solutions of 5mg/L was prepared from the stock and administered to the plants and care was taken to avoid leaching of water from the pots. The metal uptake was estimated once in every 20 days up to 60 days (2 months). The sample plants were removed from the pots and washed under tap water and then with distilled water. The collected plants were air dried, then placed in a dehydrator for 2-3 days and then oven dried for four hours at 100 ºc. The dried samples of the plant were powdered and stored in polyethylene bags. The powdered samples were subjected to acid digestion.1gm of the powdered plant material were weighed in separate digestion flasks and digested with HNO_3 and HCl in the ratio of 3:1. The digestion on hot plate at 110ºc for 3-4 hours or continued till a clean solution was obtained. After filtering the filtrate was analyzed for the metal contents in AAS.

The metal concentration, transfer and accumulation from soil to roots and shoots was evaluated in terms of Bioconcentration Factor (BCF) and Translocation Factor (TF). The plants showing high BCF and TF values (greater than one) are suitable for phytoextraction. While the plants showing TF value less than one can be used for phytostabilization.

Bioconcentration Factor (BCF)

Metal concentrations in plants vary with plant species. The concentration, transfer and accumulation of metals from soil to roots and shoots was evaluated in terms of Biological Concentration Factor (BCF), Translocation Factor (TF). Biological Concentration Factor (BCF) was calculated as metal concentration ratio of plant roots to soil (Yoon *et al.,* 2006).

The Bioconcentration Factor (BCF) of metals was used to determine the quantity of heavy metal absorbed by the plant from the soil. This is an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the soil (Ghosh and Singh, 2005).

Translocation Factor (TF)

Translocation Factor (TF) was described as ratio of heavy metals in plant shoot to that in plant root (Li *et al.,* 2007). To evaluate the potential of this species for Phytoextraction, the Translocation Factor (TF) was calculated. This ratio is an indication of the ability of the plant to translocate metals from the roots to the aerial parts of the plant. Metals that are accumulated by plants and largely stored in the roots of plants are indicated by TF values <1, with values greater indicating translocation to the aerial part of the plant (Yoon *et al.,* 2006).

Results and Discussion

Accumulation of heavy metals in *Acalypha indica*

Accumulation of lead (mg/kg) in *Acalypha indica*

Acalypha indica was grown in pots and each set was administered with one heavy metal for sixty days. The heavy metals were gradually absorbed by the roots and translocated to aerial parts of the plant i.e. stem and leaves. The rate of translocation of nutrients and non-nutrients absorbed by the roots are transferred to the above ground plant parts at different rates.

The *Acalypha indica* was tested for its capacity to absorb heavy metals viz. lead, nickel, zinc, cadmium and chromium for 60 days. The accumulation in the plant was measured at a 20 day interval. A total of 44.85 mg/kg lead was present in the total plant in control set of which the roots contained 21.16±0.16 (0.05level) mg/kg while the stem and leaves contained 15.83 and 7.86 mg/kg of lead, respectively. Approximately 47% of lead is available for the plant for absorption and the remaining is translocated to stem and leaves on regular administration of aqueous solution of lead. The concentrations increased by 20^{th} day to 49.47 and reached highest value of 98.14 mg/kg by the 60^{th} day.

The concentration of lead in the root by 20^{th} day was 23.89 mg/kg. This was a marginal increase of accumulation in root i.e. 2.3 mg/kg during the first 20 days. The accumulation in the stem during the first 20 days was 9.2 mg/kg and that in leaves was 11.68±0.18.

This reveals that by 20^{th} day the lead that has accumulated in the roots was translocated to stem and leaves in a slow manner. By 40^{th} day the total accumulation was 54.62 of which highest accumulation was observed in stem (21.26±0.16) and this was higher by at least 5 mg/kg compared to leaves and root.

By 60^{th} day the root has shown highest accumulation followed by leaves and stem in that order. The total accumulation also increased considerably.

Accumulation of nickel (mg/kg) in *Acalypha indica*

Acalypha indica absorbed 22.9 mg/kg of nickel by 20^{th} day. Much of the nickel has remained in the root (11.17 mg/kg). Approximately 50% of the absorbed nickel was translocated to stem and leaves. The accumulation in the stem has increased by three fold in the stem by 40^{th} day and then the accumulation was marginal till 60^{th} day. On the whole the accumulation of lead was low in leaves throughout. All the plant parts have shown a marginal increase of accumulation of nickel from 40^{th} day to 60^{th} day. The translocation of nickel was effective from roots to stem and low from stem to leaves.

Accumulation of cadmium (mg/kg) in *Acalypha indica*

Cadmium is a non-essential nutrient but absorbed through roots along with the other nutrients. The observations in the present study showed that the cadmium absorbed through the roots is not translocated effectively to the stem and roots. The differences in the accumulation of cadmium in the roots stem and leaves reveal the same. The concentrations of cadmium measured on 20^{th}, 40^{th} and 60^{th} days in leaves and stem showed more or less uniform or very slow increase of concentrations. However, the concentration of cadmium increased substantially from 40^{th} day to 60^{th} day (from 5.54 to 17.59 mg/kg) in the root and low concentrations in stem and leaves during the same period affirm that the absorbed cadmium remained only in the roots and not translocated to the above ground plant parts.

Accumulation of chromium (mg/kg) in *Acalypha indica*

Acalypha indica showed a differential accumulation of chromium in different plant parts. The accumulation of chromium was maximum during the first 20 days and then stabilised. During the first 20 days the absorption was found to be high when compared to accumulations by 40^{th} and 60^{th} days. Only leaves have shown substantial increase of accumulation from 20^{th} day to 40^{th} day, while a marginal increase was observed in stem and roots. The total accumulation of chromium in roots was higher by 50% compared to stem and leaves. The higher concentrations of chromium in the roots reveal that the chromium absorbed through the root system was partially translocated to the stem and leaves. The accumulation of chromium in the below ground biomass was much higher than those of the above ground plant parts. The order of accumulation of chromium in the plant parts is roots>stem>leaves. The quantity of absorption was appreciably higher than the cadmium in all the plant parts of the *Acalypha indica*.

Accumulation of heavy metals in *Abutilon indicum*

Accumulation of lead (mg/kg) in *Abutilon indicum*

The plant parts were analysed to estimate the accumulation of lead by 20th, 40th and 60th days. The accumulation of lead was lowest in the roots and highest in the stem. The lead that is absorbed from the soil by the roots is translocated to the above ground stem and leaves.

The translocation of lead from roots to stem was higher compared to that of the stem to leaves. Most of the lead that is translocated to stem remained in the stem and gradually accumulated to the tune of 17.21 mg/kg. The accumulation was consistent throughout in the root system.

The accumulation of lead showed a sudden increase by 20th day in the stem from 16.81 to 31.24 mg/kg and from then the accumulation was though marginal, it was consistent. Lead accumulation in the leaves also showed similar trend but with less concentration.

Accumulation of nickel (mg/kg) in *Abutilon indicum*

The total accumulation of nickel in the roots was lowest among the plant parts (6.9 mg/kg) during the whole experimental period. Out of the total nickel accumulated by 60th day (30.44 mg/kg) only 6.90 mg/kg is accumulated in the roots while the accumulation in leaves and stem was more or less equal (11.57 and 11.97 mg/kg, respectively). The results reveal that the nickel that is absorbed from the soil is translocated to roots and in turn the roots have translocated to the stem and then to leaves. The leaves and stem of the *Abutilon indicum* have the same potential to absorb nickel.

Accumulation of cadmium (mg/kg) in *Abutilon indicum*

Cadmium metal is not an essential element for the plant. But it enters in to the plant body along with other nutrients through the root system. The highest concentration of cadmium was recorded in the roots by 60th day showing a total accumulation of 14.08 mg/kg (55.6% of the total accumulation). Further it was observed that the maximum accumulation in roots took place between 40th and 60th day. From the beginning of the experiment, there was a consistent increase of the concentration of cadmium in leaves and stem. However, the total accumulation of cadmium in leaves and stem was much lower than in roots. The cadmium translocation was very poor from roots to stem and leaves in *Abutilon indicum.*

Accumulation of chromium (mg/kg) in *Abutilon indicum*

Abutilon indicum showed a tendency of high absorption of chromium by the root system. The roots have accumulated 33.18 mg/kg (63.7%) of chromium during the experimental period and the accumulation in leaves and stem was low and consistent from 20th day up to 60th day. However, chromium was actively absorbed by the stem and leaves during the first 20 days of the experimental period. The chromium was not translocated to above ground plant parts and hence only 36% of the chromium was found in leaves and stem.

Accumulation of heavy metals in *Physalis minima*

Accumulation of lead (mg/kg) in *Physalis minima*

Highest concentration of lead was recorded in the roots followed by leaves and stem. The quantity of lead absorbed by the roots of *Physalis minima* was translocated to stem and then to leaves.

The lowest concentration of lead in the stem was because the lead that received from the roots was translocated to leaves leaving only marginal quantity in the stem. The absorption of lead was highest in the leaves between 40th day and 60th day. The observations reveal that much of the lead absorbed was retained in the roots.

Accumulation of nickel (mg/kg) in *Physalis minima*

The capacity of absorbing nickel by *Physalis minima* was found to be very less. Throughout the experimental period, the absorption of nickel was consistent except between 20th and 40th day in leaves. The total accumulation was very high in leaves compared to roots and stem. About 63% of the nickel accumulated in the leaves only.

Accumulation of cadmium (mg/kg) in *Physalis minima*

The availability of cadmium is less in nature. Cadmium is not an essential nutrient for the plants. The absorption of cadmium was slow and the accumulation was also less in the aerial parts of the *Physalis minima*. Though the concentrations of cadmium were less but the absorption gradually increased during the experimental period except between 40th and 60th day in roots. Sixty eight percent of the total cadmium accumulated in the roots of while the accumulation in leaves and stem of *Physalis minima* was very less.

Accumulation of chromium (mg/kg) in *Physalis minima*

Physalis minima have good potential of removing chromium through its roots. There was a steady increase of concentrations in the roots during the experimental period, while in leaves and stems there was only marginal increase in leaves and stems during 40-60 days. There was also a marked variation in the accumulation in different parts of the plant.

The roots system is proved to be a good absorber of chromium with 67% retained in roots. Only 5.43 mg/kg of chromium accumulated in stem during the experimental period while the accumulation was 9.01 mg/kg in the leaves. The accumulation of chromium in *Physalis minima* was good compared to cadmium among heavy metals and among other plant species also.

Acalypha indica

The control set of experiments showed varied levels of metals in leaves, stem and roots of *Acalypha indica*. The absorption of metals lead, nickel, cadmium and chromium was compared in leaves, stem and roots. The leaves of *Acalypha indica* showed highest concentration of lead followed by chromium, cadmium and nickel in that order.

The order of total concentration accumulated in the stem was nickel followed by chromium, lead and cadmium. Nickel accumulated in highest (19.15 mg/kg) in stem and cadmium accumulated in lowest (0.91 mg/kg) concentration in the stem in 60 days of experimental period in *Acalypha indica.* Lead was recorded in highest quantities (38.4 mg/kg) followed by chromium, nickel and cadmium in that order. Whereas the total accumulation of metals in roots of *Acalypha indica* followed a different way. In case cadmium accumulation appears to be very high in roots but the translocation of the metal s decreased from day 20-40 to 40-60.

Abutilon indicum

The quantities of metals absorbed by *Abutilon indicum* are moderate with respect to different parts and total accumulations. Cadmium and chromium were accumulated in substantially high quantities in roots (14.07 mg/kg, 33.18 mg/kg respectively).

This revealed that the cadmium and chromium remained in the roots with being translocated to the above ground plant parts. A completely inverse picture was witnessed in case of nickel and lead.

In cases of lead, nickel, cadmium and chromium the total accumulation was more or less uniform in leaves and stem. Cadmium concentrations were lowest (5.75mg/kg in leaves and 5.49 mg/kg in stem).

These differences of accumulations are attributed to the plant requirement. Cadmium and chromium enter the plant body along with the nutrients though they do not have any defined metabolic activity.

Physalis minima

The total accumulation of metals in the plant varied from a lowest of 18.81 mg/kg (nickel) to a highest of 91.16mg/kg (lead). The leaves accumulated lead in highest quantities followed by nickel (11.92 mg/kg), chromium (9.0 mg/kg) and cadmium (6.16 mg/kg) in that order. It is evident that the accumulations of all the metals in leaves was higher than stem which was unique for *Physalis minima* and was not observed in any other plant under study. The difference of accumulation between stem and leaves of chromium and cadmium was less than 50% whereas it was a little about 5 times higher in nickel and lead.

The translocation of nickel was effective from roots to leaves was compared to other metals. The roots of *Physalis minima* recorded highest accumulation of metals except nickel which accumulated in higher quantities in leaves.

Stem of *Physalis minima* is not a good accumulator it showed accumulation levels only after roots and leaves.

Phytoremediation term applied for the use of plants for remediation of organic and inorganic contaminant of soils. Phytoremediation, the use of plants to extract, sequester, and detoxify pollutants, has been reported to be an effective, non-intrusive, inexpensive, aesthetically pleasing, socially accepted technology to remediate polluted soils.

The present study identifies that *Acalypha indica* was a good accumulator of lead, nickel and chromium. The plant species can be recommended for phytoextraction of lead, nickel and chromium contaminated soils. *Abutilon indicum* was good accumulator of chromium.

The species can be recommended for the phytoextraction of chromium contaminated soils. *Physalis minima* were good accumulator of lead. The species can be recommended for the phytoextraction of the lead contaminated soils.

Table.1 Accumulation of lead (mg/kg biomass) in different plant parts of *Acalypha indica* during the experimental period

Plant part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	7.86±0.09	11.68±0.18	16.83±0.11	30.49±0.12	22.63
Stem	15.83±0.11	9.2±0.13	21.26±0.16	26.5±0.18	10.68
Root	21.16±0.16	23.89±0.19	16.53±0.17	41.14±0.16	19.98
Total Accumulation	44.85	49.47	54.62	98.14	53.29

Table.2 Accumulation of nickel (mg/kg biomass) in different plant parts of *Acalypha indica* during the experimental period

Plant part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	2.27±0.44	5.7±0.19	7.77±0.11	9.83±0.13	7.57
Stem	1.69±0.48	6±0.13	19.78±0.16	20.85±0.18	19.15
Root	2.75±0.16	11.17±0.17	24.88±0.18	26.1±0.16	17.35
Total Accumulation	6.71	22.9	52.43	56.78	50.07

Table.3 Accumulation of cadmium (mg/kg biomass) in different plant parts of *Acalypha indica* during the experimental period

Plant Part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	0.38±0.13	2.07±0.19	2.95±0.11	3.65±0.13	3.27
Stem	1.04±0.11	1.65±0.12	1.68±0.15	1.95±0.17	0.91
Root	1.93±0.16	5.52±0.18	5.54±0.18	17.59±0.16	15.65
Total Accumulation	3.35	9.24	10.17	23.19	19.83

Table.4 Accumulation of chromium (mg/kg biomass) in different plant parts of *Acalypha indica* during the experimental period

Plant Part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	6.31±0.12	11.72±0.19	25.44±0.11	27.44±0.13	21.13
Stem	10.88±0.11	24.4±0.13	27.01±0.16	28.22±0.18	17.33
Root	9.45±0.16	53.34±0.18	53.33±0.18	53.55±0.19	44.1
Total Accumulation	26.64	89.46	105.78	109.21	82.56

Table.5 Accumulation of lead (mg/kg biomass) in different plant parts of *Abutilon indicum* during the experimental period

Plant part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	5.69±0.32	12.84±0.08	15.73±0.12	17.76±0.16	12.07
Stem	16.81±0.13	31.24±0.19	32.56±0.19	34.02±0.08	17.21
Root	28.78±0.08	29.63±0.17	29.82±0.1	30.03±0.05	1.25
Total Accumulation	51.28	73.72	78.11	81.81	30.53

Table.6 Accumulation of nickel (mg/kg biomass) in different plant parts of *Abutilon indicum* during the experimental period

Plant part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	1.28±0.50	5.08±0.08	10.85±0.13	12.85±0.19	11.57
Stem	2.6±0.13	7.07±0.16	11.71±0.18	14.57±0.05	11.97
Root	9.7±0.08	9.88±0.07	10.51±0.06	16.6±0.03	6.9
Total accumulation	13.59	22.03	33.08	44.02	30.44

Table.7 Accumulation of cadmium (mg/kg biomass) in different plant parts of *Abutilon indicum* during the experimental period

Plant Part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	0.21±0.09	1.04±0.08	2.54±0.13	5.96±0.19	5.75
Stem	0.47±0.13	3.49±0.16	3.49±0.15	5.96±0.08	5.49
Root	1.44±0.08	3.81±0.07	3.87±0.06	15.52±0.04	14.08
Total Accumulation	2.12	8.34	9.9	27.44	25.31

Table.8 Accumulation of chromium (mg/kg biomass) in different plant parts of *Abutilon indicum* during the experimental period

Plant part	Control	20th day	40th day	60th day	Total accumulation
Leaf	3.75±0.19	11.32±0.08	12.26±0.13	12.55±0.19	8.8
Stem	7.87±0.13	17.79±0.16	17.82±0.19	17.95±0.08	10.09
Root	11.78±0.08	12.57±0.04	27.76±0.07	44.96±0.03	33.18
Total accumulation	23.4	41.68	57.84	75.46	52.07

Table.9 Accumulation of lead (mg/kg biomass) in different plant parts of *Physalis minima* during the experimental period

Plant Part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	53.89±0.41	53.89±0.13	52.35±0.08	76.02±0.17	22.13
Stem	34.5±0.07	43.04±0.15	47.26±0.19	38.31±0.19	3.81
Root	32.94±0.02	96.32±0.13	97.72±0.17	98.61±0.15	65.67
Total Accumulation	121.34	193.25	197.34	212.95	91.61

Table.10 Accumulation of nickel (mg/kg biomass) in different plant parts of *Physalis minima* during the experimental period

Plant part	Control	20th day	40th day	60th day	Total Accumulation
Leaf	2.73±0.45	5.38±0.13	12.33±0.08	14.65±0.17	11.92
Stem	12.02±0.08	12.16±0.15	13.52±0.19	13.9±0.19	1.88
Root	9.9±0.01	12.15±0.12	12.17±0.18	14.91±0.16	5.01
Total accumulation	24.65	29.7	38.02	43.46	18.81

Table.11 Accumulation of cadmium (mg/kg biomass) in different plant parts of *Physalis minima* during the experimental period

Plant Part	Control	20^{th} day	40^{th} day	60^{th} day	Total accumulation
Leaf	0.22±0.15	0.69±0.13	40.16±0.08	6.38±0.19	6.16
Stem	0.3±0.08	1.14±0.15	2.1±0.17	3.35±0.17	3.05
Root	0.39±0.01	6.26±0.12	6.73±0.19	20.29±0.15	19.91
Total Accumulation	0.91	8.09	48.99	30.02	29.12

Table.12 Accumulation of chromium (mg/kg biomass) in *Physalis minima* during the experimental period

Plant part	Control	20th day	40th day	60^{th} day	Total accumulation
Leaf	4.59±0.15	5.83±0.13	12.13±0.08	13.6±0.17	9.01
Stem	14.12±0.08	14.13±0.19	19.18±0.18	19.55±0.19	5.43
Root	19.43±0.07	24.36±0.13	42.7±0.19	49.12±0.18	29.69
Total accumulation	38.14	44.32	74.01	82.27	44.12

References

Alkorta, I., and Garbisu, C. 2001. Phytoremediation of organic contaminants. *Bio resource Technol*., Pp. 273–276.

Chen, Y.X., Y.F. He, Yang, Y, Yu. Y. L, Zheng. S. J, Tian. G. M., Luo, Y. M. and Wong, M. H. 2003. Effect of cadmium on nodulation and N2-fixation of soybean in contaminated soils. *Chemosphere*., Pp. 781–787.

Fitz, W.J., and Wenzel, W.W. 2002. Arsenic transformations in the soil–rhizosphere–plant system fundamentals and potential application to phytoremediation. *J. Biotechnology*., Pp. 259-278.

Garbisu, C., Hernandez Allica, J, Barrutia, O, Alkorta, I. and Becerril, J.M. 2002. Phytoremediation: A technology using green plants to remove contaminants from polluted areas. *Rev. Environ. Health*., Pp. 75–90.

Ghosh, M., and Singh, S. P. 2005. A review on phytoremediation of heavy metals and utilization of its by-products. *Applied Ecology and Environmental Research*., Pp. 1-18.

Jadia, C.D., and Fulekar, H. 2008. Phytotoxicity and remediation of heavy metals by fibrous root grass (sorghum). *J. Appl. Biosciences*., Pp. 491 – 499.

Karenlampi, S., Schat, H, Vangronsveld, J, Verkleij, J.A.C, Mergeay, M. and Tervahauta, A.I. 2000. Genetic engineering in the improvement of plants for phytoremediation of metal polluted soils. *Environ. Pollut*., Pp. 25-231.

Kramer., U. 2010. Metal hyperaccumulation in plants. *Annu. Rev. Plant Biol*., Pp. 517–534.

Lanza, G.R., and Flathman, P.E. 2001. Phytoremediation technologies: Hazardous and Radioactive waste treatment technologies Handbook. Chang Ho. Oh, (eds), CRC Press, Baca Raton. FL. USA. 5.6-1 to 5.6-13.

Lasat., M. M. 2002. Phytoextraction of Toxic Metals: A Review of Biological Mechanisms. *J. Environ. Qual.*, Pp.31.

Li, M.S., Luo, Y.P. and Su, Z.Y. 2007. Heavy metal concentrations in soils and plant accumulation in a restored manganese mine land in Guangxi, South China. *Environmental Pollution*., Pp. 168-175.

Madrid, F., Liphadzi, M. S. and Kirkham, M. B. 2003. Heavy metal displacement in chelate-irrigated soil during phytoremediation. *Journal of Hydrology*. Pp. 107-119.

McGrath, S.P., and Zhao, F.J. 2003. Phytoextraction of metals and metalloids from contaminated soils. *Curr. Opin. Biotechnol*., Pp. 277–282.

McGrath, S.P., Zhao, F.J. and Lombi, E. 2001. Plant and rhizosphere process involved in phytoremediation of metal-contaminated soils. *Plant Soil*., Pp.207–214.

Meagher, R.B. 2000. Phytoremediation of toxic elemental and organic pollutants. *Current Opinion in Plant Biology*. Pp. 153-162.

Palmer, E.F., Warwick, F. and Keller, W. 2001. Brassicaceae (Cruciferae) family, plant biotechnology and phytoremediation. *International Journal of Phytoremediation*. Pp. 245-287.

Prasad, M.N.V. 2003. Metal hyperaccumulators in plants-Biodiversity prospecting for phytoremediation technology. *Electronic J. Biotech*., Pp. 276-372.

Prasad, M.N.V., Greger, M. and Landberg, T. 2001. *Acacia nilotica* L. bark removes toxic metals from solution: Corroboration from toxicity bioassay using *Salix viminalis* L. in hydroponic system. *International Journal of Phytoremediation*. Pp. 289-300.

Scragg, A. 2006. Environmental Biotechnology (2nd Edition), Oxford University Press, Oxford.

Subhashini, V., and Swamy, A.V.V.S. 2014. Phytoremediation of Metal (Pb, Ni, Zn, Cd and Cr) contaminated soils using *Canna indica*, *Current World Environment.* Pp. 780-784

Weber, O., Scholz, R.W., Buhlmann, R. and Grasmuck, D. 2001. Risk perception of heavy metal soil contamination and attitudes toward decontamination strategies. *Risk Analysis* Pp. 967–977.

Wei, S. H., Zhou, Q. X., Wang, X., Cao, W.,. Ren, L. P. and Song, Y. F. 2004. Potential of weed species applied to remediation of soils contaminated with heavy metals. *J. Environ. Sc*i,. Pp. 868-73.

Yoon, J., Cao, X., Zhou, Q. and Ma, L.Q. 2006. Accumulation of Pb, Cu, and Zn in native Plants growing on a contaminated Florida site. *Sci. Total Environ*., Pp. 456- 464.