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ORIGINAL ARTICLE

Assessment of phytoremedial potential of invasive weeds *Acalypha indica* and *Amaranthus viridis*

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Abstract

In the present study intercropping of two plant species was carried out over a soil contaminated with five heavy metals lead (Pb), cadmium (Cd), chromium (Cr), cobalt (Co) and nickel (Ni). The experimental setup was designed in such a manner that the effluent stream passed intermittently for 60 days through the plant species *Acalypha indica* and *Amaranthus viridis* grown on-site after which the species were uprooted and processed further to check the heavy metal concentration in several parts of the plant such as roots, stem, leaves and flowers as well as the soil. The flowers of *A. indica* accumulated a maximum amount of Pb and least in the stem with a Translocation Factor (TF) of 21.49 and a Bioconcentration Factor (BCF) value of 2 and the highest concentration of Cr in flowers followed by leaves, root and stem regions with a TF of 11.5 and BCF value of 244.59. Co accumulation in *A. indica* was noted to be maximum in the flowers and least in the stem with a TF of 12.03 and a BCF value of 3.77, while it was highest in the flowers and least in the root with 8.2 and 0.9 TF and BCF values respectively, for Cd, whereas for Ni it was highest in the flowers and least in stem with 18.19 TF and 11.04 BCF. *A. viridis* accumulated maximum amount of Pb in leaves followed by flowers and least in stem with a TF of 8.64 and BCF of 259.93. It accumulated highest amount of Cr in the leaves followed by flowers, stem and root region with a TF of 10.55 and BCF of 212.49. The leaves of *A. viridis* accumulated a maximum amount of Co and the least in the stem region with a TF of 7.05 and BCF of 4.95 while the concentration of Cd was highest in leaves and least in roots with 18.37 and 1.61 TF and BCF respectively. *A. viridis* accumulating trend for Ni was leaves > flowers > root > stem with a TF of 8.15 and BCF of 10.48. Hence as per the values obtained both the species exhibited successful phytoextraction of all the five heavy metals in their aerial parts making both of them good bioaccumulator species.

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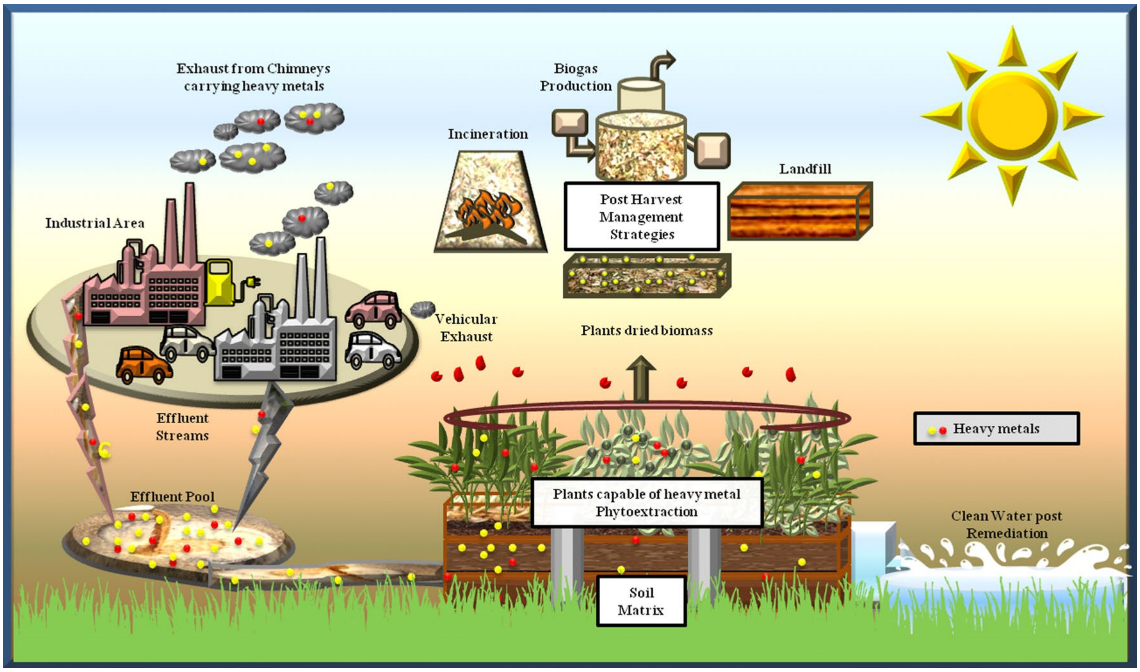
Graphic Abstract



Keywords Phytoextraction · Bioaccumulator · Translocation factor (TF) · Bioconcentration factor (BCF) · Heavy metals

Introduction

Heavy metals are one of the most noxious inorganic pollutants (Khan et al. 2011). Several natural processes have contributed to their concentrations in different sinks of the ecosystems as reported by several studies (Noman et al. 2017). Elements such as lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), iron (Fe), cadmium (Cd), nickel (Ni), manganese (Mn), cobalt (Co), aluminum (Al) and mercury (Hg) are termed as heavy metals due to a density higher than 5 g/cm^3 and a higher atomic number (Dehghani et al. 2016). The main sources of heavy metals are anthropogenic such as metallurgical activities, combustion of fossil fuels, industrial effluents, paint and pigment residues, electrical appliances, automobile exhaust, and mining activities etc. which contribute to their high concentration in soil, water and air (Korzeniowska and Stanislawska-Glubiak 2015). Heavy metals are non-biodegradable (Benavides et al. 2005) hence, they get biomagnified while trespassing from one medium to the other (Chary et al. 2008). Heavy metals at elevated concentrations in the human bodies cause irreversible damage to heart, kidneys, lungs, brain and get deposited in the tissues of the body disrupting the normal functioning and elasticity of several organs (Chen et al. 2014; Shyleshchandran et al. 2018). Numerous technologies have evolved to clean up the heavy metal contaminated soil as well as water (Ali et al. 2016). These technologies mostly include vitrification, bioaugmentation, encapsulation, adsorption, electrokinetics, excavation, leaching etc. All the methods applied so far are cost-intensive (Padmavathiamma and Li 2007). These physical and chemical treatments alter and in extreme cases also kill the native micro-flora which are essential for the nutrient cycling in soil (Capozzi et al. 2020). Hence, a green technology popularly known as phytoremediation came into practice. Phytoremediation uses green plants to clean up the contaminated medium by extracting the heavy metals in their aboveground biomass (Sarwar et al. 2017). Several plants with good accumulation trend have been studied so far. Most of the species discovered until now belong to the Brassicaceae family (Chaplygin et al. 2018). Phytoextraction and Phytostabilization are the two mechanisms usually studied when dealing with heavy metals such as Zn, Pb, Cu, Cr, Mn, Cd etc. (Boechat et al. 2016). Phytovolatilization is mainly focused when phytoremediation of Hg and Se has to be carried out. Phytoextraction deals with removal and transport of metals from the contaminated medium towards the aboveground biomass whereas phytostabilization focuses on arresting the metals near its root zone by preventing them from further leaching towards the groundwater (Andrade et al. 2007). The selected species are grown over the contaminated medium for a required amount of time and then the plant biomass is harvested (Hanikenne et al. 2008). The biomass without any physical alteration sequesters huge amount in its shoot part i.e. the harvestable region of the plant. This biomass can further be incorporated as 'feed-in' for biogas production. It can also be incinerated or dumped into a landfill. So far many plant species have been tested for their phytoextraction and phytostabilization potential on a lab-scale basis. Very few studies are carried out to check the actual on-site potential of the species. Many studies have shown contradictory outcomes in which the experimental species could carry out phytoextraction of heavy metals when grown in lab confinement but failed to perform when exposed to contaminated soil on-site trial (Arena et al. 2017).

Hence, the present study focuses on exploring the phytoaccumulative efficiencies of two weedy species when grown on-site over a soil constantly under the pressure of heavy metal-rich effluents. The accumulations of heavy metals in different plant parts such as leaves, flowers, stem and roots of *Acalypha indica* and *Amaranthus viridis* were checked. This two species were intercropped over the soil contaminated with industrial debris in such a manner that an intermittent flow of effluent from the nearby paint industrial unit would also pass over the species grown in-situ for 60 days. The uptake efficiency of on-site species was also carried out by comparing the Translocation Factor (TF) and Bioconcentration Factor (BCF) values obtained for five heavy metals namely Pb, Cd, Cr, Co and Ni contaminating the soil.

Materials and methodology

Selection of plant species

A preliminary investigation was carried out before conducting the experiments in the present study; four species natively inhabiting a selected multi-metal contaminated site were checked for the heavy metal concentration in their biomass. The variety of plant species present there were *A. indica, A. viridis, Amaranthus spinosus* and *Cassia tora*. Based on the BCF and TF values obtained for Zn, Cr, Pb and Cu two species *A. indica* and *A. viridis* were selected for further studies. Both the species were intercropped over highly contaminated site (in-situ) which was constantly under the pressure of the heavy metal load to assess their phytoremediation potential.

Site selection and experimental plot design

The selected site was located at GIDC, Vitthal Udyognagar (22.54716° N 72.91414° E), Gujarat, India. The experimental plot was designed over this site loaded with paint industry waste and used to receive an intermittent flow of paint industry effluent too.

The experimental plot of approximately 4 × 12 m size was marked for plantation. This plot was further divided into three sub-plots 4 × 4 m size. The area was cleaned; small size pebbles were handpicked and the debris was removed using a garden spade and pickaxe after which the plot was tilled to ensure proper air circulation for the transplanted saplings.

Soil characterization

Prior to in-situ experiment, the soil samples from experimental plot were collected from three distinct places marked at a 100 cm distance by digging over 3 inch depth approximately. The soil samples were combined to form a composite sample which was packed in Ziploc bag and brought to the laboratory for further analysis, preserving from direct sunlight.

(i) Physico-chemical analysis

The soil texture analysis was carried out using the 'Jar Test' method ("Soil Texture Testing—Two Easy Methods"). A half-cup of uniform soil was taken in a transparent quartz jar to which half a spoon of borax was added and shaken vigorously for five minutes after which it was allowed to settle for 24 h. The actual texture of the soil was then derived from the 'Soil Textural Triangle' by marking the intersection obtained of three different layers—sand, silt and clay based on the percentage values. The formula is given below:

$$\left(\mathrm{S_DH/Total\ H}\right) \times 100 = \underline{\hspace{3cm}}\%$$
$$\left(\mathrm{S_TH/Total\ H}\right) \times 100 = \underline{\hspace{3cm}}\%$$
$$\left(\mathrm{C_YH/Total\ H}\right) \times 100 = \underline{\hspace{3cm}}\%$$

where, S_D is the sand, S_T is the silt, C_Y is the clay, H is the height of the layer.

The parameters such as electrical conductivity (EC), bulk density, pore space and moisture content were determined by using methods prescribed in the Manual of Water and Soil analysis by Maiti (2003).

For measuring pH, the soil sample was prepared by suspending 10 g of soil in 50 ml double-distilled water (1:2.5) ratio with parallel homogenization on the mechanical shaker for an hour after which the pH was measured using a digital pH meter. The organic carbon and organic matter were analyzed by a method prescribed by Walkley and Black (1934). The sodium and potassium from the soil were extracted in a sodium acetate solution after which their concentration was determined using Flame photometer by calibrating it with sodium chloride and potassium chloride salt solutions (Maiti 2003).

(ii) Heavy metal concentration

A preliminarily screening of the soil was carried out to check the level of heavy metal concentration before plantation. The collected soil sample was digested on a hot plate by providing acidic medium, 1 g of soil was taken in a measuring cylinder followed by addition of 7.5 ml concentrated nitric acid (15.9 M), 2.5 ml of concentrated hydrochloric acid (12.1 M) and 1 ml of hydrogen peroxide (34.01 M). The prepared mixture was boiled till it reached half of its volume and then it was allowed to cool. The liquid was filtered using Whatman filter paper No. 1 and was made into 25 ml volume using double distilled water (Schwartz et al. 2004). Heavy metals (Pb, Cd, Cr, Co and Ni) were determined by Inductive Coupled Plasma—Optical Emission Spectroscopy using a Perkin Elmer Model Optima 3300 RL spectrometer at Sophisticated Instrumentation Centre for Applied Research & Testing (SICART), Vallabh Vidyanagar, Gujarat, India.

Plantation of experimental species

This experimentation was carried out once in the year 2019 from February till May. The average maximum temperature recorded during the onset of the plantation at the site was 31 ℃ which showed a gradual rise and was marked 40 ℃ at the end of the study. The saplings chosen for plantation were of uniform growth of about 15 days, these plant saplings of both the species were grown in-house in the laboratory in small plastic pots filled with garden soil. The seeds were procured from matured plants already growing in the Botanical garden of Natubhai V. Patel College of Pure and Applied Sciences. The saplings of both the species *A. indica* and *A. viridis* were planted carefully keeping a distance of 0.75 × 0.75 feet between two individual plants. The plant species were intercropped in all the three sub-plots prepared on-site. A total of 30 plants were grown in each sub-plot with 15 plants of *A. indica* and other 15 plants of *A. viridis*. Regular monitoring and pruning was done to allow the growth of experimental species for sixty days. The experimental plot was also protected by a temporary metal wire fence to prevent the intrusion of animals. A site visit was done on every 3rd day of the study period to water the species from a pond adjacent to the study site.

Harvesting biomass and analysis

The plant biomass of both plant species was harvested after 60 days. Owing to the feasibility and economical perspective composite sampling of the plant species was done. For which six individual matured plants of both the species were uprooted from all the sub-plots keeping their roots intact and then were finally mixed properly to make a representative composite sample. The soil samples of the rhizospheric zone were also collected similarly in polyethylene bags. The plants were brought to the laboratory washed thoroughly under running tap water to remove the adhered impurities and then separated into plant parts like root, stem, leaves and flowers. A 1 g of representative sample of each part as well as their respective soil samples were oven-dried and processed following Schwartz et al. (2004) method of digesting the plant samples and were analyzed using ICP-OES by running a blank at SICART.

Data interpretation

The concentration of individual heavy metal in the root, stem, leaves and flowers of both the species are plotted graphically. The efficiency of the species was determined using indices such as TF and BCF which mainly categorize the plant species as an extractor or an excluder and also give an insight into the mechanism whether the plant species is capable of phytoextraction or phytostabilisation. A four scale assessment was considered which categorized BCF value < 0.01 as 'No accumulation', BCF value 0.01 to 0.1 as 'Low accumulation', BCF value 0.1 to 1.0 as 'Medium accumulation' and BCF value > 1 as 'High bioaccumulation' (Pachura et al. 2016).

(i) Translocation factor (TF):

The amount of heavy metal accumulated in the shoot region to that present in the root region is referred to as the Translocation factor. It highlights the potential of the plant to be effectively used as a bioaccumulator of heavy metal.

$$TF = \frac{Metal\ in\ the\ aboveground\ biomass}{Metal\ in\ the\ root\ region}$$

(ii) Bioconcentration factor (BCF):

$$BCF = \frac{Metal\ in\ the\ aboveground\ biomass}{Metal\ in\ the\ soil}$$

The concentration of the metal in the shoot region to that of the residual portion in the respective contaminated medium is referred to as BCF. A ratio > 1 signifies the good phytoaccumulative ability of the species.

Results

Soil textural analysis

The texture of the soil prevalent on-site was 'sandy loam' with 65.5% of sand, 18.2% clay and 16.3% silt. These percentage values were plotted individually over a soil textural triangle and the point of coincidence of all the three values revealed the soil composition to be sandy loam.

Physico-chemical characterization of soil

The bulk density of soil sample before in-situ remediation was 1.34 ± 0.23 g/cm^3 which reduced to 1.07 ± 0.45 g/cm^3 in the after in-situ remediation whereas, the concentration of pore space and moisture content showed an increase during after in-situ remediation. The pH obtained was slightly alkaline which turned acidic after the treatment while the EC values showed an improvement. The % concentration of organic carbon and organic matter also increased when analyzed after in-situ remediation. The Na and K values were also noted to be higher compared to the initial stage of the study. The concentration of heavy metals (Pb, Cd, Cr, Co and Ni) decreased at the end of the study period compared to that of the initial concentrations as shown in Table 1 (Figs. 1, 2).

Heavy metal accumulation

Maximum Pb accumulation was recorded in flowers of *A. indica* with a net accumulation of 28.813 mg/kg followed by 22.087 mg/kg accumulation in leaves whereas the stem showed the least concentration of 0.647 mg/kg (Fig. 3). The roots had 2.398 mg/kg concentration of Pb. *A. indica* showed the highest TF value of 21.49 for Pb when compared to all the heavy metals. The BCF value indicated very good phytoaccumulative ability of the species (Figs. 4, 5, 6, 7).

The concentration of Cd in the flowers, leaves, stem and root of *A. indica* was 0.07033, 0.05427, 0.04042 and 0.02383 mg/kg respectively, with 8.2 TF and 0.9 BCF values. *A. indica* accumulated the highest Cr i.e. 19.889 mg/kg in flowers followed by 18.009 mg/kg in leaves, 3.401 mg/kg in root and 1.237 mg/kg in the stem region with a TF of 11.5 and BCF of 244.59. The flowers of *A. indica* accumulated maximum amount of Co with a net accumulation of 1.289 mg/kg followed by 1.171 mg/kg accumulation in leaves and 0.21 mg/kg in root and the least concentration of 0.067 mg/kg in the stem region with a TF of 12.03 and a BCF value of 3.77. The concentration of Ni in the flowers,

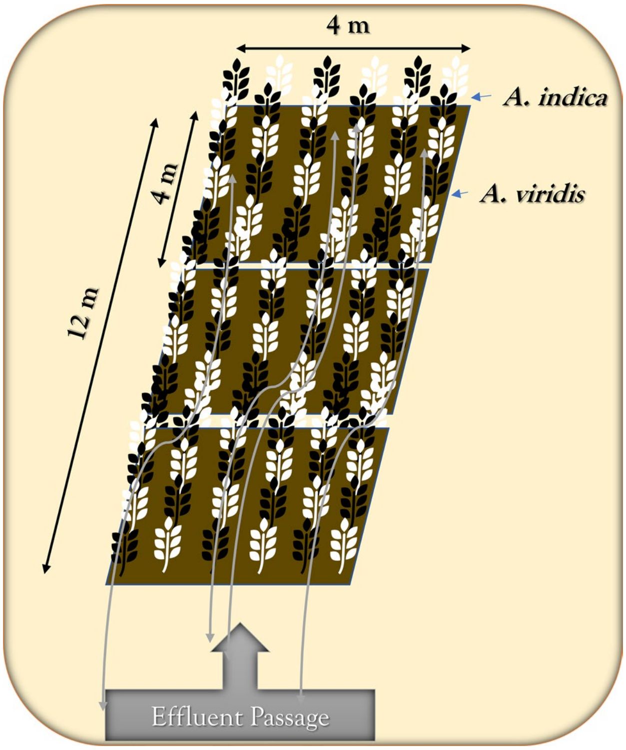


Fig. 1 Schematic representation of the plantation over the contaminated site and the course of effluent passage via the sub-plots

Table 1 Physico-chemical parameters of the soil in the pre-remediation and post-remediation phases (results are mean value of three replicates ± standard deviation)

Sr. no.	Physico-chemical parameters	Units	Before in-situ remediation	After in-situ remediation
1	Bulk density	(gm/cm^3)	1.34 ± 0.23	1.07 ± 0.45
2	Pore space	(%)	3.80 ± 0.02	9.7 ± 0.06
3	Moisture content	(%)	49.43 ± 0.19	59.622 ± 0.54
4	Ph		7.2 ± 0.12	6.9 ± 0.18
5	EC	(µS/cm)	578 ± 0.9	654 ± 0.7
6	Organic carbon	(%)	0.7 ± 0.11	1.0 ± 0.19
7	Organic matter	(%)	1.204 ± 0.01	1.72 ± 0.04
8	Sodium	(mg/kg)	78 ± 0.34	95 ± 0.56
9	Potassium	(mg/kg)	15 ± 0.03	21 ± 0.21
10	**Heavy metals**			
a	Pb	(mg/kg)	64.33 ± 0.12	25.737 ± 0.10
b	Cd	(mg/kg)	0.215 ± 0.02	0.182 ± 0.08
c	Cr	(mg/kg)	0.227 ± 0.06	0.16 ± 0.04
d	Co	(mg/kg)	0.074 ± 0.01	0.067 ± 0.02
e	Ni	(mg/kg)	1.087 ± 0.05	0.888 ± 0.02

leaves, root and stem of *A. indica* was 5.318, 4.199, 0.539 and 0.29 mg/kg respectively, with a TF and BCF of 18.19 and 11.04 respectively.

The leaves of *A. viridis* accumulated maximum amount of Pb with a net accumulation of 17.043 mg/kg followed by 11.893 mg/kg accumulation in flowers and 3.164 mg/kg in root and the least concentration of 3.099 mg/kg in stem region with a TF of 10.13 and BCF of 1.24. The concentration of Cd in the flowers, leaves, stem and root of *A. viridis* was 0.03233, 0.2181, 0.05293 and 0.0168 mg/kg respectively, with 18.37 TF and 1.61 BCF values. It accumulated the highest Cr i.e. 21.265 mg/kg in the leaves followed by 9.427 mg/kg in flowers, 3.307 mg/kg in stem and 3.221 mg/kg in the root with a TF of 10.55 and BCF of 212.49. The leaves of *A. viridis* accumulated maximum amount of Co with a net accumulation of 2.017 mg/kg followed by 0.961 mg/kg accumulation in flowers and 0.47 mg/kg in root and the least concentration of 0.339 mg/kg in stem region with a TF of 7.05 and BCF value of 4.95. *A. viridis* accumulated 5.8, 2.525, 0.985 and 1.141 mg/kg of Ni in the leaves, flowers, stem and roots respectively, with a TF of 8.15 and BCF of 10.48.

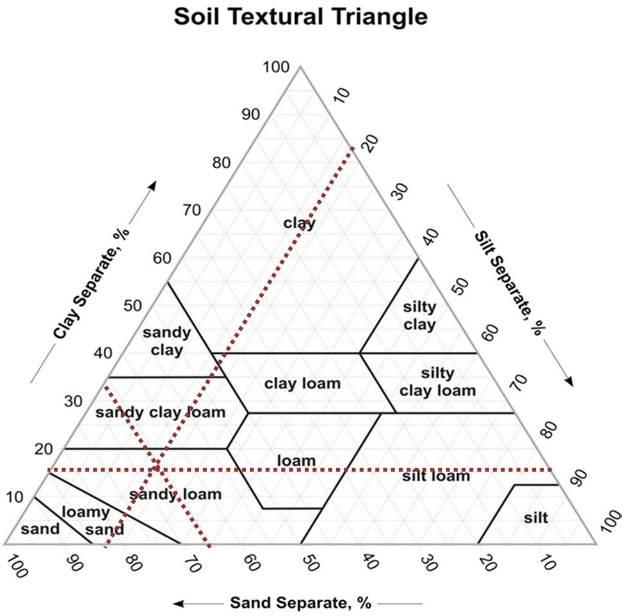


Fig. 2 Soil textural triangle. Courtesy: https://www.the-compost-gardener.com/soil-texture-testing.html

Fig. 3 Accumulation of mean Pb in various parts of *A. indica* and *A. viridis* (n = 3)

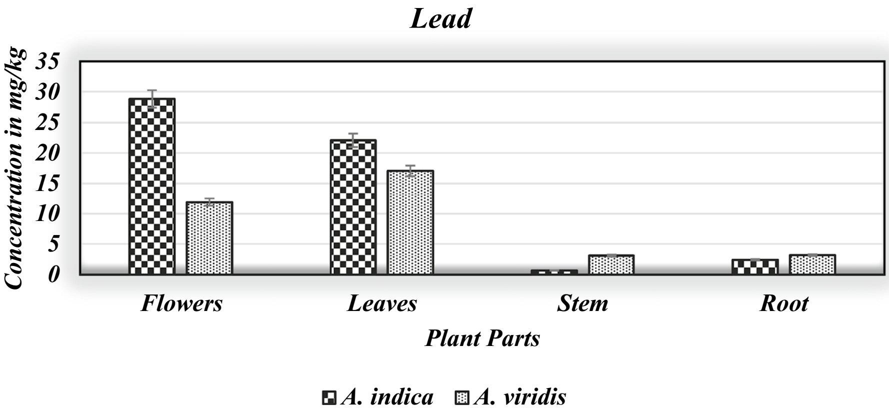


Fig. 4 Accumulation of mean Cd in various parts of *A. indica* and *A. viridis* (n = 3)

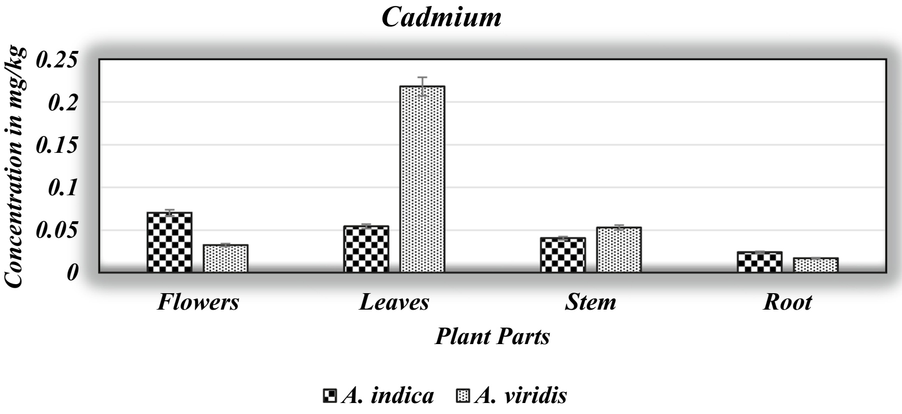


Fig. 5 Accumulation of mean Cr in various parts of *A. indica* and *A. viridis* (n = 3)

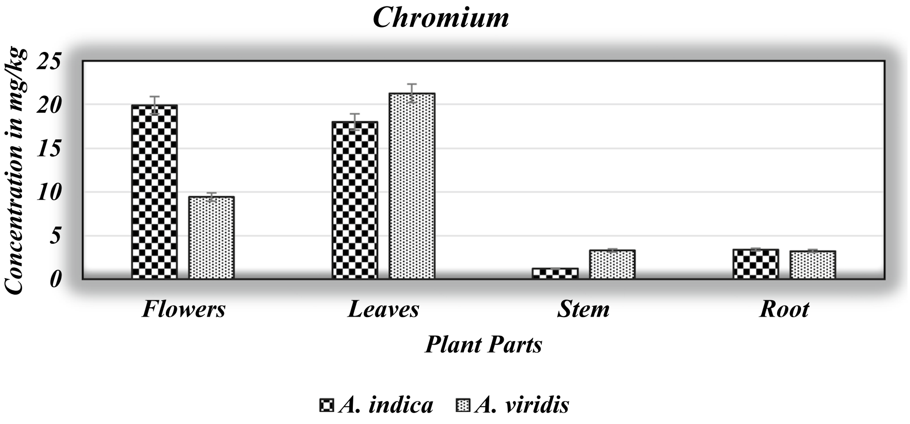


Fig. 6 Accumulation of mean Co in various parts of *A. indica* and *A. viridis* (n = 3)

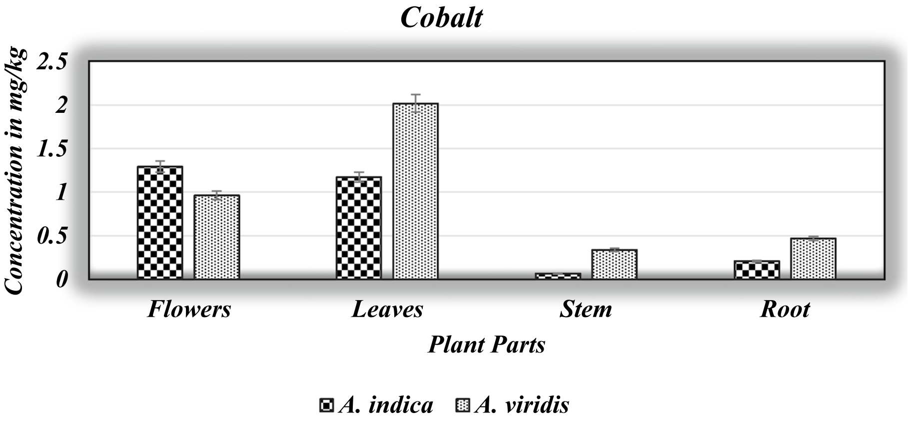
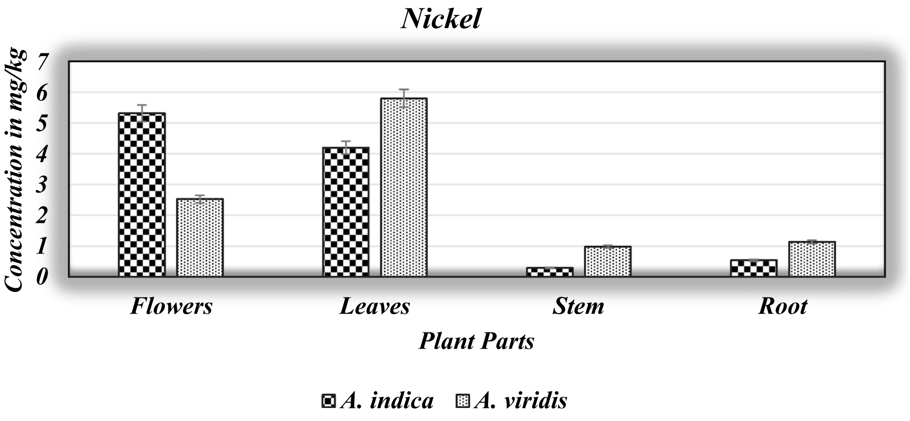


Fig. 7 Accumulation of mean Ni in various parts of *A. indica* and *A. viridis* (n = 3)



Translocation and bioconcentration factors

The value of translocation factor was highest for Pb and lowest for Cd in *A.indica*. The descending order was Pb (21.49) > Ni (18.19) > Co (12.03) > Cr (11.5) > Cd (8.2) and the bioconcentration factors were Cr (244.59) > Ni (11.04) > Co (3.77) > Pb (2) > Cd (0.9).

The value of translocation factor obtained in the descending order in case of *A. viridis* was Cd (18.37) > Cr (10.55) > Pb (10.13) > Ni (8.15) > Co (7.05) and the bioconcentration factors as Cr (212.49) > Ni (10.48) > Co (4.95) > Cd (1.24) > Pb (1.24) (Figs. 8, 9, 10, 11).

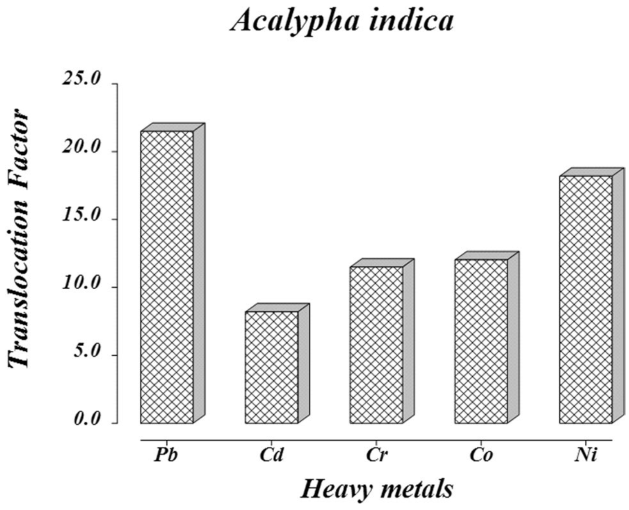


Fig. 8 Translocation factors of *A. indica* for heavy metals

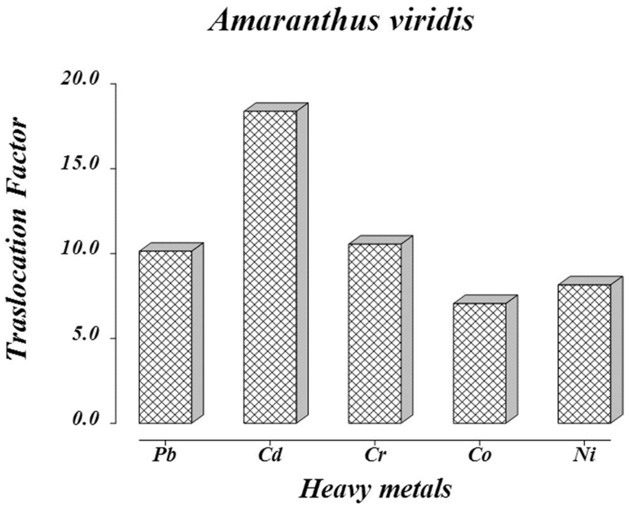


Fig. 10 Translocation factor of *A. viridis*

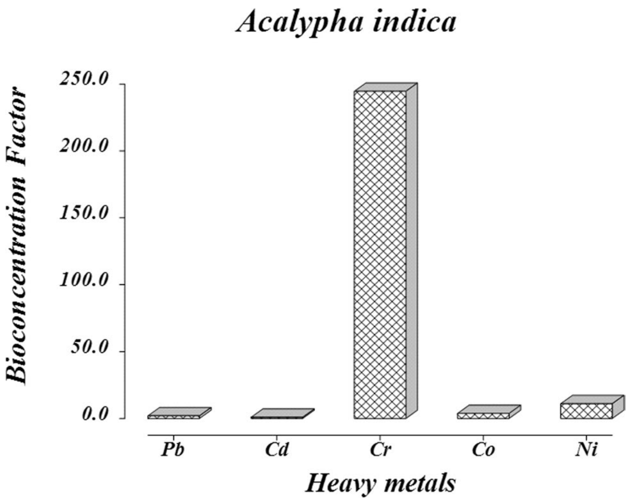


Fig. 9 Bioconcentration factors of *A. indica* for heavy metals

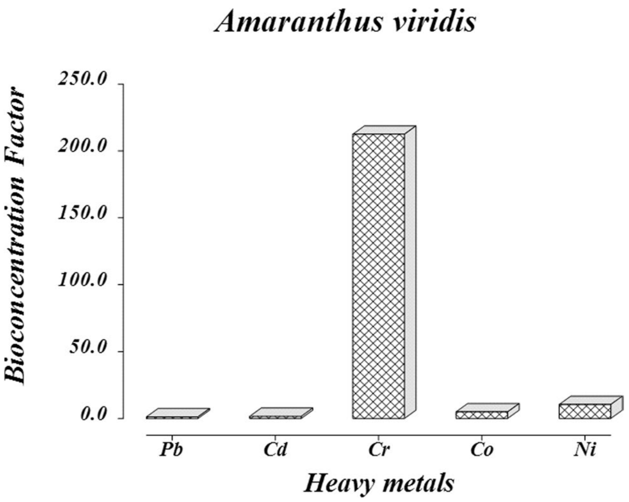


Fig. 11 Bioconcentration factor of *A. viridis*

Discussion

The present study focuses on exploring the potentials of two weed species *A. indica* and *A. viridis* in remediating heavy metals when grown in-situ over the contaminated site. The selected site for the said purpose falls in an industrial area constantly under the pressure of heavy metals liberated via paint industry discharges. Many species studied so far have shown good accumulation traits when grown in laboratories conditions under a confined setup (Ashraf et al. 2016; Upadhyay and Panda 2009). Such a study setup using the two experimental species has already been carried out previously as ex-situ experimentation where the species were grown in soil spiked with different doses of paint industry effluent by the author (Ramanlal et al. 2020). But the current work investigates the remediation potentials of the species when grown in-situ over soil contaminated with paint industry effluent and also to check the level of tolerance the plants exhibit under pressure when directly grown on-site rather than exposing to calculative doses of effluents. Such weedy species which are successful at the site are more economical compared to the other edible species which have specific requirements to be dealt with. Hence, explorations made in this direction will enhance the credibility of phytoremediation as a worthy technology which can lessen the adverse effects caused by heavy metal leaching to the underground aquifers as well as sequester high amounts of metals in its above-ground biomass which can be easily harvested thereby eliminating the need for expensive technologies to clean up multi-metal contaminated sites (Mench et al. 2009). Several experimentations have been conducted so far to seek heavy metal accumulation potential of several plants and to identify appropriate accumulator species for phytoremediation (Zhai et al. 2016). In the present study, a high organic matter content as well as high amount of Na and K was reported after in-situ remediation. The organic matter in the soil has the potential to form complexes which may increase or decrease the bioavailability of the metals based on the pH of the soil solution (Halim et al. 2003). The plant's growth over the contaminated soil enhanced the quantity of plant matter and its residual litter thereby increasing the micro-biota for its decomposition, increasing the overall quality of soil by carrying out nutrient cycling. Kee et al. (2018) reported that the process of phytoremediation enhances the soil quality by improving the fertility and organic matter of the soil. Herbaceous plants generally can restrict the mobility of the Pb near the root region preventing its further transport towards the shoot region (Sidhu et al. 2016). It has been noted that certain species when grown over highly metal-rich soils, tend to restrict the amount of metal to their root zones preventing further transport to the shoot zone as a defense mechanism (Bech et al. 2012). Pan et al. (2019) reported that plants growing naturally over mining areas show strong tolerance towards heavy metals and the amount of concentration present in their biomass is higher compared to that obtained in control species growing over uncontaminated soils. Ghosh and Singh (2005) stated that the acidic pH enhances the heavy metal uptake capability of plants; here the pH of the soil was reported to be 6.9 after in-situ remediation. Similarly, in the present study, both *A. indica* and *A. viridis* showed very high accumulation of Pb in both leaves and flowers which was 28.813 mg/kg Pb accumulation in flowers and 22.087 mg/kg in leaves of *A. indica* whereas 17.043 mg/kg in leaves and 11.893 mg/kg in the flowers of *A. viridis*. Wen et al. (2018) reported a contradictory result showing 7.82 mg/ kg of Pb accumulation by *Lolium perenne*, which was very low, compared to the current study. Species growing over contaminated soils show several mechanisms such as phytostabilization, hyperaccumulation, translocation and exclusion of the metals in their biomass depending upon their varied capacities and tolerance mechanisms (Suchkova et al. 2010). Sherameti and Varma (2015) observed that the plants which grow over the contaminated areas from many generations evolve into metallophytes, which specifically adapt to thrive well in metal-polluted mediums. Xu and Wang (2014) found Kentucky bluegrass could potentially phytostabilize Cd when grown over contaminated soils which supported the current findings in case of *A. indica* with a BCF value for Cd to be 0.9. Liu et al. (2019) stated Cd to inhibit the chlorophyll production mechanism in the plants thereby preventing its uptake by most of the plant species. Chandra and Kumar (2017) stated that only a few plant species are capable of tolerating high concentration of Cd in soils. The highest accumulation of Cd was observed in leaves and stem of *A. viridis* i.e. 0.2181 and 0.05293 mg/kg which was above the permissible limit recommended by WHO for Cd in plant species (being 0.02 mg/kg) (Nazir et al. 2015). The uptake of Cd increases with the availability of Cd in the soil but it also results in a gradual reduction in the plant growth (Eissa and Abeed 2019). Jeddi and Chaieb (2018) explained the presence of a linear relationship between heavy metal concentrations in soil and its uptake by the experimental species *Erodium glaucophyllum* where the higher the concentration of heavy metal in soil the higher is the plants' capability of HM absorption was observed based on which it was stated that certain species can be used as bioindicators of heavy metal pollution in the soil. In a study by Afonso et al. (2019) the author used *Solanum viarum* as as an experimental species and showed a TF greater than or equal to one 1 for metals such as Al, Cu, Zn, Mn, Cr, and Pb. Hence, the species exhibited a potential application over area contaminated with the metal tailings. Metal hyperaccumulation depends on the metallothioneins and phytochelatins which are peptides responsible for metal binding leading to metal detoxification or sequestering in the vacuoles of the plants (Callahan et al. 2006). Chandra and Kumar (2017) showed a reduction in the heavy metals Cr, Zn, Fe, Cd, Mn and Pb in post-treated distillery sludge except for Ni and Cu remediated by using 15 species native to the place of study. Kee et al. (2018) showed a similar trend with TF > 1 observed in *Werneria nubigena* plant species growing natively over metal-contaminated sites for Cd (2.36), Ni (2.42) and Pb (1.17). Khalid et al. (2019) reported the highest BCF values recorded for Ni and Cd > 1 in case of *Xanthium strumarium* where the value of Ni ranged between 1.02–1.65 which was lower compared to that of the present study which was 11.04 in *A. indica* and 10.48 in *A. viridis*. A huge fraction of total metal concentration in the soil is insoluble and hence it is not readily bioavailable to the plant species (Hesami et al. 2018). Plant species which can restrict translocation from the root region to shoot region can be categorized as beneficial phytostabilizers (Ali et al. 2013). Capozzi et al. (2020) during a study noted that the concentration of bio-available Cd to the roots of the plants is solely dependent on the native concentration of Cd in the soil; the higher the level of contaminants the lower the BCF value observed in the species. As per the suggestions given by Kahle(1993), a high concentration of metals in the roots may be due to the immobilization of the absorbed metals by insoluble organic polymers which are present in the root tissues of the plant. Nagajyoti et al. (2008) observed that the groundnut species when grown under the influence of 25% industrial effluent showed an increase in the physiological traits of the plant, hence at lower concentrations the effluent can enhance the growth parameters of the plant species. Afonso et al. (2019) suggested that the species capable of phytoaccumulating higher amounts of heavy metals from contaminated soil only makes the applicability of the species worthy for remediating such lands.

Conclusion

In the present study both the experimental species, *A. indica* and *A. viridis* showed good accumulation of heavy metals (Pb, Cd, Cr, Co and Ni) when grown over polluted soil. The BCF value in both the species (except for Cd which was reported to be 0.9) was > 1 for all the heavy metals and hence these species are categorized as high bioaccumulator species. The TF values for all the heavy metals was reported to be > 1 which shows a good transfer of sequestered HMs from root to the harvestable above ground parts. Thus it can be said that *A. indica* and *A. viridis* can be used on-site to remediate heavy metal contaminated soils. From the present study and several other studies carried out related to heavy metal remediation suggest that species natively growing over the polluted sites or regions evolve pollution tolerance mechanisms. Some species wherein can accumulate more amount of pollutants/heavy metals in its harvestable biomass which can be dumped further into the landfill sites while the other species exclude the heavy metals from entering its vessels thereby preventing the toxicity. Hence, studies pertaining to the growth of species on-site and checking its accumulatory trends therein can provide a clear cut vision into the applicability of the plant species for phytoremediation.

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Compliance with ethical standards

Conflict of interest There are no conflicts of interest amongst the authors.

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