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A Study on Heavy Metal Contamination of Yard Soils and its Remediation Potential by Weedy Species

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The present study was undertaken to analyse the phytoremediation potential of weedy plants growing at dump yards. Two dump yard sites were chosen. Based on the distribution and abundance, 11 weedy species were collected bi-annually using the plot method along with soil samples. Both plants and soils were analysed for heavy metals, and the bioconcentration factor (BCF) was calculated to assess the extent of soil contamination and the remediation potential of weedy plants.

The weed plants collected from two yard sites showed an accumulation of metals, and the rate of accumulation varied among plant species. In the species at the dumping yard site, a higher accumulation of metals was observed for *Panicum ciliare* (As and Zn), *Indigofera hirsuta* (Cd and Ni), *Chloris barbata* (Cr), and *Indigofera aspalathoides* (Pb). *Goiania macrocarpa* has accumulated more As, Cu, Ni, and Zn metals in the industrial yard. The accumulation levels in plant tissues were assessed through BCF in the whole plant. The study results confirm that *Panicum cillarae, Indigofera hirsuta,* and *Sida acuta* at dump yard soils and *Indigofera aspalathoides* at industrial yard soil reported BCF values of more than one, indicating the potential of these plants for phytoremediation for selected metals.

Six of the 11 weedy species were specific to accumulating metals from yard soils. They are *Indigofera aspalathodies* for Cd; *Sida acuta, Panicum ciliare,* and *Indigofera hirsuta* for As; *Oldenlandia corymbose* for Zn and As; and *Gouinia macrocarpa* for Zn. The findings suggest that weedy species growing naturally in the two yards sites adopted higher concentrations of the metals and can accumulate them to a higher degree in their body parts.

Keywords: phytoremediation, heavy metals, metal uptake, bioconcentration factor, hyperaccumulator.

Introduction

Soil and sediment metal contamination has been widely accepted due to the presence of heavy metals because of urban, rural, agricultural, and industrial activities in many dump yard sites (Burges et al., 2017; Pietrzykowski et al., 2018; Varkouhi et al., 2006; Varkouhi, 2009). The accumulation of these pollutants in the soil poses hazard to humans through food chain contamination (Ramirez et al., 2021). Among heavy metals, a few metals are recalcitrant pollutants known as potentially toxic elements (PTEs) (Ramirez et al., 2021). The prominent PTEs present in heavy metal-contaminated soils are Pb, Cd, Cr, Zn, As, etc., which are considered primary sources of human exposure to these metals (Pietrzykowski et al., 2018; Reilly Conor, 2008; Li et al., 2017). Therefore, sound strategies are required to harvest or immobilize PTEs from the soil through effective and economical techniques such as phytoremediation. Among phytoremediation techniques, the phytoextraction method is widely used to remove contaminants in the plant's harvestable parts (Chaney et al., 2020). Phytoextraction also aims to release the metal content in soil by inducing changes in their solubility or the pH/redox potential (Antosiewicz et al., 2008). The efficient uses of these techniques would allow treated soil to be reused for various purposes and prevent PTEs from entry into the environment and food chains. However, the success of phytoremediation depends on selecting plant species that can tolerate soil contamination and have remediation abilities. Many crop plants, such as brassica, alfalfa, and maize, have been tested with exclusive agronomic practices (Ramirez et al., 2021).

The careful selection of hyperaccumulator species is vital to achieving desirable results in the remediation of contaminants. Compared with other plants, these plants can absorb metals in high concentrations, and the concentration can exceed thousands of ppm (Reeves and Baker, 2000). In addition, transgenic plants (gene editing, stacking genes, and transformation) and native weedy plants are gaining importance for their strong endurance for local environmental conditions, high biomass, minimal or no agronomic practice tolerance to diseases (Venegas-Rioseco et al., 2021; Tussipkan and Manabayeva, 2022; Kafle et al., 2022; Panda et al., 2020; Yang et al., 2022). The present study aims to study the phytoremediation potential of weedy plants growing in and around solid waste dump yard sites.

Materials and Methods

Study areas

Visakhapatnam is a city in North Coastal Andhra Pradesh state, India, with over 30 significant and minor industries. Both industrialization and urbanization are responsible for generating solid waste in large quantities. More than 1000 tonnes of municipal solid waste per day are generated from various services of residential and commercial complexes. Solid waste has been disposed of at a dump yard, known as Kapuluppada dump yard, since 2001. It is 20 km from the city and near the national highway. The site is all under a natural depression covered with hills on two sides and a narrow opening connected to the highway.

The industrial site is a marshy area that covers more than 200 hectares in Gnanapuram, and port activities handle it for industrial purposes. The site is home to warehouses that process and store various goods. The marshy terrain poses a unique challenge for construction and maintenance, but port operations have successfully navigated and utilized the area. Overall, the industrial site benefits the local economy and contributes to regional industrial growth (*Fig. 1*).

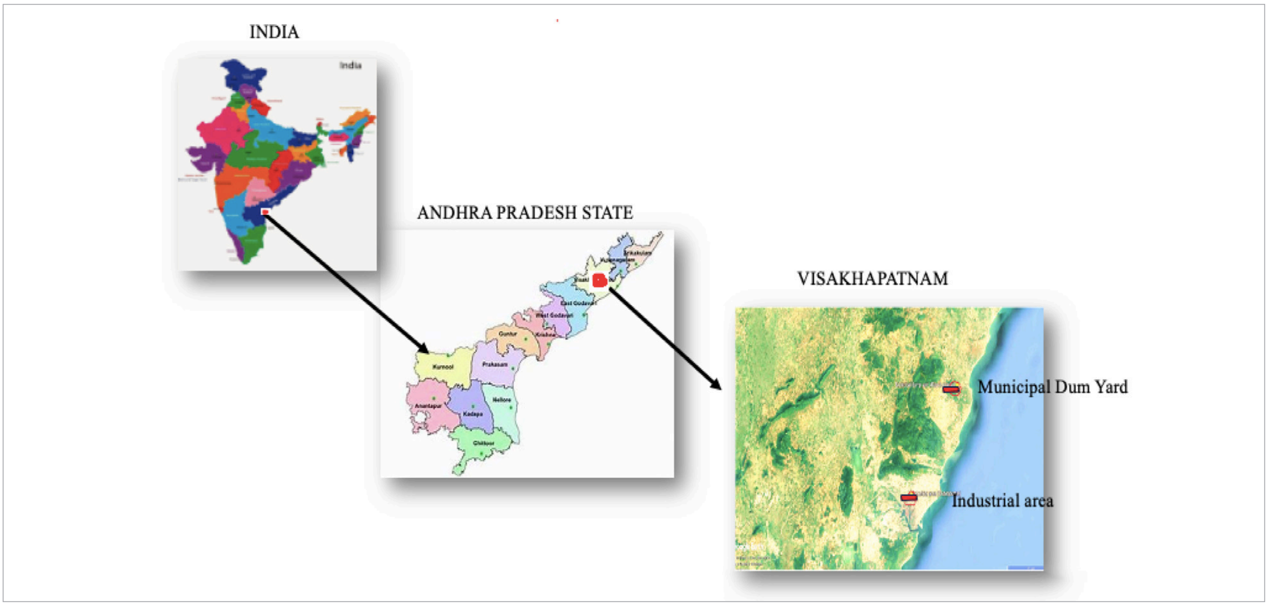
Plant species of the dump yard and industrial yard site

Eleven dominant species were selected from the study sites based on the distribution and abundance of weedy plants. The species are *Acalypha praemorsa* (Euphorbiaceae), *Chloris barbata* (Poaceae), *Goiania macrocarpa* (Rhamnaceae), *Indigofera hirsuta* (Leguminosae), *Indigofera aspalathoides* (Leguminosaceae), *Sida acuta* (Malvaceae), *Koeleria macrantha, Oldenlandia corymbose* (Rubiaceae), *Pouzolzia indica* (Urticaceae), *Panicum ciliare* (Poaceae), and *Sida rhombifolia* (Malvaceae). The plant and soil samples from the study site were collected biannually for two years. A plot of 10 m x 10 m area at the study site was selected. Each plot was divided into ten subplots, each of 1 m^3 area.

Physico-chemical characteristics of the soils

The parameters analysed for physicochemical characteristics were pH, conductivity, bulk density, organic matter, exchangeable calcium, magnesium, sodium, potassium, and available phosphates. They were estimated using standard methods Radojevic and Bashkin (1999).

Fig. 1. *Maps showing study areas of municipal dump yard and industrial yard sites in Visakhapatnam*



Bio concentration factor

The heavy metal concentration in plant biomass divided by the amount of heavy metal in soils is known as the bioconcentration factor (BCF) (Raj et al., 2020). It plays a key role in phytoremediation by providing data on metal absorption, mobilization into plant tissue, and storage in the various regions of the plant. (Newman and Unger, 2003). BCF values > 1 suggest a possible heavy metal hyperaccumulator species and are used to quantify the efficiency of heavy metal accumulation in plants (1) (Zhang et al., 2002).

$$BCF = \text{Heavy metal concentration in plant tissue} / \text{Heavy metal concentration in soil} \quad (1)$$

Acid digestion process and estimation of heavy metals in plants and soils

The collected plant and soil samples were dried at 60°C, crushed into a fine powder using mortar and pestle, and sieved using a 63 µm stainless steel sieve. The known amount of sieved material was digested in a mixture of 7:3:1, HNO3: HF: HClO4, for 2 hours, and after cooling, a known amount of ultrapure distilled water was added and filtered. The filtrate was further diluted to the required level, and the metal concentration was quantified using ICP-MS (Perkin Elmer 3110). CRM SO-1 (Canadian reference soil material) was used to ensure the quality of metal analysis (Machender et al., 2011).

Results and Discussion

Physico-chemical characteristics of the soils

The studied parameters include bulk density, pH, organic carbon, available phosphorus, exchangeable sodium, potassium, calcium, and magnesium. In addition, heavy metals such as arsenic (As), chromium (Cr), cobalt (Co), copper (Cu), molybdenum (Mo), lead (Pb), silver (Ag), stomium (St), nickel (Ni), rubidium (Rb), zinc (Zn) and vanadium (V) were analyzed (*Table 1*). The soil of the dump yard site was dark brownish black with a strong odor. The study soils were rich in organic carbon, ranging from 4.26% to 4.13%. The pH and bulk density of municipal dump yard and industrial yard soils were 7.05 ± 0.04 and 1.18 ± 0.11 (g/cc); 6.47 ± 0.33 and 1.11 ± 0.12, respectively. In the present study, both soils had a pH favorable for metal availability. Heavy metal concentrations in both yard soils were reported to be within permissible limits except for cadmium, copper, lead, and zinc in dump yard soils (WHO, 2000; FAO, 2007). The primary issue with heavy metals is that they cannot readily degrade and transform from one oxidation to another, making elements either less toxic or more water-soluble or convert into a volatilized form or less bioavailable (Garbisu and Alkorta, 2003). The use of plants and microorganisms helps remove metals from soil.

Table 1. *Physico-chemical characteristics of soils at the dump yard and the industrial yard*

Parameter	Dump yard soil Mean ± SD	Industrial yard soil Mean ± SD	Permissible limits
pH	7.05 ± 0.04	6.47 ± 0.33	7.50 to 8.94 *
Bulk density (g)	1.18 ± 0.11	1.11 ± 0.12	-
Organic matter (%)	7.53 ± 1.72	4.26 ± 1.66	-
Exchangeable Ca (%)	1.07 ± 0.08	0.59 ± 0.20	-
Exchangeable Mg (%)	0.05 ± 0.01	0.07 ± 0.02	-
Exchangeable Na (%)	0.01 ± 0.00	0.04 ± 0.02	-
Exchangeable K (%)	0.05 ± 0.01	0.02 ± 0.01	-
Available phosphates (%)	0.03 ± 0.01	0.03 ± 0.01	-
Arsenic (ppm)	2.50 ± 0.49	3.60 ± 1.66	5 mg/kg**
Barium (ppm)	961.71 ± 74.43	642.34 ± 54.76	-
Cadmium (ppm)	7.50 ± 0.96	5.78 ± 0.49	3-6 mg/kg**
Chromium (ppm)	107.64 ± 3.41	106.40 ± 14.57	100 mg/kg**
Cobalt (ppm)	10.42 ± 0.88	13.41 ± 5.28	20 mg/kg**
Copper (ppm)	229.46 ± 12.74	66.35 ± 13.55	135–270 mg/kg**
Lead (ppm)	746.29 ± 65.63	167.99 ± 28.58	250–500 mg/kg**
Manganese (ppm)	13.85 ± 0.97	16.35 ± 1.91	2000 µg/g
Nickel (ppm)	56.21 ± 2.99	61.50 ± 4.97	85 mg/kg**
Rubidium (ppm)	71.37 ± 1.72	67.55 ± 7.57	-
Strontium (ppm)	113.73 ± 62.72	111.82 ± 9.56	-
Vanadium (ppm)	68.51 ± 14.39	0.34 ± 0.06	100 mg/kg**
Zinc (ppm)	506.22 ± 47.37	256.28 ± 46.31	300–600 mg/kg**

Mean ± SD, standard deviation; ppm, parts per million; -, no data available;
**Ramirez et al., 2021; **WHO, World Health Organization (2000) and FAO (2007)*

Table 2. *Heavy metal concentration in weedy species at the dump yard*

Name of the heavy metal	Name of the weed plant species					
	Acalypha praemorsa	Chloris barbata	Indigofera aspalathoides	Indigofera hirsuta	Panicum ciliare	Sida acuta
Arsenic (ppm)	2.215 ± 1.491	0.301 ± 0.046	1.929 ± 0.042	4.941 ± 1.14	5.281 ± 0.113	7.729 ± 0.407
Cadmium (ppm)	0.759 ± 0.627	0.178 ± 0.133	12.189 ± 2.748	2.602 ± 0.83	5.319 ± 3.964	0.797 ± 0.09
Chromium (ppm)	17.13 ± 3.634	19.881 ± 3.05	18.873 ± 2.008	8.512 ± 1.96	12.599 ± 1.935	14.113 ± 2.65
Copper (ppm)	19.076 ± 1.619	15.528 ± 0.480	24.192 ± 0.304	16.956 ± 1.53	18.648 ± 0.576	34.751 ± 2.167
Lead (ppm)	39.735 ± 5.057	7.728 ± 0.555	44.45 ± 1.204	66.128 ± 13.89	2.89 ± 0.207	41.998 ± 4.374
Nickel (ppm)	7.049 ± 1.894	2.274 ± 0.473	13.519 ± 2.154	4.042 ± 2.51	7.031 ± 1.463	8.139 ± 1.981
Zinc (ppm)	66.214 ± 12.173	82.401 ± 10.409	76.142 ± 6.089	129.135 ± 4.13	138.132 ± 17.448	119.817±19.156

Mean ± SD, standard deviation; ppm, parts per million

Table 3. *Heavy metal concentration in weedy species at Industrial Yard*

Name of the heavy metal	Name of the weed plant species				
	Gouania microcarpa	Koeleria macrantha	Oldenlandia corymbosa	Pouzolzia indica	Sida rhombifolia
Arsenic (ppm)	26.019 ± 0.568	2.178 ± 1.466	5.281 ± 0.1333	2.075 ± 0.109	4.941 ± 1.14
Cadmium (ppm)	0.754 ± 0.17	0.214 ± 0.177	5.319 ± 3.964	0.262 ± 0.03	2.602 ± 0.83
Chromium (ppm)	12.795 ± 1.362	9.001 ± 1.909	12.599 ± 1.935	7.501 ± 1.408	8.512 ± 1.96
Copper (ppm)	26.648 ± 0.333	19.8 ± 1.68	18.648 ± 0.576	16.035 ± 1.814	16.956 ± 1.53
Lead (ppm)	25.102 ± 0.68	29.37 ± 3.738	2.89 ± 0.207	30.734 ± 3.201	66.128 ± 13.89
Nickel(ppm)	352.396 ± 1.74	8.388 ± 1.542	138.132 ± 1.463	151.58 ± 1.682	4.042 ± 2.51
Zinc(ppm)	26.019 ± 18.182	181 ± 19.276	5.281 ± 12.448	2.075 ± 29.234	129.135 ± 4.13

Mean ± SD, standard deviation; ppm, parts per million

Heavy metal uptake by weedy species

Heavy metal uptake by various plant species has been described by many researchers, and it has been suggested that phytoremediation is a viable and eco-friendly technology to treat heavy metal pollution of soils or sludges at a low cost (Ramirez et al., 2021). The accumulation of heavy metals such as As, Cd, Cr, Cu, Pb, Ni and Zn in plant tissues of the present study is presented in *Tables 2* and *3*. The results were discussed with earlier research findings (*Table 4*).

Among the species of dump yard sites, higher levels of metal accumulation for Cr and Pb were reported in *Indigofera hirsuta* and Cd and Ni in *Indigofera aspalathoides* and Zn in *Panicum ciliare*, whereas As and Cu accumulation was reported maximum in *Sida acuta*. The minimum level of metal accumulation for AS, Cd, Cr, Cu, and Ni was reported in *Chloris barbata*, Pb in *Panicum ciliare*, and Zn in *Acalypha praemorsa*. *Goiania macrocarpa* accumulated all studied metals at significant levels except Pb and Cd in industrial yard soils. *Gouania macrocarpa* accumulated higher metal concentrations of As, Cr, Cu, and Ni in the industrial yard site. Other metals reported higher were Cd in *Oldenlandia corymbose*, Pb in *Sida rhombifolia* and Zn in *Koeleria macrantha* species.

In contrast, *Pouzolzia indica* showed lower metal uptake for As, Cr, Cu and Zn. The uptake of these metals and their transport or accumulation pattern in plants are strongly influenced by soil properties, type of plant species, metal concentration, and availability (Garbisu and Alkorta, 2003). The present study shows that metal accumulation is specific to species in a dump yard, whereas in industrial yard soils, *Goiania macrocarpa* and *Oldenlandia corymbose* exhibit multiple metal uptake. This might be due to more soil organic acid content, such as citric, malic, and histidine, which act as potential ligands for heavy metals and could play a role in their tolerance and detoxification (Adreer et al., 2019). The study results also confirm that a higher concentration of heavy metals was recorded in the soil and weed species of the dump yard site compared with the industrial yard site. The variation in the uptake of heavy metal concentration in these plants of the same site may also be ascribed to the difference in their morphology and physiology for heavy metal uptake, exclusion, accumulation, and retention (Zhang et al., 2019).

From *Table 4*, it is observed that in the present study, heavy metal uptake by weedy plants in both dump yards and industrial areas was reported as low compared with the test species (*Thlaspi caerulescens, Pteris vittate, and Brassica juncea*) used by various researchers respective to the heavy metal studied. The identified significant feature of the present study is that all weedy plants showed an uptake for multiple metals at a time, and the species survived without any inhibition. Another advantage is aesthetically pleasing, has a solar energy-driven cleanup with minimal environmental disruption, and preserves topsoil (Tanghu et al., 2011). One of the reasons for limited metal uptake by weedy species is the bioavailability of metals in the soil medium apart from diversity. This can be altered by adding bridgeable chelating agents and micronutrients (Van Ginneken et al., 2007).

Table 4. *Heavy metal uptake by various plant species reported by previous studies and the present study*

Heavy metal	Heavy metal uptake reported by previous studies		Heavy metal uptake reported by present studies
	Plants and values	Reference	
Arsenic (As)	Pteris vittate 8331 ppm	Kalve et al., 2011	Dump yard (ppm) Uptake range Minimum: *Chloris barbara 0.301* Maximum: *Sida acuta 7.725* Industrial Yard (ppm) Uptake range Minimum: *Pouzolzia indica 2.075* Maximum: *Gouania macrocarpa 26.019*
	Pteris ryukyuensis 3647 ppm	Srivastava et al., 2006	
	Corrigiola telephiifolia 2110 ppm	García-Salgado et al., 2012	
Cadmium (Cd)	Azolla pinnata 740 ppm	Rai, 2008	Dump yard (ppm) Uptake range Minimum: *Chloris barbara 0.178* Maximum: *Indigofera aspalathoides 12.189* Industrial Yard (ppm) Uptake range Minimum: *Koeleria macrantha 0.214* Maximum: *Oldenlandia corymbosa 5.319*
	Turnip landraces 52.94–146.95 ppm	Li et al., 2016	
Chromium (Cr)	Pteris vittata 20 675 ppm	Kalve et al., 2011	Dump yard (ppm) Uptake range Minimum: *Indigofera hirsuta 8.512* Maximum: *Chloris barbara 19.881* Industrial yard (ppm) Uptake range Minimum: *Pouzolzia indica 7.501* Maximum: *Gouania macrocarpa 12.795*
Copper (Cu)	Scirpus littoralis – copper sulfate, 1000 ppm	Bhattacharya et al., 2006	Dump yard (ppm) Uptake range Minimum: *Chloris barbara 15.528* Maximum: *Sida acuta 34.751* Industrial yard (ppm) Uptake range Minimum: *Pouzolzia indica 16.035* Maximum: *Gouania macrocarpa 26.480*
Lead (Pb)	Scirpus littoralis – lead nitrate, 1000 ppm	Bhattacharya et al., 2006	Dump yard (ppm) Uptake range Minimum: *Chloris barbara 15.529* Maximum: *Indigofera hirsuta 66.956* Industrial yard (ppm) Uptake range Minimum: *Oldenlandia corymbosa 2.890* Maximum: *Sida rhombifolia 66.128.*
	Medicago sativa 43 300 ppm	Koptsik, 2014	
	Brassica juncea 10 300 ppm	Koptsik, 2014	
	Brassica nigra 9400 ppm	Koptsik, 2014	
Nickel (Ni)	Scirpus littoralis nickel sulfate 1000 ppm	Bhattacharya et al., 2006	Dump yard (ppm) Uptake range Minimum: *Chloris barbara 2.274* Maximum: *Indigofera aspalathoides 13.519* Industrial yard (ppm) Uptake range Minimum: *Sida rhombifolia 4.042* Maximum: *Gouania macrocarpa 10.921*
	Isatis pinnatiloba 1441 ppm	Altinözlü et al., 2012	

Heavy metal	Heavy metal uptake reported by previous studies		Heavy metal uptake reported by present studies
	Plants and values	Reference	
Zinc (Zn)	Thlaspi caerulescens 51 600 ppm	Sakakibara et al., 2011	**Dump yard (ppm)** Uptake range Minimum: *Chloris barbara 82.401* Maximum: *Panicum ciliare 138.132* **Industrial yard(ppm)** Uptake range Minimum: *Pouzolzia indica 151.580* Maximum: *Gouania macrocarpa 352.396*
	Eleocharis acicularis 11 200 ppm	Sheoran et al., 2009; 2011	
	Thlaspi calaminare 10 000 ppm	Kucharski et al., 2005	
	Deschampsia cespitosa 3614 ppm	Kucharski et al., 2005	

The critical variable to define phytoremediation is the bioconcentration factor (BCF), plant biomass, and soil mass (Clemens, 2001). The evaluation of metals' BCF showed the capacity of some of the studied plants to remediate selected metals. Concerning individual metals at dump yard soils, As showed a BCF of 1 or > 1 in *Panicum ciliare, Indigofera hirsuta,* and *Sida acuta*. Similarly, *Indigofera aspalathoides* BCF for Cd was > 1 (2.71). In industrial soils, only *Oldenlandia corymbose* reported BCF of > 1 for Zn and As (*Figs. 2* and *3*). The results conclude that BCF values in weedy species are higher in dump yard soils compared with industrial soils. Findings suggest that weedy species growing naturally in the contaminated environment have adopted higher concentrations of the metals and can accumulate them to a higher degree in their body parts. The results of BCF were used to evaluate the potential ability of these weedy species to get heavy metals in their tissue and their suitability for phytoremediation.

Fig. 2. *Bioconcentration factor of weedy species in the dump yard*

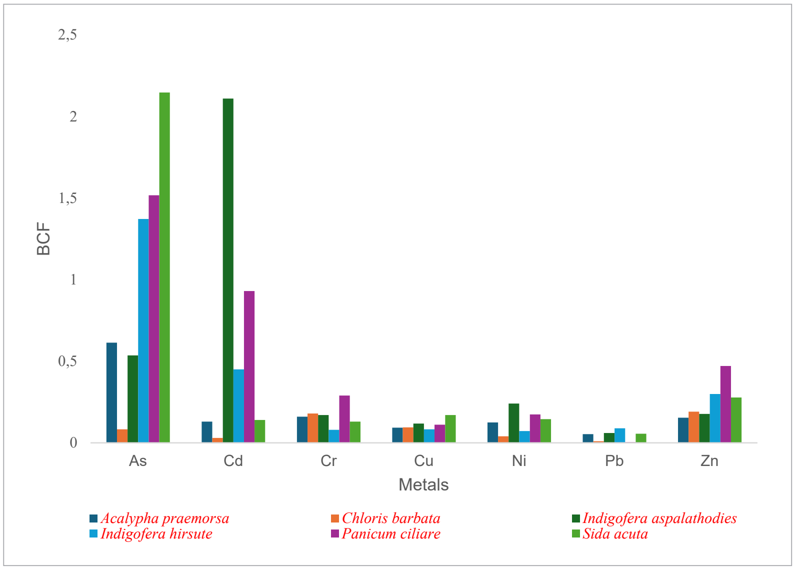
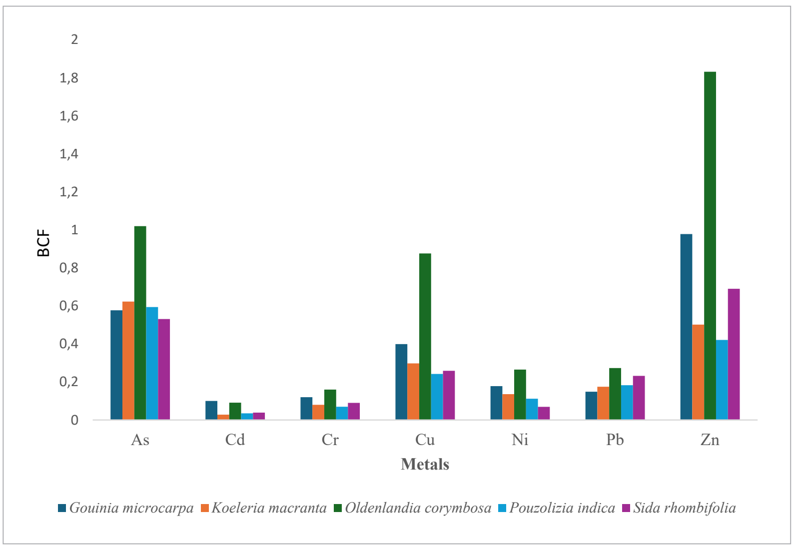


Fig. 3. *Bioconcentration factor of weedy species in the industrial yard*



Conclusion

In the present work, the weed plants collected from two yard sites showed an accumulation of metals specific to plant species. Among the species at dump yard sites, a higher accumulation of metals was observed in *Panicum* *ciliare* for As and Zn, *Indigofera hirsuta* for Cd and Ni, *Chloris barbata* for Cr, and *Indigofera aspalathoides* for Pb. *Goiania macrocarpa* accumulated As, Cu, Ni, and Zn metals in industrial yard soils. Based on the bioconcentration factor BCF values reported above 1 for weedy species, it may be confirmed that *Panicum cillarae, Indigofera hirsuta,* and *Sida acuta* in the dump yard site and *Indigofera aspalathoides* in the industrial yard site are effective in the natural remediation of metals from the soils of these respective areas.

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