Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Assessment of phytoremediation potential of native plant species naturally growing in a heavy metal-polluted industrial soils

Avaliação do potencial fitorremediador de espécies vegetais nativas que crescem naturalmente em solos industriais poluídos por metais pesados

R. Naz[a*†], M. S. Khan[a], A. Hafeez[b], M. Fazil[a], M. N. Khan[a,c†], B. Ali[b], M. A. Javed[d], M. Imran[a], A. A. Shati[e], M. Y. Alfaifi[e], S. E. I. Elbehairi[e,f] and A. E. Ahmed[g,h*]

[a]Islamia College, Department of Botany, Peshawar, Pakistan
[b]Quaid-i-Azam University, Department of Plant Sciences, Islamabad, Pakistan
[c]The University of Agriculture, Agriculture University Public School and College, Boys – AUPS & C, Peshawar, KP, Pakistan
[d]Government College University, Institute of Industrial Biotechnology, Lahore, Pakistan
[e]King Khalid University, Faculty of Science, Biology Department, Abha, Saudi Arabia
[f]Egyptian Organization for Biological Products and Vaccines – VACSERA Holding Company, Cell Culture Lab, Giza, Egypt
[g]King Khalid University, College of Science, Department of Biology, Abha, Saudi Arabia
[h]South Valley University, Faculty of Veterinary Medicine, Department of Theriogenology, Qena, Egypt

Abstract
The present study was carried out in Hayat Abad Industrial Estate located in Peshawar to assess the levels of cadmium (Cd) that were present in the soil as well as the plant parts (Roots and shoots). To evaluate the phytoremediation potential of the plants different factors i.e. Bioconcentration Factor (BCF), Translocation Factor (TF), and Bioaccumulation Coefficient were determined. These plants were grown in their native habitats (BAC). We have analysed, cadmium concentration from soil which are collected from 50 different locations ranged from 11.54 mg/Kg (the lowest) to 89.80 mg/Kg (highest). The maximum concentration (89.80 mg/Kg) of cadmium was found in HIE-ST-16L Marble City and HIE-ST-7 Bryon Pharma (88.51 mg/Kg) while its minimum concentration (12.47 mg/Kg) were detected in the soil of Site (HIE-ST-14L Royal PVC Pipe) and (11.54 mg/Kg) at the site (HIE-ST-11 Aries Pharma). Most plant species showed huge potential for plant based approaches like phyto-extraction and phytoremediation. They also showed the potential for phyto-stabilization as well. Based on the concentration of cadmium the most efficient plants for phytoextraction were *Cnicus benedictus, Parthenium hysterophorus, Verbesina encelioides, Conyza canadensis*, *Xanthium strumarium, Chenopodium album, Amaranthus viridis, Chenopodiastrum murale, Prosopis juliflora, Convolvulus arvensis, Stellaria media, Arenaria serpyllifolia, Cerastium dichotomum*, *Chrozophora tinctoria, Mirabilis jalapa, Medicago polymorpha, Lathyrus aphaca, Dalbergia sissoo, Melilotus indicus* and *Anagallis arvensis*. The cadmium heavy metals in the examined soil were effectively removed by these plant species. *Cerastium dichotomum*, and *Chenopodium murale* were reported to be effective in phyto-stabilizing Cd based on concentrations of selected metals in roots and BCFs, TFs, and BACs values.

Keywords: bioconcentration factor, cadmium, translocation factor, soil and plants, industrial zone, Peshawar.

Resumo
O presente estudo foi realizado em Hayat Abad Industrial Estate, localizado em Peshawar, para avaliar os níveis de cádmio (Cd) que estavam presentes no solo, bem como nas partes da planta (raízes e brotos). Para avaliar o potencial de fitorremediação das plantas foram determinados diferentes fatores, ou seja, Fator de Bioconcentração (BCF), Fator de Translocação (TF) e Coeficiente de Bioacumulação. Essas plantas foram cultivadas em seus habitats nativos (BAC). Analisamos a concentração de cádmio do solo coletada em 50 locais diferentes, variando de 11,54 mg/Kg (o mais baixo) a 89,80 mg/Kg (o mais alto). A concentração máxima (89,80 mg/Kg) de cádmio foi encontrada em HIE-ST-16L Marble City e HIE-ST-7 Bryon Pharma (88,51 mg/Kg) enquanto sua concentração mínima (12,47 mg/Kg) foi detectada no solo do local (HIE-ST-14L Royal PVC Pipe) e (11,54 mg/Kg) no local (HIE-ST-11 Aries Pharma). A maioria das espécies de plantas mostrou um enorme potencial para abordagens baseadas em plantas, como fitoextração e fitorremediação. Eles também mostraram o potencial de fitoestabilização. Com base na concentração de cádmio, as plantas mais eficientes para fitoextração foram *Cnicus benedictus*, *Parthenium hysterophorus*, *Verbesina encelioides*,

*e-mail: reshmanaz@yahoo.com; aabdelrahman@kku.edu.sa
†These authors contributed equal to this work.
Received: May 30, 2022 – Accepted: August 25, 2022

Conyza canadensis, *Xanthium strumarium*, *Chenopodium album*, *Amaranthus viridis*, *Chenopodiastrum murale*, *Prosopis juliflora*, *Convolvulus arvensis*, *Stellaria media*, *Arenaria serpyllifolia*, *Cerastium dichotomum*, *Chrozophora tinctoria*, *Mirabilis jalapa*, *Medicago polymorpha*, *Lathyrus aphaca*, *Dalbergia sissoo*, *Melilotus indicus* e *Anagallis arvensis*. Os metais pesados de cádmio no solo examinado foram efetivamente removidos por essas espécies de plantas. *Cerastium dichotomum* e *Chenopodium murale* foram relatados como eficazes na fitoestabilização do Cd com base nas concentrações de metais selecionados nas raízes e nos valores de BCFs, TFs e BACs.

Palavras-chave: fator de bioconcentração, cádmio, fator de translocação, solo e plantas, zona industrial, Peshawar.

1. Introduction

Abiotic stress is defined as the negative impact of non-living factors on living organisms in a specific environment. The stresses include drought (Wahab et al., 2022), cold, salinity (Khan et al., 2023; Hussain et al., 2023), low or high temperatures (Saeed et al., 2022), heavy metals (Nawaz et al., 2022), pesticides (Anwar et al., 2023), nutrient deficiency (Adnan et al., 2022; Ahmad et al., 2022) and other environmental extremes. Abiotic stresses, especially hypersalinity (Ali et al., 2022a, b, c) and drought (Farooq et al., 2022) and heavy metals (Ma et al., 2022a, b; Zainab et al., 2021) are the primary causes of crop loss worldwide. Plants respond to environmental stresses at multiple levels such as molecular (Singh et al., 2022), cellular, tissue, anatomical, morphological, and whole-plant physiological levels (Mehmood et al., 2021; Amna et al., 2021; Afridi et al., 2022; Dola et al., 2022).

Phytoremediation is the direct use of living green plants for in situ, or in place, removal, degradation or containment of contaminants in soils, sludges, sediments, surface water and groundwater (Devi et al., 2016). Phytoremediation technique is a clean, efficient, inexpensive and environmentally non-disruptive method. It is less costly, non-invasive and is publicly acceptable way to redress the removal of environmental contaminants (Schwitzguebel et al., 2009). This technique is potentially applicable to a variety of contaminants and it encompasses a number of different methods that can lead to contaminant removal through accumulation (phytoextraction) or phytovolatilization, phytodegradation or immobilization (phytostabilization) (Devi et al., 2016). Phytoremediation is becoming a technology of choice for remediation projects in developing countries because it is cost-efficient and easy to implement. The biological processes are ultimately solar driven, phytoremediation is almost tenfold cheaper than engineering-based remediation such as soil excavation, soil washing or burning. Phytoextraction is one of the phytoremediation techniques that exploits the unique ability of some plants to accumulate unusually high amount of chemicals/toxic metals including salt ions in their harvestables (Devi et al., 2016; Hauptvogl et al., 2019). Phytoremediation encompasses five processes of metal removal from soil or water. These processes include: rhizofilteration, phytostabilisation, phytoextraction, phytovolatilization and phytodegradation (Okunowo and Ogunkanmi, 2010). A list of plant species reported for phytoremediation of toxic elements includes the genera *Acer*, *Arundo*, *Astragalus*, *Betula*, *Brassica*, *Cannabis*, *Castor*, *Eucalyptus*, *Helianthus*, *Jatropha*, *Linum*, *Miscanthus*, *Phalaris*, *Pisum*, *Populus*, *Quercus*, *Ricinus*, *Robinia*, *Salix*, *Sarcocornia*, *Sorghum*, *Zea mays* and many others (Calheiros et al., 2012; Barbosa et al., 2015; Dixit et al., 2015; Ziarati et al., 2015; Luo et al., 2016; Mahar et al., 2016; Pandey et al., 2016; Tariq and Ashraf, 2016; Fiorentino et al., 2017; Gerhardt et al., 2017; Mleczek et al., 2017). Similarly identification and phytoremediation potential ability of five plant species [millet (*Eleusine coracana*), mustard (*Brassica juncea*), jowar (*Sorghum bicolor*), black gram (*Vigna mungo*), and pumpkin (*Telfairia occidentalis*)] surveillance in metal contaminated soils were reported by Padmapriya et al. (2016). Phytoremediation Potentials of Some Nigerian Weeds (*Phyllanthus amarus, Chromolaena odorate, Stachytarpheta indica, Bryophyllum pinnatum* and *Murraya koenigii)* in the remediation of soil polluted by heavy metals were documented by Eddy and Ekop (2007). Plants used for remediation purposes should be able to grow in less favourable edaphic conditions concerning soil salinity, soil pH, and water content. They should create a dense root system and be resistant to pathogens and diseases (Mleczek et al., 2017; Solanki et al., 2022).

Heavy metals are currently of much environmental concern. The adverse environmental effects of excessive heavy metals include contamination of water and soil, phytotoxicity and soil degradation, and pose serious risks to human health. Their destructive impacts on environments are causing increasing concern in scientists, politicians and the general public worldwide (Nazir et al., 2011; Sajad et al., 2020). The pollution caused by heavy metals has been reported as critical environmental problem and has profound effects on health of human beings (Farid et al., 2013). Numerous struggles have been done to invent processes for the restoration of effected soils, comprising ex-situ method of washing of soil with physiochemical technique, and immobilization of heavy metal toxins as ex situ method (Ali et al., 2013). In recent times, the phytoextraction of metal contaminants from disturbed soils has been fascinated due to its lesser cost of implementation than others and loads of environmental paybacks (Farid et al., 2013). Pollution of soils and groundwater with Cd is a global problem. Different approaches have been proposed for prevention of Cd contamination or its remediation. Wastewater cleaning, control of Cd levels in landfills and mines, and reduction of the use of Cd-contaminated phosphate fertilizers may help reduce soil and water contamination (Makino et al., 2006; Qiao et al., 2017). Various approaches could be used to remove Cd from the soil and to prevent food chain contamination. One of the proposed approaches is soil washing with chemicals, where different amendments have been proposed for agricultural use (Bashir et al., 2018; Subašić et al., 2022). It has been reported that high-biomass cultivars be utilized with suitable chemical actions to increase the solubility of heavy metals in soil and transportation from plant roots to the shoots (Begonia et al., 2002).

Cadmium (Cd) is a non-essential element for plants and humans but is present in many soils in excessive amounts. When it enters into the food chain, it poses a major threat to the living biota. The control of Cd accumulation in plants is complicated by the fact that most of the essential nutrient transporters, such as copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn), also facilitate Cd uptake (Raza et al., 2020). Among the heavy metals, the toxicity of cadmium (Cd) is considered 2-20 times greater than that of others (He et al., 2015). Cd may be produced as part of industry processes, such as Zn smelting, and historically, it has found uses in batteries, semiconductors, electroplating, and stabilizers. Phosphatic (P) fertilizers are a major source of Cd in agricultural systems, and increased Cd content in soil was observed in countries where P fertilizer is used extensively (McLaughlin et al., 2021). Absorption of Cd from the soil and its (re)distribution between roots and shoots is a highly regulated process where several key players are involved: metal transporters of the root cell plasma membrane, xylem and phloem loading/unloading and leaf/shoot sequestration and detoxification. Plants absorb cadmium through the roots, and there are several factors that can affect availability of cadmium to plants, such as above-mentioned pH, the rhizosphere, and organic acids (Ismael et al., 2019; Saleem et al., 2022). Cd affects plants by inhibiting photosynthesis and respiration, reducing water and nutrient uptake, altering gene and protein expression, inducing and inhibiting enzymes, enhancing accumulation of reactive oxygen species (ROS), enhancing lipid peroxidation, and disturbing metabolism (Semane et al., 2010; Faryal et al., 2022). The objectives of this study were 1) to determine the concentration of Cadmium and to find out ways and means for eradicating its environmental impacts, 2) to quantify the concentration levels of Cadmium soil and their transfer and accumulation in plants, 3) to investigate the uptake potential of Cadmium of the collected plants by calculating bioconcentration factor (BCF) and to calculate the translocation of the accumulated Cadmium from root to shoots by calculating translocation factor.

2. Materials and Methods

2.1. Site details

The Peshawar district Peshawar has an area of 1,257 km^2, situated between 33°44/ and 34°15/ North (latitude) and 71°22/ and 71°42/ East (longitudes) and approximately 1173 feet. Surrounded in the Western by Mohmand and Khyber Agency, in the Northern side by Charsadda District, by Nowshera District in the Eastern and the southern-east parts are bounded by tribal areas joining Kohat and Peshawar District. With semi-arid climate District Peshawar has very hot summers and mild winters (Khan et al., 2018). The climate of Peshawar is tropical with a mean maximum temperature of 40 °C in summer (May-Aug) and 10 °C in winter (Nov-Mar). The relative humidity varies from 46% in June to 76% in August. The District is almost a fertile plain. The central part of the district consists of fine alluvial deposits. The cultivated tracts consists of a rich, light and porous soil, composed of a pretty even mixture of clay and sand which is good for cultivation (Jamshed et al., 2014). Hayatabad Township is situated approximately 15km, south west of the main city centre spread over an area of 3360 acres. It is close to Khyber agency and is separated from by the hills at phase- VI and -VII. Hayatabad is the place of diverse cultures from all sorts of families from Khyber Pakhtunkhwa and also is a home for Afghani refugees for so many years since the start of cold war. Presently, it consists of seven phases i.e. Phase –I (523 acres), Phase-II (749 acres), phase –III (342 acres), phase- VI (326 acres), phase- V (307 acres) phase- VI (674 acres) and phase- VII (439 acres). Two tributaries of River Kabul are passing through the area naming Narai Khwar and Gandao Khwar. The public has been provided with facilities of parks including Bagh-e-Naran, Tatara Park, Shalman Park and Ladies Park. Hayatabad Industrial Estate (HIE) is a famous industrial zone, considered as 3rd largest industrial estate in KP province, covering an area of about 868 acres. It is located on main Jamrud road in the west of Peshawar city. According to Sarhad Development Authority, the current registered units in HIE are 389 by 2015. Among these industries two big paper manufacturing industries have set up at Hayatabad Industrial Estate (Khan et al., 2016) as shown in Figure 1.

2.2. Collection and identification of plants

Twenty different plant taxa viz (*Cnicus benedictus, Parthenium hysterophorus, Verbesina encelioides, Conyza canadensis*, *Xanthium strumarium, Chenopodium album, Amaranthus viridis, Chenopodiastrum murale, Prosopis juliflora, Convolvulus arvensis, Stellaria media, Arenaria serpyllifolia, Cerastium dichotomum*, *Chrozophora tinctoria, Mirabilis jalapa, Medicago polymorpha, Lathyrus aphaca, Dalbergia sissoo, Melilotus indicus* and *Anagallis arvensis*) were collected from 4 spots and 20 different sites which are located in Hayat Abad Industrial Estate, Peshawar. The samples being dried in a proper way in a newspaper (stem, leaves and roots), preserved. Polythene bags, newspapers and blotting papers were changed after a week to avoid fungus attack, free moisture and rotting. The specimens were treated with $HgCl_2$ solution in Ethylene to protect them from insect and fungal attacks. Collected plants were identified with the help of flora of Pakistan (Stewart, 1967a, b; Ali, 1978; Qaiser et al., 2019), other literature (Badshah et al., 2016; Khan and Badshah, 2019; Khan et al., 2022), The plant names were confirmed with the International Plant Names Index (IPNI, 2022) and The Plant List (2022).

2.3. Soil collection and analysis

The soil sampling tubes were used to collect the soil samples up to a depth of 20 cm from each site and each plant zone. The samples were air dried, grinded for composite sample, sieved through 2 mm screen to remove the stone pieces and large root particles. The soil samples were placed at room temperature for Cadmium (Cd) metal detection. Cadmium was analyzed on Graphite Furnace Atomic Absorption Spectrophotometer with standard procedure of (Abbas et al., 2010).

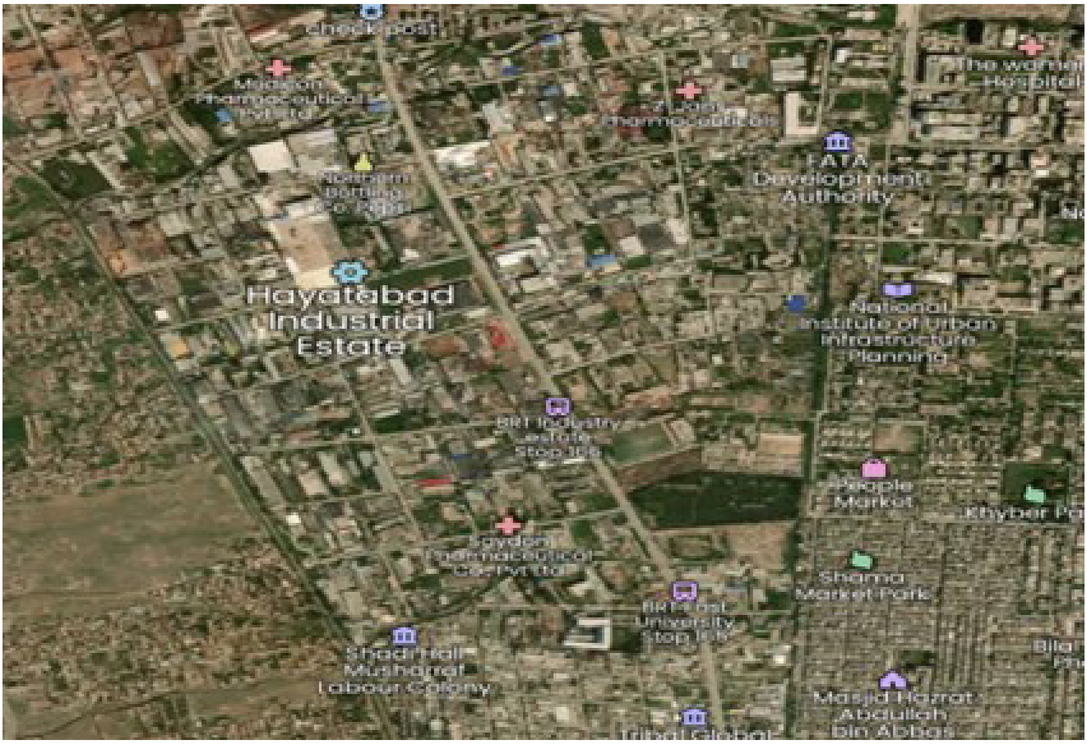

Figure 1. Map of Hayat Abad Industrial Estate, Peshawar.

2.4. Analysis of accumulated cadmium (Cd) in plant samples

Each plant part was thoroughly washed with tape water and then with distilled water in order to remove dusts and soil particles. The clean plant part was dried in an oven at 105 °C for 24 hours. Then the samples were digested according to the methods of (Awofolu 2005; Awofolu et al., 2005), 0.5 g samples of the plant was taken into a 100 mL beaker, 5 mL concentrated (65%) HNO_3 and 2 mL $HCLO_4$ was added to it and heated on hot plate until the digest become clear. The digest were allowed to cool and then filtered through a Whatman filter paper. The filtrate was collected in a 50 mL volumetric flask and diluted to the marks with distilled water. The filtrate was used for the analysis of Cadmium (Cd) metal. The samples were placed at room temperature for Cadmium (Cd) metal detection. Cadmium (Cd) metal was measured with Atomic Absorption Spectrophotometer (AAS, Perkin- Elmer 700).

2.5. Bio concentration and translocation factor

Bio concentration factor (BCF) indicates the efficiency of a plant in up taking Cadmium (cd) from soil and accumulating them into its tissues. "It is a ratio of the concentration of the Cadmium (Cd) in shoots to that in its roots". It is calculated as follows (Equation 1).

$$BCF = \frac{C\,harvested\,tissue}{C\,soil} \quad (1)$$

where $C_{harvested\ tissue}$ is the concentration of the metal in the plant harvested tissue (roots, stem or leaves) and C_{soil} is the concentration of the same metal in soil.

Translocation factor (TF) shows the efficiency of the plant in translocating the accumulated Cadmium (Cd) from roots to shoots. "It is a ratio of the concentration of the Cadmium (Cd) in shoots to that in its roots". It is calculated as given Equation 2:

$$TF = \frac{C\,shoots}{C\,roots} \quad (2)$$

where C shoots is the concentration of the metal in shoots and C roots is the concentration of the metal in roots. Both bioconcentration factor and translocation factor of the collected plants for Cadmium metal were calculated according to the above formulas. From these calculations, the feasibility of the plants for the phytoextraction of the Cadmium (Cd) were evaluated via (Adesodun et al., 2010; Nazir et al., 2011; Sajad et al., 2020).

3. Results

3.1. Cadmium (Cd) concentration in plants (mg/kg) in spot-1

We have analyzed the cadmium concentration from different spot of hayatabad industrial zone viz spot-1, spot-2, spot-3 and spot-4. Results shown in Table 2, Figure 2 described the Cd metal concentrations in root, shoot and as well as in soil. Maximum Cd concentration were found in shoot (283.7±0.01) of *Cnicus benedictus* followed by roots (282.6±0.022) while lesser amount were observed in soil (21.4±0.3) at HIE-ST-2 Imperial Furniture. *Parthenium* *hysterophorus* shoot had maximum concentration of Cd (310.8±0.08) followed by root (292.2±0.20) and soil (20.28±0.21) at site HIT-ST-3 Iftikhar Eng. Works. *Verbesina encelioides* and *Xanthium strumarium* shows highest Cd concentration in shoot fragments (309.4±0.01) and (456.1±0.20) followed by roots (307.3±0.01) and (417.2±0.085) at site HIE-Beside Main road-Prime Poly Tax and HIE-ST-4 FF Steel. Similarly *Conyza canadensis* detect maximum Cd contents in root (393.6±0.01) followed by shoot (39.9±0.11) and soil (36.35±0.03) as given in Table 2. It has been resulted that the quantity of Cd in soil, as well as in the roots and shoots of plants, were reported to vary from "17.68-46.98", " 21.5-451.7" and "22.5-456.1" mg/Kg respectively as compared to the standard (Table 1).

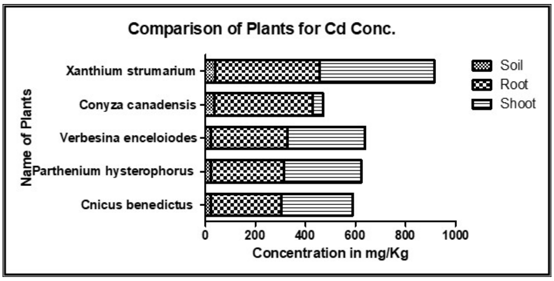

Figure 2. Conc. of Cd in Soil, Roots & Shoot of Spot-1 in different plants of Hayatabad Industrial Estate.

3.2. Cadmium (Cd) concentration in plants (mg/kg) in spot-2

Results revealed that total of five plant species (*Chenopodium album, Amaranthus viridis, Chenopodium murale, Prosopis juliflora, Convolvulus arvensis*) were observed in Cd concentration (mg/kg) at spot-2. Shoots, roots and soil has varying amount of Cd contents in all the observed plants. Therefore Cd concentration in shoots of *Amaranthus viridis* (389.7±0.21) at site (HIE-ST-7 Rehman Industry) were observed maximum followed by *Chenopodium album* (358.5±0.017) at (HIE-ST-5 Stanley Pharma), *Prosopis juliflora* (241.8±0.01) at (HIE-ST-17 LHaq Alluminium), *Convolvulus arvensis* (126.7±0.02) at (HIE-Beside Road Khan Polymers Pvt Ltd), while less amount of Cd were detected in *Chenopodium murale* (76.5±0.05) at (HIE-ST-2 Tri Star Adhesive Pro.). Roots Cd concentration

Table 1. Cadmium at the Standard Metal Concentration according to EPA and WHO.

Sr. No.	Name of Metal	Effects	Standards by EPA & WHO
1	Cadmium (Cd)	· Carcinogen as per Environmental Protection Agency (EPA) · Short Term effects: Sickness, Vomiting, Loose stool, Muscle cramp, Liver damage/injury, renal failure. · Kidney damage, Liver damage, Bone damage and Blood damage.	· According to EPA: the maximum level of containment is 0.5 mg/Kg. · According to WHO: The maximum cadmium limit is: 0.003 mg/L

Table 2. Plant species and their concentration of Cadmium (mg/kg) in different partsin Hayat Abad Industrial Estate.

Hayat Abad Industrial Estate Spots	Species	*C.P	Name of Site	Conc. of Cadmium (mg per Kg)		
				Soil	Root	Shoot
Spot 1	*Cnicus benedictus* L.	1.	HIE-ST-2 Imperial Furniture	21.4±0.3	282.6± 0.022	283.7±0.01
	Parthenium hysterophorus L.	2.	HIE-ST-3 Iftikhar Eng. Works	20.28±0.21	292.2±0.20	310.8±0.08
	Verbesina encelioides (Cav.) Benth. and Hook. f. ex A. Gray	3.	HIE-Beside Main Road-Prime Poly Tax	20.67±0.05	307.3± 0.01	309.4±0.01
	Conyza canadensis L. Cronquist.	4.	HIE-ST-6 Sana Aluminum Indust.	36.35±0.03	393.6± 0.01	39.9±0.11
	Xanthium strumarium L.	5.	HIE-ST-4 FF Steel	40.5±0.02	417.2±0.085	456.1±0.20

*C.P means Collection Point, HIE means Hayatabad Industrial Estate, and ST means Street, Conc. of Cd in soil & in the parts of plant, is shown as mean (n=3) ±SD.

were varying from 388.1±0.10- 62.7±0.4 in decreasing order. Highest amount of Cd were present in *Amaranthus viridis* followed by *Chenopodium album*, *Convolvulus arvensis*, *Prosopis juliflora* and *Chenopodium murale* (388.1±0.10, 352.3±0.01, 350.9±0.04, 342.8±0.004 and 62.7±0.43) at different sites. Therefore soil Cd contents were also depicted from 43.9±0.056 to 26.67±0.30 in which highest were recorded for *Amaranthus viridis* (43.9±0.056), *Chenopodium murale* (42.15±0.078), *Prosopis juliflora* (31.77±0.45), *Chenopodium album* (27.52±0.03) and *Convolvulus arvensis* (26.67±0.30) as shown in Table 3, Figure 3.

3.3. Cadmium (Cd) concentration in plants (mg/kg) in spot-3

Results in Table 4, Figure 4 representing Cd concentrations in five different plant taxa (*Stellaria media, Arenaria serpyllifolia, Cerastium dichotomum, Chrozophora tinctoria,* and *Mirabilis jalapa*) and its different parts (shoots, roots and soil) in Spot 3. Highest amount of Cd in soil were found in *Stellaria media* (46.98±0.66) followed by *Cerastium dichotomum* (41.25±0.12), *Arenaria serpyllifolia* (39.45±0.03), *Mirabilis jalapa* (23.1±0.41) while lowest were found in *Chrozophora tinctoria* (17.68±0.26) mg/kg at sites (HIE-ST-9 Deluce Food Ind. Pvt Ltd., HIE-ST-10 NeutraBiotics, HIE-ST-9 Coca Cola Ind. Pvt Ltd., HIE-ST- 16L Marble City, and HIE-ST-5 Bilour Industries). Roots Cd concentration were found to be highest in *Stellaria media* (420.3±0.07) at (HIE-ST-9 Deluce Food Ind. Pvt Ltd) while lowest were found in *Cerastium dichotomum* (21.5±0.012) at (HIE-ST-10 NeutraBiotics). Similarly shoots Cd concentration were also analyzed, thus representing highest content in in *Stellaria media* (416.2±0.11) at (HIE-ST-9 Deluce Food Ind. Pvt Ltd) while lowest were detected in *Cerastium dichotomum* (22.5±0.11) at (HIE-ST-10 NeutraBiotics).

3.4. Cadmium (Cd) concentration in plants (mg/kg) in spot-4

Spot 4 comprised on 5 plant taxa (*Medicago polymorpha, Lathyrus aphaca, Dalbergia sissoo, Melilotus indicus* and *Anagallis arvensis*) having Cd concentration at different levels in shoot, roots, and soil as given in Table 5, Figure 5. *Medicago polymorpha* shows highest percentage of shoot

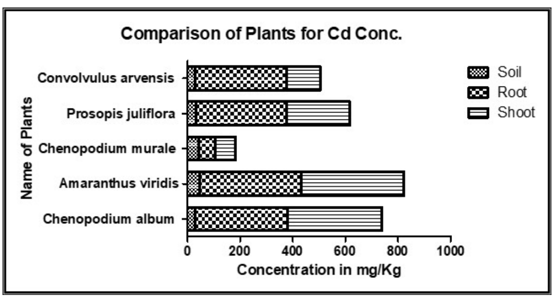

Figure 3. The concentration of Cadmium in Soil, Roots, and Shoot of Spot-2 in different plants of Hayatabad Industrial Estate.

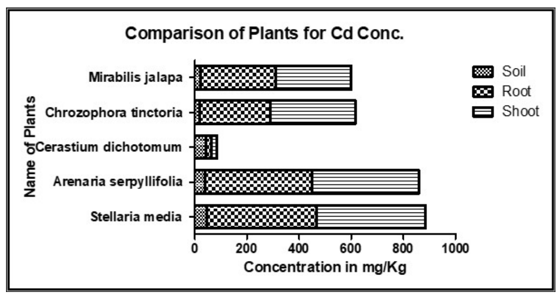

Figure 4. Concentration of Cadmium in Soil, Roots, and Shoot of Spot-3 in different plants of Hayatabad Industrial Estate.

Table 3. Plant species and their concentration of Cadmium (mg/kg) in different partsin Hayat Abad Industrial Estate.

Hayat Abad Industrial Estate Spots	Species	*C.P	Name of Site	Concentration of Cadmium (mg/Kg)		
				Soil	Root	Shoot
Spot 2	*Chenopodium album* L.	1.	HIE-ST-5 Stanley Pharma	27.52±0.03	352.3±0.01	358.5±0.017
	Amaranthus viridis L.	2.	HIE-ST-7 Rehman Industries	43.9±0.056	388.1±0.10	389.7±0.21
	Chenopodium murale L.	3.	HIE-ST-12 Tri Star Adhesive Pro.	42.15±0.078	62.7±0.43	76.5±0.05
	Prosopis juliflora (Sw.) DC.	4.	HIE-ST-17L HaqAlluminium	31.77 ±0.45	342.8 ±0.004	241.8 ±0.01
	Convolvulus arvensis L.	10	HIE-Beside Road-Khan Polymers Pvt Ltd.	26.67±0.30	350.9±0.04	126.7±0.02

*C.P means Collection Point, HIE means Hayatabad Industrial Estate, and ST means Street, Conc. of Cd in soil and in the parts of plant, is shown as mean (n=3) ±SD.

(369.5±0.12), followed by roots (363.1±0.018), and soil (26.51±0.25) at site (HIE-Beside Road-Prime PVC Pipe) while *Lathyrus aphaca* had maximum Cd concentration in roots (420.9±0.046), shoots (408.4±0.054) and soil had less amount of Cd detected (30.16±0.68) at site HIE-ST-9 Pepsico Industries. *Dalbergia sissoo* possesses maximum Cd contents in roots (451.7±0.08), shoots had (421.4±0.06) and soil had (30.16±0.048) at site (HIE-Beside Road Shangai PVC Pipe). Similarly *Melilotus indicus* at site (HIE-ST-6 Lahore Still Mills) and *Anagallis arvensis* at site (HIE-ST-10 ARY Steel Mills) observed varying amount of Cd concentration in shoots, roots and in soil.

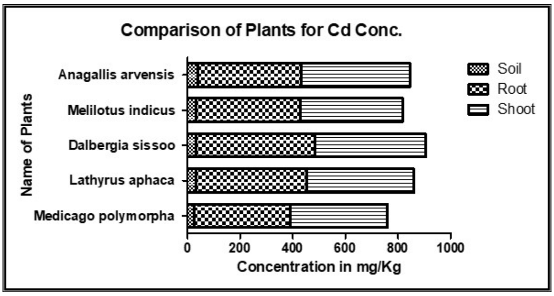

Figure 5. Concentration of Cadmium in Soil, Roots and Shoot of Spot-4 in different plants of Hayatabad Industrial Estate.

3.5. Evaluation of plants for the phytoremediation of Cd and their factors

The analysis of each plant was made via calculations in order to determine the different factors i.e. bioconcentration factor (BCF), the translocation factor (TF), and the Bioaccumulation Coefficient (BAC). The potential of each

Table 4. Plant species and their concentration of Cadmium (mg/kg) in different partsin Hayat Abad Industrial Estate.

Hayat Abad Industrial Estate Spots	Species	*C.P	Name of Site	Concentration of Cadmium (mg/Kg)		
				Soil	Root	Shoot
Spot 3	*Stellaria media* (L.) Vill.	11	HIE-ST-9 Deluce Food Ind. Pvt Ltd.	46.98±0.66	420.3±0.07	416.2 ±0.11
	Arenaria serpyllifolia L.	12	HIE-ST-9 Coca Cola Ind. Pvt Ltd.	39.45±0.03	408.9±0.065	410.8±0.75
	Cerastium dichotomum L.	13	HIE-ST-10 NeutraBiotics	41.25±0.12	21.5±0.012	22.5±0.11
	Chrozophora tinctoria (L.) Raf.	14	HIE-ST-5 Bilour Industries	17.68±0.26	271.5±0.004	325.4±0.04
	Mirabilis jalapa L.	15	HIE-ST- 16L Marble City	23.1±0.41	287±0.00	290 ±.077

*C.P means Collection Point, HIE means Hayatabad Industrial Estate, and ST means Street, Conc. of Cd in soil & in the parts of plant, is shown as mean (n=3) ±SD.

Table 5. Plant species and their concentration of Cadmium (mg/kg) in different partsin Hayat Abad Industrial Estate.

Hayat Abad Industrial Estate Spots	Species	*C.P	Name of Site	Concentration of Cadmium (mg/Kg)		
				Soil	Root	Shoot
Spot 4	*Medicago polymorpha* L.	16	HIE- Beside Road -Prime PVC Pipe	26.51±0.25	363.1±0.018	369.5±0.12
	Lathyrus aphaca L.	17	HIE-ST-9 Pepsico Industries	30.16±0.68	420.9±0.046	408.4±0.054
	Dalbergia sissoo Roxb.	18	HIE-Beside Road- Shangai PVC Pipe	30.16±0.048	451.7±0.08	421.4±0.06
	Melilotus indicus (L.) ALL.	19	HIE-ST-6 Lahore Still Mills	30.15±0.94	396.9±0.016	390±0.08
	Anagallis arvensis L.	20	HIE-ST-10 ARY Steel Mills	38.21±0.23	393.6±0.09	411.7±0.05

*C.P means Collection Point, HIE means Hayatabad Industrial Estate, and ST means Street, Conc. of Cd in soil & the parts of plant, is shown as mean (n=3) ±SD.

plant species for the phytoremediation of Cd were assessed, and the results were given intable 6. Most of the plant species were shown to be feasible for the phytoremediation of Cd metal which is based on Cd concentration in shoots, roots and in soil Bioconcentration factor, translocation factor, and the bioaccumulation coefficient values were determined for all examined species. Bioconcentration factor (BCF) values ranges from 2.06 to 12.11 in spot 1, 0.61 to 12.82 in spot 2, 0.66 to 29.31 in spot 3, 6.96 to 33.20 in spot 4, while translocation factor (TF) ranges from 1.02-5.26 in spot 1, 0.69-2.76 in spot 2, 0.25-1.95 in spot 3 and 0.57-2.32 in spot 4, similarly bioaccumulation coefficient values (BAC) ranges from 8.497 to 20.42 in site 1, 1.29 to 8.89 in site 2, 1.29 to 21.38 in site 3 and 5.08 to 77. 16 in site 4. Therefore the study revealed that highest BCF were recorded for *Anagallis arvensis* (33.20), *Stellaria media* (29.31), *Dalbergia sissoo* (23.88). Other highest BCF values were recorded for *Mirabilis jalapa* (16.51), *Lathyrus aphaca* (15.27), *Chenopodium album* (12.82) and *Medicago polymorpha* (12.69) while lowest BCF were observed for *Chenopodium murale* (0.61) and *Cerastium dichotomum, Prosopis juliflora* (0.66) each in all four spots. Feasibility of the plant for the phytoremediation of Cadmium (Cd) suggest that only five plant species are metal excluders and 15 plant species were metal indicators in all 4 spots. Plants that accumulate metals in the tissues of their leaves, roots, and stems are referred to as M.I++ = Metal indicators. The metal concentrations in these tissues generally reflect the metal concentrations in the soil. Plants with highest values of TF were *Cnicus benedictus* (5.26), *Chenopodium murale* (2.76), *Anagallis arvensis* (2.32). Other important plant species with high TF values were *Prosopis juliflora* and *Cerastium dichotomum* (1.95) each, *Chrozophora tinctoria* (1.83), *Parthenium hysterophorus* (1.78), and *Verbesina encelioides* (1.67) while *Mirabilis jalapa* (0.25), *Stellaria media* (0.52), and *Dalbergia sissoo* (0.57) had lowest TF values in all four spots. Finally BAC values were also calculated and found highest in *Anagallis arvensis* (77.16) followed by *Chrozophora tinctoria* (21.38). Other high BAC values were recorded for *Verbesina encelioides* (20.42), *Stellaria media* (15.41), *Lathyrus aphaca* (15.05), *Parthenium hysterophorus* (14.00), *Dalbergia sissoo* (13.67) in decreasing orders. Least BAC values were recoded for *Prosopis juliflora, Cerastium dichotomum* (1.29) each and *Chenopodium murale* had 1.70. All these plants are the most important that are capable of Cd metal phytostabilization. Based on the soil concentration of Cd and BCFs, TFs, BACs values, certain plants viz*Cnicus benedictus, Parthenium hysterophorus, Verbesina encelioides, Conyza canadensis*, *Xanthium strumarium, Chenopodium album, Amaranthus viridis, Chenopodiastrum murale, Prosopis juliflora, Convolvulus arvensis, Stellaria media, Arenaria serpyllifolia, Cerastium dichotomum*, *Chrozophora tinctoria, Mirabilis jalapa, Medicago polymorpha, Lathyrus aphaca, Dalbergia sissoo, Melilotus indicus* and *Anagallis arvensis* are the most capable plants for the phytoextraction of Cd metal. Many plants that are known to accumulate metals in their above-ground tissues at levels that are much higher than those found in the soil are referred to as metal hyper-accumulators, and their scientific term is H++. Similarly most plants (Table 6) like *Chenopodium album* and *Prosopis juliflora* contains all the qualities for phytoextraction and phytostabilization of heavy metals from polluted soil and could and remove the Cd metals from polluted soil showing its best phytoremediation function. *Melilotous indicus* show hyper-accumulation of cadmium from the polluted soil. *Stellaria media* are good in phytoextraction of Cd from polluted soil. Similarly, most plants like *Medicago polymorpha, Dilbergia sissoo,* and *Chrozophora ticntoria* contains all the qualities for phytoextraction and phytostabilization of heavy metals from polluted soil with08-10 mg/Kg concentration they can remove the Cd metals from polluted soil showing its best phytoremediation function. The Environmental Protection Agency (EPA) has decided that a Cd concentration of up to 0.5 mg/kg is permissible. According to the data presented in (Table 1), the Cd concentration in the shoots of all plants is higher than the limits that were permissible by EPA & WHO.

4. Discussions

Industrial process cause pollution problem. Industries generate wastes in the form of effluents, solid waste and fumes etc (Hadjispyrou et al., 2001). Studies revealed that there is no proper arrangement for treatment of industrial effluents and solid waste management in Pakistan, in general, and Khyber Pakhtunkhwa province, in particular (Hladun et al., 2015). Many researchers in the academic world believe that water bodies that are subjected to the effects of industrial pollution suffer negative consequences. Therefore, appropriate zoning is essential in order to forestall the unfavorable effects that improper management of industrial waste might have on the ecosystem (Lane et al., 2005). Furthermore, the industrial development and environmental protection can be made possible by applying the concept of industrial symbiosis. To reduce the impacts on environment, focus on environmental performances is of great importance (Lee et al., 2004). Our results support the observation of (Okunowo and Ogunkanmi, 2010) and investigated phytoremediation potential of water hyacinth plant on Cd. (Sajad et al., 2020) reported phytoremediation potential of some plant species of the Lower Dir, Khyber Pakhtunkhwa, Pakistan which support our results. Similarly (Hauptvogl et al., 2019) studied phytoremediation potential of fast-growing energy plants. (Padmapriya et al., 2016) phytoremediation potential of some agricultural plants on heavy metal contaminated mine waste soils. (Devi et al., 2016) investigated phytoremediation potential of some halophytic species for soil salinity. Plants with a high bioconcentration factor (BCF) and low translocation factor (TF) have the potential for phytostabilization while plants with both BCFs and TFs greater than one have the potential to be used for phytoextraction (Nouri et al., 2011). Plant abilities to uptake, translocate, and transform heavy metals, as well as to limit their toxicity, may be significantly enhanced via genetic engineering. Strategies for obtaining plants suitable for effective soil clean-up and tolerant to excessive concentrations of heavy metals are critically assessed by (Koźmińska et al., 2018). Three abundant herb species of crude oil contaminated sites, namely *Xanthium*

Table 6. Plant species and their respective bioconcentration factors, translocation factors, and bioaccumulation coefficients for cadmium metal.

Collection Point	Species	Bio-concentration and Translocation Factor & the Bioaccumulation Coefficient			Feasibility of the plant for the phytoremediation of Cadmium (Cd).
		BCF	TF	BAC	
Spot 1	*Cnicus benedictus* Linn.	2.06	5.26	10.87	M.I++
	Parthenium hysterophorus L.	7.83	1.78	14.00	M.I++
	Verbesina encelioides (Cav.) Benth. and Hook. f. ex A. Gray	12.11	1.67	20.42	M.I++
	Conyza canadensis (L.) Cronquist.	8.81	1.02	9.05	M.I++
	Xanthium strumarium L.	7.672	1.107	8.497	M.I++
Spot 2	*Chenopodium album* L.	12.82	0.69	8.89	Ɛ+
	*Amaranthus viridis*L.	8.84	1.00	8.87	M.I++
	Chenopodium murale L.	0.61	2.76	1.70	M.I++
	Prosopis juliflora (Sw.) DC.	0.66	1.95	1.29	M.I++
	Convolvulus arvensis L.	9.23	1.21	11.20	M.I++
Spot 3	*Stellaria media* (L.) Vill.	29.31	0.52	15.41	Ɛ+
	Arenaria serpyllifolia L.	11.50	0.78	9.03	Ɛ+
	Cerastium dichotomum L.	0.66	1.95	1.29	M.I++
	Chrozophora tinctoria (L.) Raf.	11.67	1.83	21.38	M.I++
	Mirabilis jalapa L.	16.51	0.25	4.23	Ɛ+
Spot 4	*Medicago polymorpha* L.	12.69	0.94	11.96	Ɛ+
	Lathyrus aphaca L.	15.27	0.98	15.05	M.I++
	Dalbergia sissoo Roxb.	23.88	0.57	13.67	M.I++
	Melilotus indicus (L.) ALL.	6.96	0.72	5.08	M.I++
	Anagallis arvensis L.	33.20	2.32	77.16	M.I++

Ɛ+ = metal excluders; M.I++ = metal indicators.

strumarium (L.), *Ageratum conyzoides* (L.) and *Polygonum hydropiper* (L.) from oil contaminated soils was best studied by (Akram and Deka, 2021) which support our work. Some literature also suggested the phytoremediation of vascular plants from different regions of the world, the most prominent were; (Nouri et al., 2009) documented 11 genera and 6 families (*C. virgata, A. verus, C. botrys, S. barbata, Z. clinopodioides, C. bijarensis, C. congestum, S. orientalis, Cousinia* sp., *C. juncea, M. jacquemontii* and *V. speciosum*) from Hame Kasi mine of Northwest Hamadan province in Iran with accumulation of heavy metals in soil and uptake by these plant species with phytoremediation potential. (Uera et al., 2007) analyzed phytoremediation potentials of selected tropical plants [(*Solanum lycopersicum*), mustard (*Brassica alba*), vetiver grass (*Vetiveria zizanioedes*), cogon grass (*Imperata cylindrica*), carabao grass (*Paspalum conjugatum*), and talahib (*Saccharum spontaneum*)] to remove EtBr (ethidium bromide) from laboratory wastes. Shoots and roots of the 12 plant species and the associated soil samples were analyzed by measurement of total concentrations of trace elements using atomic absorption spectrophotometer. *Scrophularia scoparia* was the most suitable for phytostabilization of Pb, *Centaurea virgata, Echinophora platyloba* and *Scariola orientalis* had the potential for phytostabilization of Zn and *Centaurea virgata* and *Cirsium congestum* were the most efficient in phytostabilization by Nouri et al. (2011). Twenty-four native plant species were identified in different tissues (roots, stems, and leaves) and in underlying soils. Accumulation factors (AF) in the shoots, translocation (TF) from roots to shoots, and bioconcentration (BCF) from soil-to-roots were determined by Marrugo-Negrete et al. (2016). *Paspalum scrobiculatum* and its phytoremediation potential were also documented by Ogbo et al. (2009) which support our results. Present study showed that these vascular plant species growing on contaminated sites may have the potential for phytoremediation.

5. Conclusion

Cd levels were determined to be present in Twenty (20) different plant species that belonged to different families during the course of this investigation. Both the roots and the shoots of each plant were analyzed to see whether or not they contain any metals. The concentration of Cd in the soil of Four (04) spots was found in the range of 17.68-46.98 mg/Kg respectively. The maximum concentration of Cd was found in the soil of Hayat Abad Industrial Estate Street No.19 (Left Side) (Spot 2) near Deluce Food Industries Pvt. Ltd. (46.98 mg/Kg) while its minimum concentration was reported in the soil Hayat Abad Industrial Estate Street No.5 near Bilour Industries (17.68 mg/Kg) (Spot 3). The most feasible plants for phytoextraction of Cd are from Spot 4 *Anagallis arvensis* with BCF value (33.20), Spot 2 *Stellaria media* (29.31), Spot 3 *Dalbergia sissoo* (33.88). The most feasible plants for Phytostabilization of Cd are *Cnicus benedictus*. With TF values (5.26) from Spot 3, *Chenopodium murale* (2.76) from Spot 1 and *Anagallis arvensis* (2.32) from Spot 4.

Acknowledgement

The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through large Groups (Project under grant number R.G.P.2/ 161/ 43).

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