Research Article

Assessing potential of weeds (*Acalypha indica* and *Amaranthus viridis*) in phytoremediating soil contaminated with heavy metals-rich effluent

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Abstract
This study presents the phytoremediation potential of two species *Acalypha indica* and *Amaranthus viridis* grown over soil spiked with two doses of paint industry effluent (i.e., 50% and 100%) containing four heavy metals Pb, Zn, Cr and Cu. The species were allowed to grow in the effluent spiked soil for a period of 45 days in which they were harvested and given for heavy metal analysis. The species were checked for the accumulation of Pb, Zn, Cr and Cu in its root, shoot and the residual in the soil. The accumulation across all the treatments was highly significant ($P < 0.05$) in case of both the species. In 50% treatment, *A. indica* accumulated 15.33 mg/kg and 5.14 mg/kg in the root and shoot, respectively, whereas in 100% treatment, it accumulated 58.52 mg/kg and 10.39 mg/kg Zn in root and shoot, respectively. *Amaranthus viridis* accumulated 2.81 mg/kg and 15.83 mg/kg Zn in the root and shoot exposed to 50% treatment and 27.08 mg/kg and 41.08 mg/kg Zn in root and shoot exposed to 100% treatment; it also accumulated 5.54 mg/kg and 12.0 mg/kg Cr in the root and the shoot zones, respectively, pertaining to 50% treatment and 17.84 mg/kg and 21.45 mg/kg in 100% treatment. Hence, the TF value obtained in the case of *A. indica* was > 1 only for Cr, while it was < 1 for Pb, Zn and Cu, whereas in the case of *A. viridis*, it was > 1 for Zn and Cr and < 1 for Pb and Cu.

Keywords Heavy metals · Phytoextraction · Translocation factor · Bioconcentration factor

1 Introduction

Heavy metals are the most toxic pollutants. They cause irreversible harm and deleterious effects to the environment. Heavy metals are non-biodegradable and thus tend to bioaccumulate in the tissues of humans and several other organisms [23]. It occurs naturally as constituents of the parental rocks and soil as well as the oceanic sediments. Their main entry into the environment is via weathering of the rocks as well as volcanic activities [42]. The other main sources of heavy metal contamination in the environment are anthropogenic activities [64]. The effluents from the industrial units and factories, waste water discharge, sewage discharge, agricultural run-off, etc., are the major anthropogenic sources of soil, surface as well as ground water contamination [5]. Heavy metals once entering the groundwater via soil make the drinking water unfit for consumption as well as irrigation activities [39]. The overall global production of toxic metals has escalated since 1850's [26]. The developing nations have been adversely affected by these toxicants due to overpopulation, resource limitations, improper disposal and lack of awareness. Studies revealed the concentrations of current heavy metal deposits to be almost 10–30 times

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higher than the background levels especially noted during 1970s [41]. The recent cases of heavy metal polluted soil have erupted abruptly owing to the improper management of industrial effluents [45]. The concentration of heavy metals in soil is a matter of concern as it can have multiple fates which result in adverse effects on living beings [6]. Hence, to clean up the contaminated soil and water, several technologies such as soil washing, vitrification and solidification have been practiced since years [8]. All these technologies are efficient, but consume a lot of energy and economy in the clean-up process [62]. Phytoremediation is one of the technologies which exploit plants to remediate the contaminated medium such as soil, water and air. It greatly contributes to eco-restoration of contaminated sites polluted with heavy metals, organic compounds as well as some of the radionuclides (Chen et al. [13]; Mahar et al. [34]). It is gaining much importance due to its economic feasibility [14]. Certain plants have the innate detoxifying mechanism to convert organic compounds to innocuous state, while the species of Brassicaceae family tend to volatilize organic form of Hg to inorganic form, liberating it further into the atmosphere [2]. Plants like *Helianthus annuus* extract high amount of Al; *Brassica juncea* extracts Zn and Ni, while *Paspalum vaginatum* extracted Cd, Cu and Zn into its aboveground biomass [18, 61]. Every plant has its own innate capacity of thriving in the contaminated medium and remediating it which depends on its individual pollution tolerance mechanism [53]. Phytoremediation studies conducted till date have identified more than 400 species as hyperaccumulators [1, 55], but most of them are edible ones which pose a trivial question of trespassing several levels of the food chain, while some efficient ornamental species identified for the purpose have lower biomass, making it unfavorable for phytoremediation [27, 51]. Most of the literature available has recorded edible plants with their successful traits in extracting heavy metals [12, 28]. It is the need of the current hour to explore other species such as weeds popularly termed as unwanted plants. Weedy plants are highly suitable for the purpose of phytoremediation as they are naturally resistant to pollution and due to their unsuitability as fodder [21].

Venkatachalam et al. [59] studied *Acalypha indica* to be a Pb accumulator with a defense mechanism to detoxify the Pb-induced toxic effect on it, whereas a very high accumulation of Cd, Cu and Zn was noted in *Amaranthus viridis* growing locally over heavily polluted soils [9]. Also, the literature shows the accumulating potential of species targeted for Cr, Cu, Ni, Cd, Pb and Zn as reported by [15]. The maximum accumulation of Cr(VI) was recorded in *A. viridis* growing close to the soil polluted with waste discarded by chromium producing factory [68]. Ameh et al. [3] through the study showed *A. viridis* to be a phytostabilizer of Zn and Mo when grown over heavy metal-polluted soil.

Hence, based on good accumulatory trends as per the available literature, two weed species *Acalypha indica* and *Amaranthus viridis* were selected for the present study. The study aimed at checking the accumulating efficiencies of the heavy metals from effluent contaminated soil as well as to access its translocation potential from the underground to the aboveground biomass, thereby comparing its efficiencies to other species. The main objective behind selecting these two plant species was based on the preliminary screening conducted well before the present study was designed. During preliminary study, a total of four species were checked for the heavy metal concentration in their aboveground biomass growing over the contaminated sites. The plants present there included *Amaranthus spinosus, Acalypha indica, Amaranthus viridis, Calotropis procera, Cassia tora* and *Cynodon dactylon*. Out of which only the first four species were selected and subjected to heavy metal analysis, while *Cynodon dactylon* and *Calotropis procera* were omitted as the former is a grass variety with less biomass and the latter due to it invasiveness is toxic milk producing fruits. Based on the highest BCF and TF values obtained for Pb, Zn, Cr and Cu in this two species compared to the others, they were selected for further ex situ studies.

The present study focuses on the potential of the species to thrive over soil externally spiked with two doses of paint industry effluent and to check the exact mechanism of phytoremediation and the exact localization of different heavy metals present in the effluent spiked soil finally evaluating its BCF and TF factors. The hypothesis of the present work states the positive correlation of heavy metals in the biomass of the species exposed to different treatments of paint industry effluent.

2 Methodology

2.1 Characterization of the experimental soil

2.1.1 Collection of composite soil sample

The Botanical Garden of Natubhai V. Patel College of Pure and Applied Sciences was selected to set up the experiment for the present study. Hence, several random soil samples from 10 to 15 cm depth were collected from the garden and mixed thoroughly to make a composite sample for the physicochemical characterization. This soil was air-dried for 2 weeks and sieved with a 2-mm mesh and then preserved in polyethylene bag for further chemical analysis of soil.

2.1.2 Physicochemical analysis

The physical parameter analysis such as texture analysis was carried out using Jar Method; the bulk density, pore space and moisture content were also checked [35]. The pH was determined by suspending 20 g of soil in 100-ml double-distilled water (1:2.5) ratio, and then, it was homogenized on the mechanical shaker for about an hour after which the pH was checked using a pH meter. The organic carbon and organic matter were determined using Walkley and Black [60] method. The Na and K content from the soil was extracted in sodium acetate solution which was determined by flame photometer using sodium chloride and potassium chloride salt solutions for preparing the standard curve. The total nitrogen was estimated by Kjeldahl method, and available phosphorous was checked using Olsen's method.

2.1.3 Acid digestion for heavy metal analysis

The soil sample was acid digested on a hot plate; 1 g of soil was taken in a borosilicate measuring cylinder after which 7.5 ml concentrated nitric acid, 2.5 ml of concentrated hydrochloric acid and 1 ml of hydrogen peroxide were added to it and was further boiled till its volume halved. After cooling, it was filtered with Whatman filter paper No. 1 and the final volume was made up to 25 ml with double-distilled water [47]. Heavy metals (Pb, Zn, Cr and Cu) were than determined by inductive coupled plasma optical emission spectroscopy (ICP-OES) using a PerkinElmer Model Optima 3300 RL spectrometer at Sophisticated Instrumentation Centre for Applied Research & Testing (SICART), Anand, India.

2.2 Effluent collection and characterization

2.2.1 Effluent collection site

The effluent was collected from a paint industry effluent outlet located in Vitthal Udyognagar (22.54716° N 72.91414° E), a town in the Anand District of Gujarat with multitude of industries. The effluent was collected in a 20-L carboy and was brought to the laboratory to carry out the phytoremediation study.

2.2.2 Physicochemical characterization

The dissolved oxygen was immediately fixed at the point of collection and was further analyzed using Winkler method in laboratory [38]. The sample was used for other physicochemical analysis too such as turbidity using nephelometric method, pH using a digital pH meter calibrated using buffer tables of 4 and 9 pH range, electrical conductivity using conductivity meter calibrated using standard potassium chloride solution, biochemical oxygen demand using direct method, chemical oxygen demand by dichromate reflux method [37], sulfate using turbidimetric method, and phosphate was analyzed using stannous chloride method, sodium and potassium using flame photometric method, chloride by Mohr method [30], nitrate by phenoldisulfonic acid method, hardness (calcium and magnesium) by titrimetric method and the total solids using Whatman filter paper. All these parameters were analyzed within 7 days from the day of sampling, and the analysis was carried out using Handbook of water and wastewater analysis [35], while the heavy metal analysis of the effluent was carried out using ICP-OES at SICART.

2.3 Experimental setup

2.3.1 Preparation of soil bed to grow experimental species

An appropriate place receiving moderate sunlight and proper water supply was selected in the garden. Six experimental plots of 1.5 m × 1.2 m size were designed using bricks. A total of two plots were designed for species grown under controlled condition, one for *Acalypha indica* and the other for *Amaranthus viridis*, and the other four plots were prepared with two for each species grown under two effluent treatments, i.e., 50% and 100% (Fig. 1).

2.3.2 Spiking of the soil with the effluent treatments

The plants species were exposed to 50% and 100% paint industry effluent treatments. The 50% dose was prepared by diluting one-half of the effluent with distilled water. After that, two plots were spiked with 5 L of 50% dose, while the other two were spiked with 5 L of 100% dose for *Acalypha indica* as well as for *Amaranthus viridis*, respectively. Composite soil samples were collected from all the four individual plots containing doses as well as from both the control plots for the initial heavy metal analysis before transplanting the experimental species. Now, the plant saplings of both the species were grown over the spiked soil in 3 rows and 5 columns such that the distance between saplings in column was 15 inches, while that in row was 10 inches. The experiment was carried out for a period of 45 days with water sprinkled ever third day on the species till the end of the experiment.

2.3.3 Sampling and analysis of plant biomass and the soil

All the treated plants were uprooted carefully, and their respective soil samples were collected too, followed by proper washing of plants, and finally, they were separated into root and shoot parts. Further, they were sun-dried for

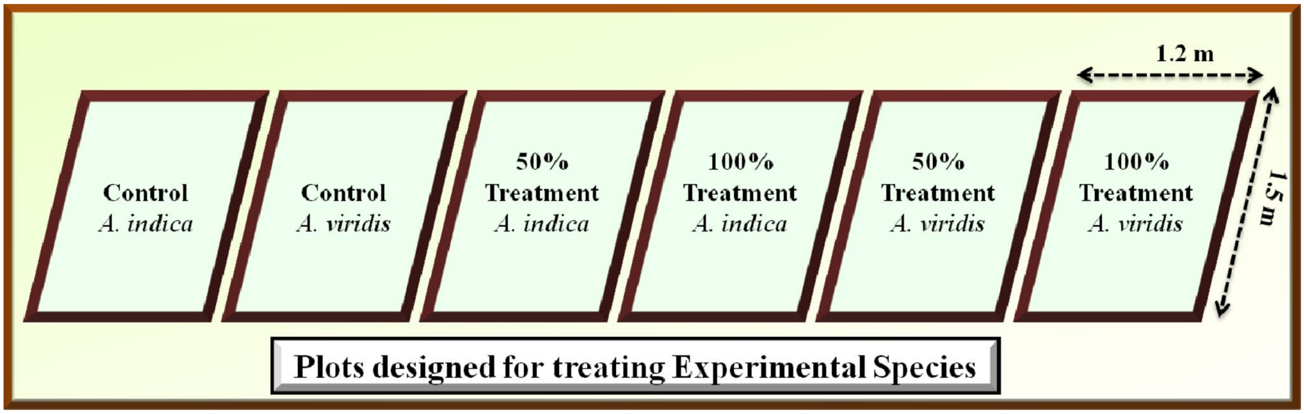

Fig. 1 Schematic diagram of the designed plots for the experimental study

a period of a week and crushed using mortar and pestle. One gram of each dried sample was acid digested and given for ICP-OES analysis at SICART.

3 Evaluating the remedial quotient of the plant species

3.1 Bioconcentration factor (BCF)

Bioconcentration factor accounts for the total amount of heavy metal accumulated in the plant from the contaminated medium. It also gives an insight into the capability of plant to serve the purpose of phytoextraction or phytostabilization [31, 33].

$$[\text{Heavy Metal}]_{\text{Plant Biomass}}/[\text{Heavy Metal}]_{\text{Soil}} \quad (1)$$

3.2 Translocation factor (TF)

The translocation factor states the potential of the species under study to transfer the element absorbed in the root zone to further transport it to the aboveground biomass [11, 52].

$$[\text{Heavy Metal}]_{\text{Root}}/[\text{Heavy Metal}]_{\text{Shoot}} \quad (2)$$

3.3 Statistical analysis

The data were analyzed using PAST version 3.24, and the treatment means were analyzed separately using Dunn's test after it was determined that there was significant difference ($P<0.05$) on the accumulation efficiencies pertaining to the application of several doses using one-way analysis of variance.

4 Results

The experimental soil was slightly acidic with moderate organic carbon and organic matter as given in Table 1.

The paint industry effluent (PIE) had an acidic pH of 5.7 and EC 567 µS/cm, the BOD measured was 358 mg/l, while the COD content was 743 mg/l, the TDS and TSS of the effluent were 1195 and 1200, and the sodium and potassium were 155 mg/l and 8 mg/l, respectively, the DO was 1.89 mg/l, and the turbidity measured was 42 NTU, while the phosphate, sulfate and nitrate were detected to be 4.33 mg/l, 30.8 mg/l and 15 mg/l, respectively, and the hardness of calcium and the magnesium was 147 mg/l and 181 mg/l (Table 2). The heavy metal composition of paint industry effluent is given in Table 3.

Table 1 Physicochemical characterization of the experimental soil

Parameters	Unit	Value
Physical parameters		
Sand	%	66.66
Silt	%	11.90
Clay	%	21.44
Bulk density	gm/cm^3	1.34
Moisture content	%	3.80
Pore space	%	49.433
Chemical parameters		
pH	–	6.7
EC	µs/m	589
Organic carbon	%	1.2
Organic matter	%	2.07
Sodium	mg/kg	60
Potassium	mg/kg	140
Available phosphorous	mg/kg	9.86
Total nitrogen	%	0.13

Table 2 Heavy metal composition of the experimental soil

Heavy metals	Unit	Value
Lead	mg/kg	ND
Zinc	mg/kg	3.02
Chromium	mg/kg	0.92
Copper	mg/kg	1.26

ND not detected

Table 3 Heavy metal composition of the paint industry effluent

Heavy metals	Concentration obtained in PIE in (mg/l)	Effluent discharge standards maximum limit BIS (2012) in (mg/l)
Pb	12.48	2.0
Zn	18.36	5.0
Cr	9.54	2.0
Cu	5.67	3.0

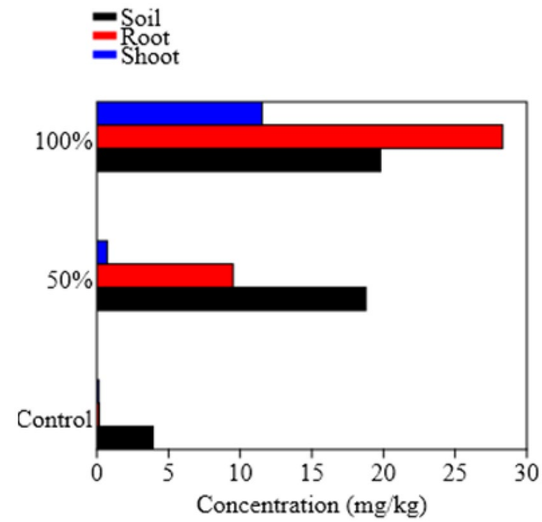

Fig. 2 Accumulation of lead in root and shoot region of *Acalypha indica*

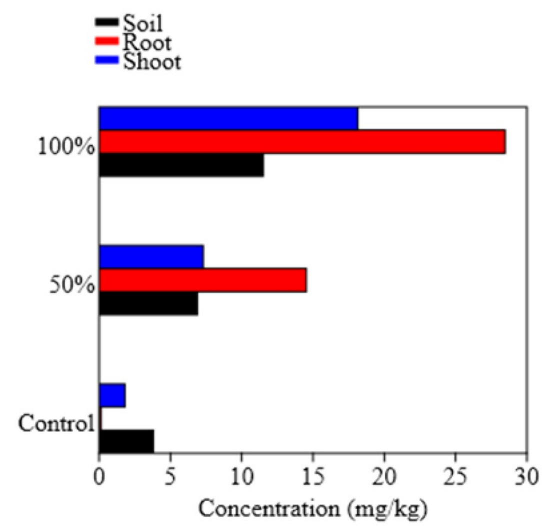

Fig. 3 Accumulation of lead in root and shoot region of *Amaranthus viridis*

4.1 Heavy metal distribution over the root and shoot regions

Acalypha indica showed a moderate 9.5 mg/kg of Pb accumulation in the root zone transferring 0.73 mg/kg to the shoot spiked with 50% effluent with an overall accumulation of 32.78% in its overall biomass (root + shoot) leaving 18.76 mg/kg in soil and 28.32 mg/kg root accumulation transferring 11.54 further to the shoot zone in 100% effluent treatment accumulating a total of 63.87% leaving 19.8 mg/kg residual Pb portion in the soil.

Similarly, *A. viridis* also accumulated 14.53 mg/kg and 7.3 mg/kg Pb in the root and the shoot zones leaving 6.9 mg/kg in soil with an overall sequestration of 69.96% pertaining to 50% treatment and 28.47 mg/kg and 18.13 mg/kg with total accumulation of 74.67% in 100% treatment leaving 11.5 mg/kg residual in soil, and it was significantly different at ($P < 0.05$) (Figs. 2, 3).

Acalypha indica accumulated 5.14 mg/kg of Zn in the root zone and 15.33 mg/kg in the shoot zone leading to an overall 44.58% Zn accumulation in 50% treatment leaving 20.13 mg/kg residual Zn in the soil. In 100% treatment, it accumulated 58.52 mg/kg in the root zone, while in the shoot, it accumulated 10.39 mg/kg with an overall 75.06% Zn accumulation leaving 22.2 mg/kg residual in the soil. The Zn accumulation across several parts of species was significant at ($P < 0.05$).

Similarly, *A. viridis* accumulated 2.81 mg/kg and 15.83 mg/kg in the root and shoot regions, respectively, exposed to 50% treatment with an overall accumulation of 40.61% leaving 21.9 mg/kg residual portion of Zn in soil and 27.08 mg/kg and 41.08 mg/kg in root and shoot exposed to 100% treatment with overall 74.24% accumulation leaving 21.4 mg/kg as residual portion in soil (Figs. 4, 5).

The present study revealed that *A. indica* sequestered 6.26 mg/kg of Cr in the root part transferring 10.91 mg/kg to the shoot leaving 5.9 mg/kg in soil in 50% effluent treatment with an overall chromium accumulation of 71.99% in its biomass and 15.89 mg/kg root accumulation and further transferring 20.78 mg/kg to the shoot zone in 100% effluent treatment accumulating total of 76.87% leaving 8.96 mg/kg residual Cr portion in the soil, and the values obtained were significantly different for different treatments ($P < 0.05$).

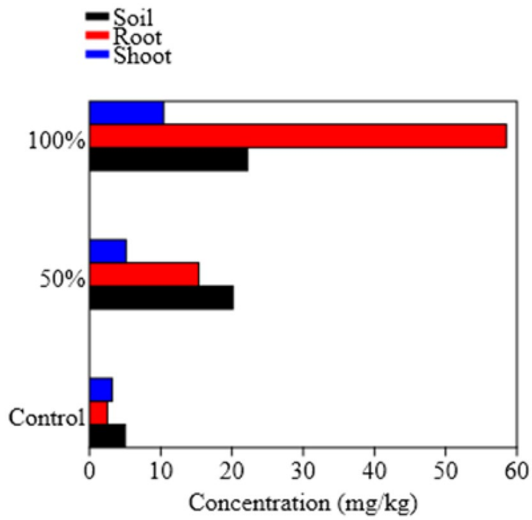

Fig. 4 Accumulation of zinc in root and shoot region of *Acalypha indica*

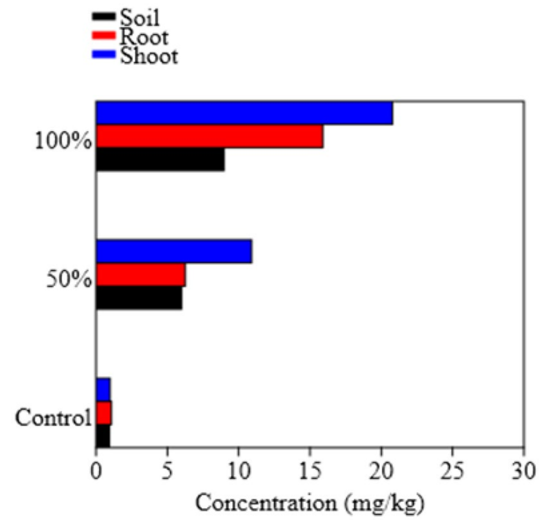

Fig. 6 Accumulation of chromium in root and shoot region of *Acalypha indica*

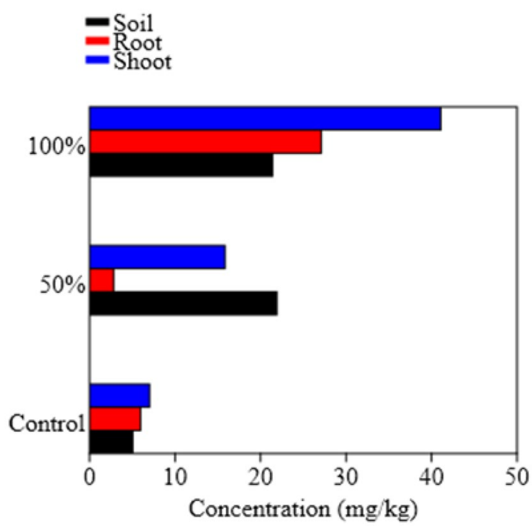

Fig. 5 Accumulation of zinc in root and shoot region of *Amaranthus viridis*

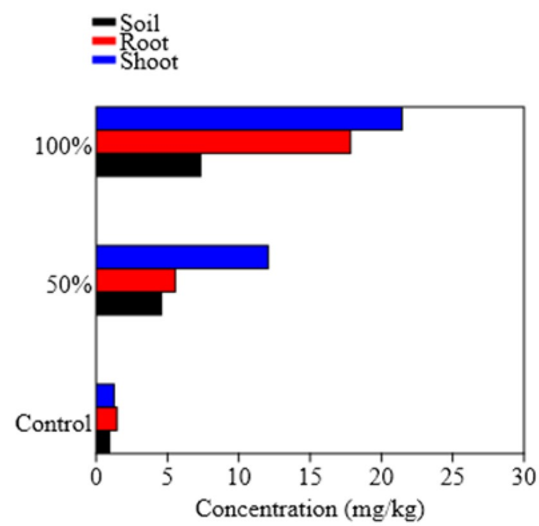

Fig. 7 Accumulation of chromium in root and shoot region of *Amaranthus viridis*

Similarly, *A. viridis* also accumulated 5.54 mg/kg and 12.0 mg/kg Cr in the root and the shoot zones, respectively, leaving 4.56 mg/kg in soil with an overall sequestration of 73.75% pertaining to 50% treatment and 17.84 mg/kg and 21.45 mg/kg leaving 7.32 mg/kg in soil with total accumulation of 82.36% in 100% treatment which was significant ($P < 0.05$) (Figs. 6, 7).

Acalypha indica accumulated 7.94 mg/kg of Cu in the root translocating 3.99 mg/kg to the shoot region leaving 5.56 mg/kg in soil in 50% effluent treatment with an overall accumulation of 84.19% in its biomass and 15.54 mg/kg root accumulation transferring 4.98 mg/kg further to the shoot zone in 100% effluent treatment accumulating total of 66.46% leaving the 8.32 mg/kg residual Cu portion in the soil, and it was not significantly different at ($P < 0.05$).

Similarly, *A. viridis* also accumulated 7.91 mg/kg and 1.67 mg/kg of Cu in the root and the shoot zones with 6.21 mg/kg residual in the soil with an overall sequestration of 67.6% pertaining to 50% treatment and 17.25 mg/kg in root and 2.98 mg/kg in shoot with total accumulation of 71.35% in 100% treatment leaving 7.32 mg/kg residual Cu in soil which was not significant at ($P < 0.05$) (Figs. 8, 9).

The BCF value obtained in case of *A. indica* for 100% treatment was Cr (4.09) > Zn (3.1) > Cu (2.46) > Pb (2.01), and a similar trend in 50% treatment was seen, i.e., Cr (2.09) > Zn (1.01) > Cu (2.09) > Pb (0.54), and in 100%

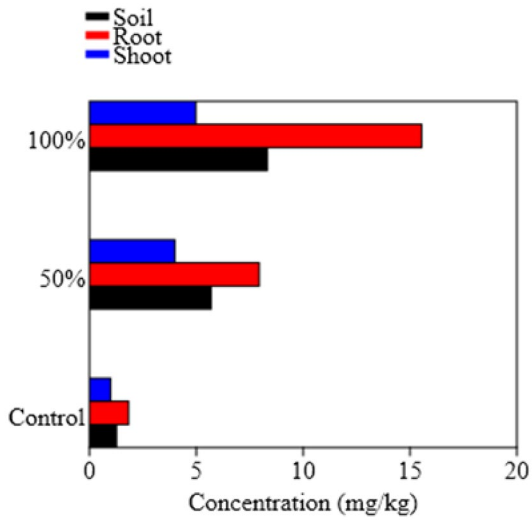

Fig. 8 Accumulation of copper in root and shoot region of *Acalypha indica*

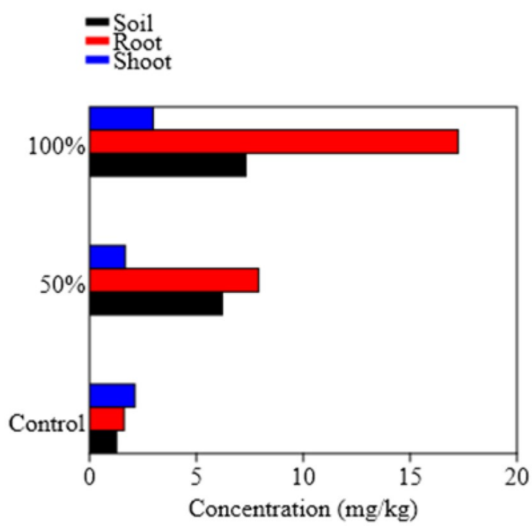

Fig. 9 Accumulation of copper in root and shoot region of *Amaranthus viridis*

treatment of *A. viridis*, it was Cr (5.36) > Pb (4.05) > Zn (3.1) > Cu (0.17), while in 50% treatment, it was Cr (3.85) > Pb (3.16) > Cu (1.54) > Zn (0.85).

The TF in case of *Acalypha indica* was > 1 only for Cr, while it was < 1 for Pb, Zn and Cu, whereas in case of *Amaranthus viridis*, it was > 1 for Zn and Cr and < 1 for Pb and Cu.

Here, as per the data, it was observed that *Acalypha indica* showed high bioaccumulation of all the heavy metals except 50% Pb treatment and the values were also significantly different at ($P < 0.05$) for all the heavy metals. Similarly, *Amaranthus viridis* showed high bioaccumulation of all the heavy metals and the exception being 50% Zn was noted and also the data were significant at ($P < 0.05$).

5 Discussion

Gunwal et al. [22] stated Pb to be a heavy metal having less solubility and so usually even at elevated levels, it shows restricted mobility and if it gets accumulated in the root, it transfers very less amount to other aerial parts of most of the plants. Ancona et al. [7] in their classification of heavy metals showed Pb and Cr to be the least bioavailable among all. This report justifies with the current findings where at elevated levels of Pb in the soil, the uptake in the shoot of *A. indica* increased in 100% treatment, i.e., 63.87% Pb accumulation in the total biomass compared to 32.78% accumulation in 50% treatment. El-Mahrouk et al. [19] findings supported this trend as he reported that higher TF values in plant species are observed when high metal concentration is present in the soil, making it available to the root region thereby successively translocating a good amount to the shoot part. Plants having > 1 TF are good at phytoextraction [24]. Fritioff and Greger [20] stated the mechanism and utility of plant sequestering highest amount in the root region which is termed as phytostabilization wherein the plant arrests the contaminants near the substrate, further preventing it from spreading or leaching into the ground or to other mediums. Here, for both the treatments, a higher accumulation in the root region was observed with a TF of < 1 for both the treatments and for both the species which shows the plants to be good at phytostabilizing Pb rather than phytoextracting it. In a study conducted by ur Rehman et al. [57], *A. indica* naturally growing in the ambience of industrialized area was collected and analyzed with Pb concentration noted to be 2.5 mg/kg and 2.9 mg/kg in the shoot and root region, respectively, with a 0.9 TF value. The translocation from the root to shoot is also depended on the type of metal ion being phytoextracted, and the affinity of the plant species towered it [48]. Since the advent of phytoremediation took place, many more weedy species were discovered which played an immense role in accumulating good amount of heavy metals despite unfavorable climatic conditions and improper growth medium [16, 44]. Similar to the current study, the level of Pb recorded for *A. viridis* was 1.7 and 1.9 mg/kg in the shoot and root, respectively [57]. Iya et al. [25] showed an accumulation trend using *A. wilkesiana* where it was seen that the plant had good BCF value but poor TF value which corroborated well with the values obtained during the present study. Ziarati and Alaedini [66] checked the % Pb accumulation during three successive harvests and recorded it to be 32.1%, 33.6% and 35.1% and stated that the young saplings of Amaranth sps were

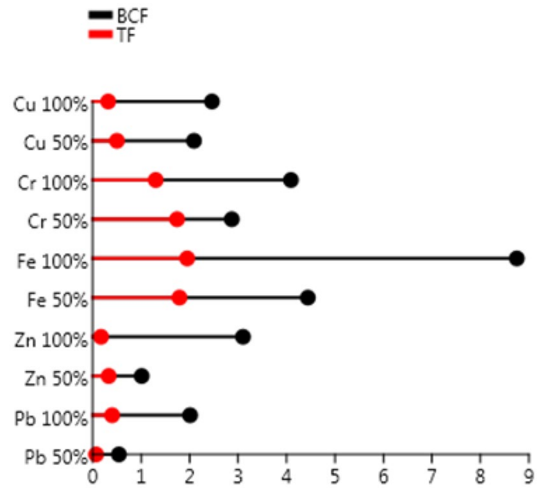

Fig. 10 Bioconcentration and translocation factor of *Acalypha indica*

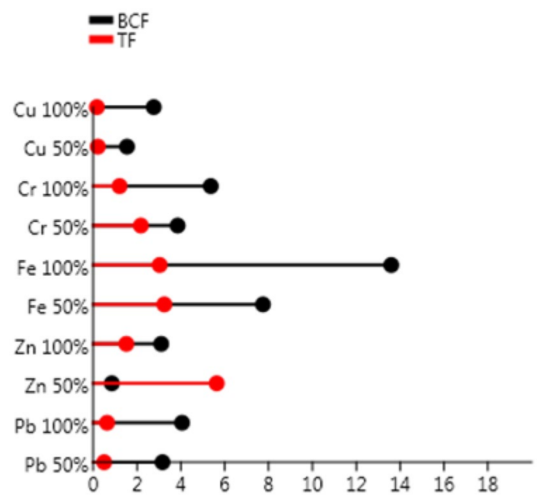

Fig. 11 Bioconcentration and translocation factor of *Amaranthus viridis*

the most potent in sequestering Pb. Hence, from the data, it can be said that though both the plants have low TF values, yet on comparing both the species it can be stated that *A. viridis* is a good translocator of Pb compared to *A. indica* from (Figs. 10, 11).

Zinc is an essential element required by plants as well as humans to carry out several metabolic activities as well as enzymatic activities; hence, it is needed in appropriate proportion, but when the concentrations exceed the normal required range, it can cause ill effects leading to malfunctioning and unwanted accumulation in different zones of the body [10]. On analyzing the BCF and TF values, it can be concluded that *A. indica* showed high accumulation of Zn in the root zone with a translocation factor of < 1 and a BCF > 1 for both the treatments of Zn showing phytostabilization of Zn and less phytoextraction in the aboveground biomass, whereas in *A. viridis*, it not only showed > 1 BCF value but also had > 1 TF value in 100% treatment, making it a good candidate for phytoextraction of Zn at elevated concentrations. It can be seen that despite higher concentration of Zn in the soil, both the plant species extracted good amount in its biomass showing high tolerance toward Zn. Liu et al. [32] stated that though some plants accumulate good amount of heavy metals from the contaminated soil, yet only few species translocate it to the stem as well as leaves, while the rest of the portion remains localized in the root region of the plant owing to the self-defense mechanism of plant.

Several studies have reported chromium to be an essential nutrient for growth of plants at low levels, but at elevated levels, it also poses to have carcinogenic effect [50]. Recently, the concentration of chromium in the environment has been increasing due to its wide range of applications in many industries with paint and pigment being an important area of its use [54]. As per the results obtained, it was observed that the values of BCF exceeded 1 in case of both the species and for both the treatments for Cr, even the TF values for both of them were more than 1 which were contradictory to that of [49].

Reeves and Baker [46] stated that for a species to be a Cu hyperaccumulator, it has to accumulate a total of 1000 mg/kg of heavy metal in its aboveground biomass. In the present study, *A. indica* accumulated 7.94 mg/kg of Cu in the root translocating 3.99 mg/kg to the shoot region in 50% effluent treatment and 15.54 mg/kg root accumulation transferring 4.98 mg/kg further to the shoot zone in 100% effluent treatment which corroborated well with the findings by Iya et al. [25], where in *A. wilkesiana* the highest accumulation of 101.23 ± 2.92 mg/kg was found in the root region, while that in the stem accounted to 76.93 ± 1.27 and in the leaf region was 79.39 ± 2.57 mg/kg. Generally, the plant species have been observed to have very less potential in phytoextracting Cu from the soil compared to other heavy metals [56]. Also, the accumulation of multimetal contaminated soil depends on different factors such as soil pH, soil organic matter, its affinity with other metals present as well as the plant species and the texture of the soil [29]. The accumulation of Cu in the aerial parts of the plants is solely dependent on the concentration of the metal present in the soil, and its uptake increases at elevated levels of Cu in the soil [58, 63]. The results thus obtained exhibited a pattern similar to the one obtained by [65]. In a study, a gradual increase in the % Cu uptake was recorded to be 10.76, 12.46 and 13.09 during three consecutive harvests in Amaranth sps. during the 45 day study with the maximum uptake rate recorded on the 30th day [66]. The overall BCF for Cu was higher in case of A. indica for both the effluent treatments but had low TF, and

A. viridis accumulated very less amount of Cu supported by low BCF values for both the treatments as well as very low TF values showing that it was an excluder of Cu as per the observations made from the present study. Zhao and Duo [65] reported in a study that some of the plants act as excluders by not letting the pollutants enter their metabolic pathways to protect themselves as a self-defensive action and inhibiting the concentration to exceed in the root zone by eliminating its entry selectively.

The prime mode of entry of any element is the root cells which are in deep association with the soil to fulfill its nutritional needs, and it thus also makes way for the entry of many more non-essential elements such as heavy metals present anthropogenically in the root via the soil by liberating natural organic chelating agents and increasing the solubility of these heavy metals which finally reaches the foliar zones of the plants [17].

Hence, these default mechanisms observed have been applied to clean the contaminated lands and to seek out such potential plants for the reclamation purpose.

Ndeda and Manohar [40] state that the plant applicable for the purpose of phytoremediation requires high bioconcentration factor (BCF); the higher the BCF, the more the accumulation in the plant tissue compared to its contaminated medium. Similarly, a translocation factor (TF) above 1 shows its transferring mechanism from root to shoot; hence, it makes it a good choice for reclamation and finally an appropriate choice for aboveground harvesting of the heavy metals over wastelands.

As adopted by Pachura et al. [43], a four-scale study to differentiate the levels of heavy metal accumulation among the species was considered and it categorized > 0.01 BCF value as 'no accumulation,' 0.01 to 0.1 as 'low accumulation,' 0.1 to 1.0 as 'medium accumulation' and < 1 to be 'high bioaccumulation.' It was observed that the BCF values increased with the increase in the respective doses of every heavy metal; hence, it can be said that the BCF values are dose as well as species dependent [67]. Hence, as shown in (Figs. 10, 11), a high amount of essential heavy metals was accumulated in the shoot tissues of both the experimental species which was also in accordance with other findings of [4, 36].

6 Conclusion

In the present study, it was observed that both the species *Acalypha indica* and *Amaranthus viridis* sequestered good amount of heavy metals in their biomass, making it feasible for growing over contaminated sites for reclamation purpose. In 50% treatment, *A. indica* accumulated 15.33 mg/kg of Zn in the root zone and 5.14 mg/kg in the shoot zone, whereas in 100% treatment, it accumulated 58.52 mg/kg in the root zone, while 10.39 mg/kg Zn in the shoot. *A. viridis* accumulated 2.81 mg/kg and 15.83 mg/kg Zn in the root and shoot regions, respectively, exposed to 50% treatment and 27.08 mg/kg and 41.08 mg/kg Zn in root and shoot exposed to 100% treatment; it also accumulated 5.54 mg/kg and 12.0 mg/kg Cr in the root and the shoot zones, respectively, pertaining to 50% treatment and 17.84 mg/kg and 21.45 mg/kg in 100% treatment. From the study, it was derived that exploiting plants which are not edible and are pollution tolerant can enhance the rate of phytoremediation and also can stop its transfer across several trophic levels of the food chain.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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