sustainability

Article

Potential of Ornamental Trees to Remediate Trace Metal Contaminated Soils for Environmental Safety and Urban Green Space Development

Shamim Umer [1], Zaheer Abbas [2], Irfan Aziz [3], Maria Hanif [4], Zainul Abideen [3,5,*], Simeen Mansoor [6], Neelofar Hamid [7], Mohammad Ajmal Ali [8,*] and Fahad M. Al-Hemaid [8]

[1] Department of Botany, University of Agriculture, Faisalabad 38000, Pakistan; shameeemnoor111@gmail.com
[2] Department of Botany, Division of Science and Technology, University of Education Lahore, Lahore 60700, Pakistan; zaheerbot@gmail.com
[3] Dr Muhammad Ajmal Khan Institute of Sustainable Halophyte Utilization, University of Karachi, Karachi 75270, Pakistan; irfanaziz@uok.edu.pk
[4] Department of Biotechnology, Lahore College for Women University, Lahore 60700, Pakistan; mariahanif81@yahoo.com
[5] Institute of Plant Ecology, Justus-Liebig-University Giessen, D-35392 Giessen, Germany
[6] Department of Genetics, University of Karachi, Karachi 75270, Pakistan; simeenm@uok.edu.pk
[7] Department of Botany, University of Karachi, Karachi 75270, Pakistan; neelofarhamid@hotmail.com
[8] Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia; fhemaid@ksu.edu.sa
* Correspondence: zuabideen@uok.edu.pk (Z.A.); ajmalpdrc@gmail.com (M.A.A.)

Abstract: Heavy metals are notoriously toxic pollutants which can potentially harm living beings and are serious health hazards. The aim of the present study was to assess the levels of cadmium (Cd) and nickel (Ni) throughout the year in the urban areas of the densely populated industrial city of Faisalabad in eight commonly raised ornamental tree species with phytoremediation potential. High levels of Cd and Ni were recorded in all study areas, with spatio-temporal heterogeneity. Heavy metal uptake varied among plant species with Cd and Ni in soil ranging between 6.78–8.57 mgkg^{-1} and 46.31–55.85 mg kg^{-1} respectively. Plant species accumulated 6.73–8.98 mg kg^{-1} Cd and 26.42–52.50 mg kg^{-1} Ni with *Conocarpus erectus*, *Dalbergia sissoo* and *Bismarckia nobilis* showing higher accumulation potential than others. *Dalbergia sissoo* accumulated the highest levels of Ni and was shown to a good bio-indicator for this metal. The highest accumulation of Cd was recorded in *Conocarpus erectus* (9 mg kg^{-1}), followed by *Dalbergia sissoo* (8.2 mg kg^{-1}) and *Bismarckia nobilis* (8.1 mg kg^{-1}) while the leaves of *Azadirachta indica* retained the lowest (6.3 mg kg^{-1}) Cd levels. The highest levels of metals were accumulated by all species during the summer season while the second highest were observed in the autumn season. The study revealed that ornamental species can help in minimizing heavy metal pollution as well as providing green space in urban settings for maintaining a clean and healthy environment.

Keywords: automobiles; cadmium; *Conocarpus*; environmental pollution; heavy metals; nickel

Citation: Umer, S.; Abbas, Z.; Aziz, I.; Hanif, M.; Abideen, Z.; Mansoor, S.; Hamid, N.; Ali, M.A.; Al-Hemaid, F.M. Potential of Ornamental Trees to Remediate Trace Metal Contaminated Soils for Environmental Safety and Urban Green Space Development. *Sustainability* **2023**, *15*, 8963. https://doi.org/10.3390/su15118963

Academic Editor: Shibao Chen

Received: 10 April 2023
Revised: 11 May 2023
Accepted: 14 May 2023
Published: 1 June 2023

1. Introduction

High concentrations of metalloids and trace metals can pollute soils owing to industrial emissions, metal waste disposal, pesticides, coal combustion residues, mine tailings, leaded gasoline, paints, synthetic fertilizers, manures, wastewater irrigation, petrochemical spillage, atmospheric deposition, and sewage sludge [1–3]. Any metallic compound with a relatively high density that is toxic even at low concentrations is referred to as a trace metal [4]. Trace metals include aluminum (Al), arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), nickel (Ni), thallium (Tl), zinc (Zn), etc. [5]. It is commonly observed that the presence of trace metals often reduces the biodegradation of organic pollutants in the soil [6–8]. Utilization of poor-quality water, land degradation, and overexploitation of cultivated lands for farming have resulted in food insecurity at the global level [9–11]. The soils obtain trace metal pollutants from various sources, such as metal waste disposal, industrial effluents and air pollutants [12]. One of the main sources of air pollutants is traffic load in urbanized settings, which not only harms ecosystems and human health through the direct ingestion of contaminated food, but also via physical contact with polluted soil, as well as through the food chain (via soil–plant–human or soil–plant–animal–human interaction) [13]. In view of the health risks associated with urbanization, emphasis should be placed on sustainable methods for mitigating trace metal pollution. The use of ornamental plants for phytoremediation and for the beautification of urban areas seems a plausible choice [14]. Pollutants that are released into the atmosphere as suspended particles not only make the air quality poor, but, if settled on roadside soil, could harm other living beings, and pose a significant risk to humans via dermal contact, inhalation, or through direct ingestion [13].

Cadmium (Cd) is one of the most toxic metals, has a lethal impact on all biota [15], and is a nuisance to urban residential areas. Industrialization at a rapid pace and the frequent use of automobiles are the main sources of Cd pollution in urban areas. This metal is often released from automobiles through the wear and tear of tires and brakes and the corrosion of automobile parts [16]. Increasing traffic load underpins the worsening situation of the pollution in megacities worldwide. Cadmium appears to be more toxic to biological diversity than Pb [17]. The high mobility of Cd in soil makes it readily absorbable for plants, with subsequent inhibition of chlorophyll content and its synthesis, reduction in plant growth, and disruption to enzyme function as well as other effects on metabolic processes [18,19]. It enters the food chain via plants and affects animal health, including that of human beings. Cadmium is also known to disrupt cell cycle and DNA damage leading to necrosis and cell death [15]. It has no role in plant or human physiology and ingestion, even at low levels, can be lethal for metabolic functions [20]. Cadmium exposure may result in renal and pulmonary disorders and can replace minerals such as calcium (Ca) due to its equal charge, ionic radius, and chemical activity [21].

Nickel (Ni) is also a poisonous trace metal with concentrations ranging between 10 to 40 parts per million (ppm) in most soils, but exceeding 1000 ppm in serpentine soils or soils enriched with Ni-bearing ores [22]. It is an essential micronutrient for enzymatic activities and nitrogen metabolism in plants and is particularly associated with urease activity [23]. In excess concentrations, it acts as a toxic metal that reduces growth, photosynthesis and transpiration and causes oxidative damage, chlorosis, necrosis, etc. [9]. In humans, nickel acts as carcinogenic compound in the nasal cavity, lungs, and larynx and leads to cardiovascular and renal disorders as well as various types of allergies [24]. Excess Ni disrupts water relations, ion homeostasis and mineral uptake, as well as photosynthesis and other metabolic activities, resulting in oxidative stress and membrane damage in plants [25]. Contamination of Ni has increased in recent years, primarily due to its release into the environment by human activities such as metal mining, fossil fuel combustion, and urban and industrial waste [26,27].

The toxic effects of Cd and Ni may be avoided by eliminating/minimizing their concentrations to safer limits. None of the techniques (physical, chemical, mechanical) can be practiced in residential areas except for phytoremediation, as it is cost effective [28]. Phytoremediation using ornamental plants may be utilized as a non-destructive tool compared with other techniques [29]. For instance, *Pelargonium hortorum* and *Mesembryanthemum criniflorum* are not only metal hyperaccumulators but can also be grown as ornamental species in some areas [30]. Plants of industrial use as well as ornamental purpose are eco-amiable and can be grown easily in all types of areas [30,31]. Many ornamental plants are used in perfume industries and some of the known species are reported to have phytoremediation ability which could be efficiently utilized for improving urban environments [32]. Tree species such as *Alstonia scholaris*, commonly known as Dita bark tree is a beautiful evergreen plant with a tall stem, dark green shiny leaves, and scented flowers that exude a milky extract on cutting. Although this plant is found abundantly in Australia, Africa, India and Indonesia, it is successfully cultivated in Pakistan purely for ornamental purposes. This tree is very efficient at absorbing pollutant metals from an open environment.

Azadarichta indica, belonging to the family Meliaceae, is typically grown in tropical and semi-tropical regions, can tolerate high to extreme temperature, and can be a good indicator for heavy metals. Similar to other tree species, such as *Bougainvillea spectabilis, Conocarpus erectus*, *Dalbergia sissoo*, *Ficus benjamina* and *Washingtonia filifera* etc., they are grown for their beautiful inflorescence; however, little information is available on Cd and Ni removal ability. Therefore, the present study sought to assess the phytoremediation potential of Cd and Ni (during 2017–2019) using eight ornamental trees in four zones of the megacity of Faisalabad. Soil and plant samples were collected from the field and their analysis was undertaken at the University of Agriculture, Faisalabad (Pakistan). The purpose of this study was to check Cd and Ni accumulation in shoots for all four seasons, with a view to creating green space in urban areas while also decontaminating metal ions and minimizing pollution in the city. The following hypotheses were tested: (1) Cd and Ni accumulation in shoots and soils would be site, season and species specific and (2) shoot bioremediation of Cd and Ni would increase in summer with increases in soil metal bioavailability.

2. Materials and Methods

2.1. Study Area and Climate

Faisalabad ranks as the second-most industrial city in the central region of Punjab province, Pakistan. It is situated 186 m (610 ft) above sea level with a highly dense population of 3.2 million. The city experiences a wide range of average temperatures with winter extending from the middle of November to February (January being coldest with ~8 °C), spring with warmer months during March and April, long summers from May till September (June being hottest with ~44 °C) and a brief period of autumn with mild temperatures (during October) of about 35 °C. The relative humidity is highest in February (50%) while the lowest is in May (20%). Maximum day light hours are recorded in June (~14 h) while minimum light hours are recorded during December and January (~10 to 10.5 h) (Table 1).

Table 1. Seasonal variations in average high temperatures (AHT °C), average low temperatures (ALT °C), average humidity (AH %) and average light hours (ALH h/min) in Faisalabad city and its vicinity.

Months	January	February	March	April	May	June	July	August	September	October	November	December
AHT (°C)	21	23.8	29.5	36.4	41.7	44.3	42.5	40.2	38.7	35.4	28.6	23.3
ALT (°C)	8.3	10.4	14.9	22.1	28.5	32.3	33	30.8	26.9	22.5	16.5	11.2
AH (%)	47	50	46	29	20	22	35	43	39	30	29	32
ALH (h/min)	10/22	11/5	11/59	12/57	13/46	14/10	13/58	13/16	12/22	11/25	10/35	10/9

A field survey was conducted in the urban residential areas in the surrounding of the metropolitan to select the commonly raised ornamental plant species. The city was divided into four zones based on geography and industrial sites. In these zones four busy roads with heavy traffic loads were randomly selected. Eight abundantly growing plant species in these areas, *Alstonia scholaris*, *Azadirachta indica*, *Bismarckia nobilis*, *Bougainvillea spectabilis*, *Conocarpus erectus*, *Dalbergia sissoo*, *Ficus benjamina* and *Washingtonia filifera*, were selected for phytoremediation studies.

2.2. Sample Collection

Fresh biomass (gm) of plant leaves was gathered randomly from three individual plants of each species. Soil samples (0–10 cm) were also collected along with leaves, avoiding those distributed within a road edge area. Leaf samples gathered from the Botanical Garden University of Agriculture, Faisalabad which is located far from heavy traffic load was considered as control. Each year a sampling of leaves and soil was carried out in all of the four seasons i.e., spring (March/April), summer (May/June), autumn (October) and winter (December/January).

2.3. Sample Analysis

The collected leaf samples were shade dried and digested following USEPA (1996) method no.3050B, using HCl: HNO_3 (1:3) and H_2O_2. Filtrate was used for Cd and Ni analysis through a Polarized Zeeman AAS 2800 atomic absorption spectrophotometer (Hitachi, Tokyo, Japan). Quality assurance for precision and accuracy was determined by recovery of the analysis of the matrix spike and reagent blank control on a batch of each of the analyzed samples. Percentage recovery of metal analysis was calculated by using the following formula:

$$\text{Recovery } (\%) = \frac{Measured\ Value(\frac{mg}{kg})}{Certified\ Value(\frac{mg}{kg})} \times 100$$

Air C_2H_2 flame, burner head and 160 KPa oxidant gas pressure were each of the standard type. Other conditions are depicted in Table 1. The percentage recoveries for metal-spiked samples were within the acceptable limits of (80–120%) for metal analysis.

Limit of detection (LOD) as the lowest concentration of analyte was measured with the help of the following formula:

$$\text{LOD} = 3 \times s_{bl}$$

where, s_{bl} is the standard deviation of method blank. The limits of detection for Cd and Ni were 0.097 and 0.137 mg kg^{-1} respectively.

Bio-accumulation factor (BAF) was estimated by dividing the heavy metal concentration in plant parts to those found in soil samples from respective locations.

$$\text{Bio-accumulation factor (BAF)} = \frac{M\ Plant}{M\ Soil}$$

In the above given equation, M plants and M soil denote heavy metal concentrations in plants and soil grown in contaminated environments, respectively. The bio-accumulation factor of the above (1) indicates a higher uptake of heavy metal in plants compared with soil and vice versa (<1) for higher heavy metal concentration in soil than in plants. Tables 2 and 3 show the BAF values for Ni and Cd, respectively.

Table 2. Estimated heavy metal (BAF) for Cd in the various plant samples.

Towns	Bio-Accumulation Factor in Plants							
	D. sissoo	***C. erectus***	***B. nobilis***	***B. spectabilis***	***F. benjamina***	***A. scholaris***	***A. indica***	***W. filifera***
Jinnah town	0.95	1.13	0.95	0.79	0.99	0.87	0.89	1.10
Iqbal town	1.29	1.34	1.24	0.81	1.18	1.09	0.94	1.15
Lyallpur town	0.99	1.02	0.94	0.92	0.96	0.87	0.71	0.91
Madina town	1.17	1.35	1.24	1.18	1.02	1.04	0.84	1.03

Table 3. Estimated heavy metal bio-accumulation factor (BAF) for Ni in the various plant samples.

Towns	Plants							
	D. sissoo	***C. erectus***	***B. nobilis***	***B. spectabilis***	***F. benjamina***	***A. scholaris***	***A. indica***	***W. filifera***
Jinnah town	0.76	0.61	0.49	0.91	0.55	0.72	0.67	0.52
Iqbal town	0.90	0.79	0.63	0.64	0.61	0.62	0.52	0.44
Lyallpur town	0.70	0.69	0.69	0.55	0.76	0.51	0.51	0.50
Madina town	0.93	0.73	0.79	0.57	0.74	0.66	0.58	0.47

2.4. Traffic Density (TD)

Traffic density was calculated in all zones of the city for specific time intervals on specific days. The following ranking was observed in the four zones: Iqbal town < Madina town = Lyallpur town < Jinnah town.

2.5. Statistical Anaylsis

The data were analyzed using canonical correspondence analysis (CCA) to determine the association of plant species, sites, seasons, and metals through CANOCO computer package for window (V.4.5). Statistical analysis was performed using COSTAT software (Statistics 3.0) and LSD test was applied (at $p < 0.05$ significance level) for comparison of metal accumulation in plant species.

3. Results and Discussion

High concentrations of soil Cd were calculated at all study areas of the city compared with control (Figure 1), which indicated a spatio-temporal disparity. Jinnah town was the most polluted site for Cd followed by Lyallpur town, Madina town and Iqbal town respectively. The levels of Cd differed significantly ($p < 0.05$) from each other except for Madina town and Iqbal town. The Cd levels ranged between 6.78–8.57 mg/kg in different areas of the city. Although the permissible limits of soil Cd may vary in different countries [33], recommended values for soil Cd by WHO/FAO, 2007 should be <3 mg kg^{-1} [34]. The concentration of Cd in urban areas depends upon the number of industries and traffic load. In the present investigation, the areas with higher traffic density indicate higher concentrations of Cd, which in turn indicates intense automobile pollution. The age of the road also plays a significant role in retaining heavy metals and old roads generally have higher metal levels than the newer ones [35]. In present investigations Cd levels have been consistently higher in Jinnah town (the oldest area) with the highest average by human population. The canonical correspondence analysis biplot for Cd accumulation in the leaves of plant species in different areas of Faisalabad city indicates that *C. erectus*, *D. sissoo* and *B. nobilis* developed a strong association with Lyallpur town during the summer while *C.erectus*, *A. scholaris* and *B. indica* were strongly associated with Jinnah town during autumn, and *A. scholaris, B. nobilis* and *F. benjamina* had a close association with Madina town. It was observed that most of the ornamental plant species formed a strong association with Lyallpur town in almost all the seasons. However, associations of plant species with various towns were generally strong during the summer season. Our results suggest apparent seasonal changes, with summers showing a higher amount of Cd released into the environment. The levels of Cd in the soil were in the following order: summer > autumn > spring > winter. Seasonal variations may be attributed to the higher temperatures in summers as mentioned in previous investigations [36,37]. It is generally believed that soil metal concentration is directly related to its bioavailability, which may increase with the rain runoff [38]. The biosorption of metals could increase in plants, which may be attributed to the monsoon rains during summers compared with winters [39].

The metals accumulated by plant leaves in various zones of the city were not proportional to soil metal levels (Tables 4 and 5). Ornamental plant species exhibited differential Cd accumulation in their leaves (Table 4). The highest accumulation was recorded in *C. erectus* (9), followed by *D. sissoo* (8.2) and *B. nobilis* (8.1) while the leaves of *A. indica* retained the lowest (6.3 mg kg^{-1}) Cd levels (Table 4). The average range of leaf Cd in all studied species was not only higher than the normal plants (0.03–0.70 mg kg^{-1}) [40] but also crossed the suggested permissible limits (5 mg/kg) [41]. Some of the tree species are known as 'hyperaccumulators' of Cd with higher values than the proposed limit of 100 mg kg^{-1} [41], e.g., *Thlaspi caerulescens* (380 mg kg^{-1}) [16] and *Impatiens glanduliflora* (276–1560 mg kg^{-1}) [42]. Although none of the tree species in the current study were found to be hyperaccumulators, leaf Cd levels were consistently higher (Table 4) than the values recommended by the WHO [34,38]. Plant species with Cd accumulation that varied in different seasons was in the following order: summer > autumn > spring > winter. Based on their metal absorption, plants may be divided into three general categories: (1) metal excluders (with low bio-accumulation factor), (2) accumulators (higher concentrations in shoots than soil), or (3) bio-indicators (plants which can accumulate trace metals in aerial parts i.e., leaf or stem, proportional to the soil) [43]. In this study, most of the plants had BAF values ≥1 suggesting Cd bio-indication with the highest average values (Table 2) was found in in *C. erectus*. However, this was not the case for Ni (Table 3).

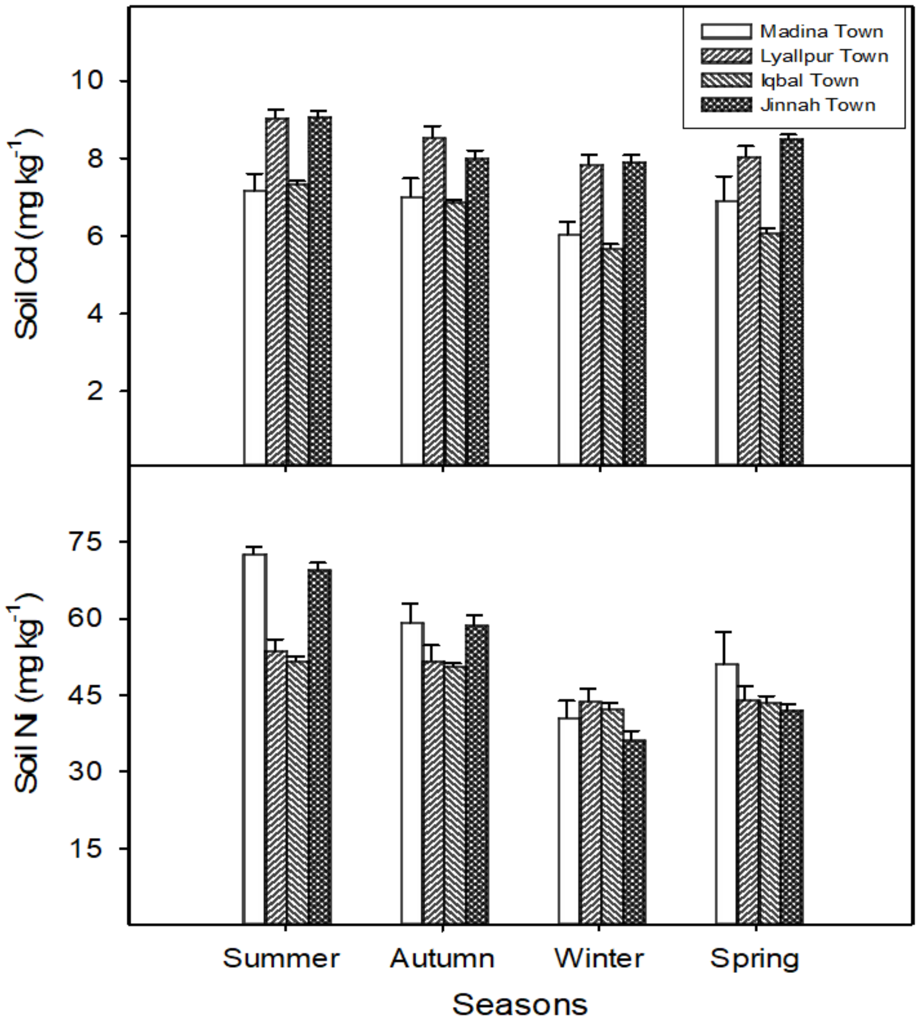

Figure 1. Concentration of Cd and Ni (mg kg^{-1} dry wt.) on the roadside soils of various towns in Faisalabad city.

Nickel concentrations in soils as per WHO/FAO, 2007 are up to 50 mg kg^{-1} [34]. In this study, Ni was highly variable in different zones of the city ranging between 46.31 to 55.85 mg/kg (Figure 1). The highest Ni accumulations were recorded in the Madina town and Jinnah town soils (Figure 1). In most of the city areas, the circumstances seemed almost similar to each other, except for traffic load and road conditions. The canonical correspondence analysis biplot for nickel association in ornamental plant species revealed that *F. benjamina*, *B. spectabilis*, *B. nobilis*, and *W. filifera* had strong links with Jinnah town during the summer season, while *C. erectus* showed a strong association with Iqbal town during the same season. During the autumn season, *F. benjamina*, *D. sissoo* and *W. filifera* displayed a strong association with Iqbal town, whereas *C. erectus*, *A. indica*, *B. spectabilis* and *A. scholaris* displayed a strong association with Madina town. In the winter season, *A. scholaris* and *B. spectabilis* obtained strong links with Madina town, while *D. sissoo* and *A. indica* developed strong associations with Iqbal town [37]. Studies suggest that high amounts of Ni are usually observed in those megacities which have a higher traffic density, for example up to 270 mg/kg in Bogra, Bangladesh [44] and 108 mg/kg in India [45]. On the contrary, negligible amounts of nickel content were observed on the roads despite higher traffic density in Riyadh, Saudi Arabia, possibly due to good road conditions and consistent traffic flow [46]. In the present investigation soil Ni levels reached up to 55.68 mg/kg which is in accordance with the poor road conditions in both Jinnah town and Madina town. Literature suggests that Ni concentration in most of the cases is positively correlated with transport activity and road conditions [47,48]. Frequent use of automobile brakes due to poor road conditions [49], high fuel consumption [50], brake wear and tear [51], increased tire friction [52], corrosion of shafts and valves [53], sandpaper and asphalt-like components on the road dust, etc., could also result in higher Ni accumulation in soils. The area with the highest Ni concentration in the current study had a comparatively lower traffic load than other areas, which could be attributed to the poor road conditions as one of the main conditions. In summary, the CCA for Cd and Ni accumulations indicates the highest levels of metal accumulation by all species during summer season, followed by autumn and a weaker association during the winter and spring seasons (represented as an ordination diagram in which scores of influencing factors are indicated as arrows for soil and plant properties).

Table 4. Extractable concentration of Cd (mg/kg) in the leaves of studied plant species in the various towns of Faisalabad. Mean Cd values with different letters are significantly different at $p < 0.05$ (LSD).

Plants	Jinnah Town	Iqbal Town	Lyallpur Town	Madina Town	Cd in Plant Species
C. erectus	9.51 ± 0.12	8.74 ± 0.1	8.53 ± 0.04	9.2 ± 0.08	8.99 a ± 0.12
D. sissoo	8.0 ± 0.12	8.42 ± 0.11	8.29 ± 0.12	7.96 ± 0.11	8.17 ab ± 0.33
B. nobilis	8 ± 0.11	8.08 ± 0.21	7.9 ± 0.11	8.43 ± 0.14	8.1 ab ± 0.34
W. filifera	9.2 ± 0.45	7.49 ± 0.02	7.62 ± 0.12	6.99 ± 0.27	7.82 ab ± 0.11
F. benjamina	8.35 ± 0.23	7.67 ± 0.41	8.05 ± 0.11	6.92 ± 0.12	7.75 ab ± 0.41
A. scholaris	7.33 ± 0.11	7.12 ±0.23	7.33 ± 0.12	7.08 ± 0.13	7.21 bc ± 0.12
B. spectabilis	6.67 ±0.01	5.3 ± 0.12	7.76 ± 0.45	8.05 ± 0.37	6.94 bc± 0.33
A. indica	7.52 ±0.01	6.11 ±0.14	6 ± 0.12	5.71 ± 0.12	6.33 c ± 0.14
Cd in towns	8.07± 0.12	7.36 ± 0.11	7.68 ± 0.33	7.54 ± 0.12	

Table 5. Extractable concentration of Ni (mg/kg) in the leaves of studied plant species in various towns of Faisalabad. Mean Ni values with different letters are significantly different at $p < 0.05$ (LSD).

Plants	Jinnah Town	Iqbal Town	Lyallpur Town	Madina Town	Ni in Plant Species
D. sissoo	39.25 ± 1.23	43.50 ± 1.02	34.08 ± 1.25	52.50 ± 2.10	42.33 a ± 0.12
C. erectus	31.58 ± 1.01	38.33 ± 1.01	33.42 ± 1.21	40.83 ± 1.21	36.04 b ± 0.12
B. nobilis	25.66 ± 1.02	30.66 ± 0.12	36.50 ± 2.11	44.21 ± 1.23	34.27 b ± 0.14
B. spectabilis	47.01 ± 1.01	31.08 ± 1.02	26.76 ± 1.01	32.01 ± 1.50	34.21 b ± 0.12
F. benjamina	28.66 ± 2.10	29.66 ± 2.10	37.01 ± 1.02	41.66 ± 3.56	34.25 b ± 0.11
A. scholaris	37.25 ± 1.20	30.33 ± 1.02	24.66 ± 2.31	37.25 ± 4.10	32.37 bc ± 0.12
A. indica	34.75 ± 1.41	25.25 ± 2.12	24.83 ± 2.10	32.42 ± 2.31	29.19 c ± 0.12
W. filifera	27.25 ± 1.01	21.25 ± 0.59	24.25 ± 2.15	26.42 ± 1.21	25.29 c ± 0.11
Ni in towns	33.92 ± 0.12	31.26 ±0.74	30.19 ± 2.41	38.41 ± 0.12	

Amongst the eight test plant species, the highest Cd accumulation was recorded in *C. erectus*, followed by *D. sissoo* and *B. nobilis* (8.1) while the leaves of *A. indica* retained the lowest (6.3 mg kg^{-1}) Cd levels. As for Ni, *Dalbergia sissoo* appeared to be the highest Ni accumulator, followed by *B. spectabalis*, *C. erectus*, and *F. benjamina i*. Some other studies have also reported *D. sissoo* and *C. erectus* as good bio-indicators for various other metals [54,55]. However, *Bismarckia nobilis*, a plant species with beautiful inflorescence has been tested for its Ni and Cd biosorption potential for the first time, and appeared to be a good bio-indicator tree species. Although the use of wild plant species for phytoremediation, such as *Calotropis procera*, *Cyprus aevigatus* etc., has been the main focus of the past studies [56,57], such species cannot be potentially raised in the city areas for both beautification and phytoremediation purposes.

Though physiochemical factors such as soil pH, bioavailability, redox potential, dissolved oxygen, cation exchange capacity, temperature, etc., play an important role in metal availability [58], the accumulation of metals in the plant species is mostly influenced by the genetic make-up of the species, the growth rate and maturity stage of the plant [59] and the different cultivars [60]. Among these factors, temperature has a great impact on the absorption and accumulations of metals in plants and generally warm conditions favor higher accumulation than cold [39]. Therefore, plants with a high temperature tolerance are deemed feasible for phytoremediation in generally hot climates. In this study, the higher temperature during summer season (exceeding up to 44 °C) with low relative humidity (20–22%) appeared to favor increased metal accumulation in most of the tree species compared with low winter temperatures (i.e., 8–10 °C). These results are in accordance with some other findings, which indicates a greater variability in metal accumulation with the changes in seasons [58,60].

Our findings suggest that the anthropogenic source of the metals is related both with automobile fluxes as well as traffic density on roads. The deposition and bioavailability of soil metals (Cd and Ni) in summer could be a result of increasing temperatures and rain runoff, as plants seemed to be influenced by these factors. However, the mobility of trace metals within the soil systems and sequestration/compartmentalization in plant parts needs further testing. The present investigation highlights the importance of cultivating ornamental tree species as they appear to have great potential in minimizing Cd and Ni levels, as indicated by the higher accumulation in leaf tissues and their bio-accumulation factor (BAF). Future studies should be focused on soil moisture content and dust deposition on foliage for metal mobilization in plants, as well as the possible role of soil microbes under various moisture regimes. Such eco-physiological studies would further boost green space development beyond environmental safety by reducing automobile pollution and beautifying the roads. The use of ornamental species in place of staple food crops with higher shoot metal accumulation would ultimately save living beings from chronic diseases while also providing an aesthetically pleasant urban environment. In urban settings, cultivation of tree species such as *C. erectus*, *D. sissoo* and *B. nobilis* is suggested to reduce Cd pollution while *D. sissoo B. spectabalis*, *C. erectus*, and *F. benjamina* may be considered appropriate species in areas heavily polluted with Ni.

4. Conclusions

The urban areas of Faisalabad, Pakistan appeared heavily polluted with cadmium and nickel throughout the year and showed greater spatio-temporal heterogeneity. The traffic load and poor road conditions seem to be possible reasons for the spatial variations in both heavy metals. Differences in temperature ranges of various seasons possibly caused temporal heterogeneity. The metal accumulation potential of eight ornamental plant species exhibited prominent variations. *Dalbergia sissoo*, *C. erectus* and *B. nobilis* indicated high level performances and emerged as the best phyto-remediator/phyto-accumulators for both metals (Cd and Ni). Plantation of tree species with effective shoot accumulation should be encouraged for purifying the urban environment as well as creating green space.

Author Contributions: Conceptualization, S.U. and N.H.; methodology, M.H.; formal analysis, S.U., Z.A. (Zainul Abideen) and S.M.; investigation, M.H.; resources, S.U., Z.A. (Zainul Abideen) and S.M.; data curation, Z.A. (Zaheer Abbas); writing—original draft preparation, Z.A. (Zaheer Abbas); writing—review and editing, I.A.; supervision, Z.A. (Zainul Abideen), M.A.A. and F.M.A.-H.; project administration, S.U.; funding acquisition, N.H., M.A.A. and F.M.A.-H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by King Saud University, Riyadh, Saudi Arabia, grant number RSP2023R306.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors extend their appreciation to the researchers supporting project number (RSP2023R306), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Khan, S.; Cao, Q.; Zheng, Y.M.; Huang, Y.Z.; Zhu, Y.G. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ. Pollut.* **2008**, *152*, 686–692. [CrossRef]
2. Zhang, M.-K.; Liu, Z.-Y.; Wang, H. Use of Single Extraction Methods to Predict Bioavailability of Heavy Metals in Polluted Soils to Rice. *Commun. Soil Sci. Plant Anal.* **2010**, *41*, 820–831. [CrossRef]
3. Sankhla, M.S.; Kumari, M.; Nandan, M.; Kumar, R.; Agrawal, P. Heavy metals contamination in water and their hazardous effect on human health-a review. *Int. J. Curr. Microbiol. Appl. Sci.* **2016**, *5*, 759–766. [CrossRef]
4. Zulfiqar, U.; Farooq, M.; Hussain, S.; Maqsood, M.; Hussain, M.; Ishfaq, M.; Ahmad, M.; Anjum, M.Z. Lead toxicity in plants: Impacts and remediation. *J. Environ. Manage.* **2019**, *250*, 109557. [CrossRef]
5. Teschke, R. Aluminum, Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Mercury, Molybdenum, Nickel, Platinum, Thallium, Titanium, Vanadium, and Zinc: Molecular Aspects in Experimental Liver Injury. *Int. J. Mol. Sci.* **2022**, *23*, 12213. [CrossRef] [PubMed]
6. Wuana, R.A.; Okieimen, F.E. Heavy metals in contaminated soils a review of sources, chemistry, risks and best available strategies for remediation. *Comm. Soil Sci. Plant Anal.* **2011**, *42*, 111–122. [CrossRef]
7. Rashid, I.; Murtaza, G.; Zahir, Z.A.; Farooq, M. Effect of humic and fulvic acid transformation on cadmium availability to wheat cultivars in sewage sludge amended soil. *Environ. Sci. Pollut. Res.* **2018**, *25*, 16071–16079. [CrossRef] [PubMed]
8. Mondal, S.C.; Sarma, B.; Farooq, M.; Nath, D.J.; Gogoi, N. Cadmium bioavailability in acidic soils under bean cultivation: Role of soil additives. *Int. J. Environ. Sci. Technol.* **2020**, *17*, 153–160. [CrossRef]
9. Hassan, M.U.; Chattha, M.U.; Khan, I.; Chattha, M.B.; Aamer, M.; Nawaz, M.; Ali, A.; Ullah-Khan, M.A.; Khan, T.A. Nickel toxicity in plants: Reasons, toxic effects, tolerance mechanisms, and remediation possibilities—A review. *Environ. Sci. Pollu. Res.* **2019**, *26*, 12673–12688. [CrossRef]
10. Mujeeb, A.; Abideen, Z.; Aziz, I.; Sharif, N.; Hussain, M.I.; Qureshi, A.S.; Yang, H.H. Phytoremediation of potentially toxic elements from contaminated saline soils using Salvadora persica L.: Seasonal Evaluation. *Plants* **2023**, *12*, 598. [CrossRef]
11. Hussain, B.; Ashraf, M.N.; Rahman, S.U.; Abbas, A.; Li, J.; Farooq, M. Cadmium stress in paddy fields: Effects of soil conditions and remediation strategies. *Sci. Total. Environ.* **2021**, *754*, 142188. [CrossRef] [PubMed]
12. Khalid, N.; Masood, A.; Noman, A.; Aqeel, M.; Qasim, M. Study of the responses of two biomonitor plant species (*Datura alba* & *Ricinus communis*) to roadside air pollution. *Chemosphere* **2019**, *235*, 832–841. [CrossRef] [PubMed]
13. Kim, K.H.; Kumar, P.; Szulejko, J.E.; Adelodun, J.E.; Junaid, A.A.; Uchimiya, M.F.; Chambers, M. Toward a better under-standing of the impact of mass transit air pollutants on human health. *Chemosphere* **2017**, *174*, 268–279. [CrossRef]
14. Rocha, C.S.; Rocha, D.C.; Kochi, L.Y.; Carneiro, D.N.M.; dos Reis, M.V.; Gomes, M.P. Phytoremediation by ornamental plants: A beautiful and ecological alternative. *Environ. Sci. Pollut. Res. Int.* **2022**, *29*, 3336–3354. [CrossRef] [PubMed]
15. Huybrechts, M.; Cuypers, A.; Deckers, J.; Iven, V.; Vandionant, S.; Jozefczak, M.; Hendrix, S. Cadmium and Plant Develop-ment: An Agony from Seed to Seed. *Int. J. Mol. Sci.* **2019**, *20*, 3971. [CrossRef]
16. Liphadzi, M.S.; Kirkham, M.B. Chelate-Assisted Heavy Metal Removal by Sunflower to Improve Soil with Sludge. *J. Crop Improv.* **2006**, *16*, 153–172. [CrossRef]
17. Mahdavi, A.; Khermandar, K.; Asbchin, S.A.; Tabaraki, R. Lead Accumulation Potential in *Acacia victoria*. *Int. J. Phytoremediation* **2013**, *16*, 582–592. [CrossRef]
18. Khan, M.B. Cadmium in plants and polluted soils: Effects of soil factors, hyper-accumulation and amendments. *Geoderma* **2006**, *137*, 19–32.
19. Zhao, H.; Guan, J.; Liang, Q.; Zhang, X.; Hu, H.; Zhang, J. Effects of cadmium stress on growth and physiological characteristics of sassafras seedlings. *Sci. Rep.* **2021**, *11*, 9913. [CrossRef]
20. Godt, J.; Scheidig, F.; Grosse-Siestrup, C.; Esche, V.; Brandenburg, P.; Reich, A.; Groneberg, D.A. The toxicity of cadmium and resulting hazards for human health. *J. Occup. Med. Toxicol.* **2006**, *1*, 22. [CrossRef]
21. Kubier, A.; Wilkin, R.T.; Pichler, T. Cadmium in soils and groundwater: A review. *Appl. Geochem.* **2019**, *108*, 104388. [CrossRef] [PubMed]
22. Mizuno, T.; Nakahara, Y.; Fujimori, T.; Yoshida, H. Natural revegetation potential of Japanese wild thyme (*Thymus quinquecostatus* Celak.) on serpentine quarries. *Ecol. Res.* **2018**, *33*, 777–788. [CrossRef]
23. Taiz, L.; Zeiger, E. *Plant Physiology*, 5th ed.; Sinauer Associates Inc.: Sunderland, MA, USA, 2010; pp. 1–23.
24. Genchi, G.; Carocci, A.; Lauria, G.; Sinicropi, M.S.; Catalano, A. Nickel: Human Health and Environmental Toxicology. *Int. J. Environ. Res. Public Health* **2020**, *17*, 679. [CrossRef] [PubMed]
25. Valivand, M.; Amooaghaie, R.; Ahadi, A. Interplay between hydrogen sulfide and calcium/calmodulin enhances systemic acquired acclimation and antioxidative defense against nickel toxicity in zucchini. *Environ. Exp. Bot.* **2019**, *158*, 40–50. [CrossRef]

26. Sreekanth, T.V.M.; Nagajyothi, P.C.; Lee, K.D.; Prasad, T.N.V.K.V. Occurrence, physiological responses and toxicity of nickel in plants. *Int. J. Environ. Sci. Technol.* **2013**, *10*, 1129–1140. [CrossRef]
27. Shahzad, B.; Tanveer, M.; Rehman, A.; Alam Cheema, S.; Fahad, S.; Rehman, S.; Sharma, A. Nickel; whether toxic or essential for plants and environment—A review. *Plant Physiol. Biochem.* **2018**, *132*, 641–651. [CrossRef]
28. Yan, A.; Wang, Y.; Tan, S.N.; Yusof, M.L.M.; Ghosh, S.; Chen, Z. Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. *Front. Plant Sci.* **2020**, *11*, 359. [CrossRef]
29. Luo, J.; Qi, S.; Gu, X.S.; Wang, J.; Xie, X. Evaluation of the phytoremediation effect and environmental risk in remediation processes under different cultivation systems. *J. Clean. Prod.* **2016**, *119*, 25–31. [CrossRef]
30. Manzoor, M.; Gul, I.; Kallarhoff, J. Screening of indigenous ornamental species from different plant families for lead Accumulation Potential exposed to metal gradient in spiked soils. *Soil Sed. Contam.* **2018**, *27*, 439–453. [CrossRef]
31. Yasin, G.; Rehman, R.; Yousaf, M.T.B. Phytoremediation potential of *E. comaludensis* and *M. alba* for copper, cadmium and lead absorption in urban areas of Faisalabad city, Pakistan. *Int. J. Environ. Res.* **2021**, *15*, 597–612. [CrossRef]
32. Khan, A.H.A.; Kiyani, A.; Mirza, C.R.; Butt, T.A.; Barros, R.; Ali, B.; Iqbal, M.; Yousaf, S. Ornamental plants for the phytoremediation of heavy metals: Present knowledge and future perspectives. *Environ. Res.* **2021**, *195*, 110780. [CrossRef] [PubMed]
33. Szwalec, A.; Mundała, P.; Kędzior, R. Monitoring and assessment of cadmium, lead, zinc and copper concentrations in arable roadside soils in terms of different traffic conditions. *Environ. Monit. Assess.* **2020**, *192*, 1–12. [CrossRef] [PubMed]
34. Mensah, E.; Kyei-Baffour, N.; Ofori, E.; Obeng, G. Influence of human activities and land use on heavy metal concentrations in irrigated vegetables in Ghana and their health implications. In *Appropriate Technologies for Environmental Protection in the Developing World: Selected Papers from ERTEP 2007, 17–19 July 2007, Ghana, Africa*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 9–14. [CrossRef]
35. De-Silva, S.; Ball, A.S.; Huynh, I.; Reichman, S.M. Metal accumulation in roadside soil in Mellbourne, Australia: Effect of road age, traffic density and vehicular speed. *Environ. Pollut.* **2016**, *208*, 102–109. [CrossRef]
36. Khalid, N.; Hussain, M.; Young, S.H. Lead concentrations in soils and some wild plant species along two busy roads in Pa-kistan. *Bull. Environ. Contam. Toxicol.* **2018**, *100*, 250–258. [CrossRef]
37. Umer, S.; Hussain, M.; Arfan, M. Spatio-temporal variations of metals in urban roadside soils and ornamental plant species of Faisalabad metropolitan (Pakistan). *Int. J. Environ. Sci. Technol.* **2021**, *19*, 491–6498.
38. Xu, D.; Shen, Z.; Dou, C.; Dou, Z.; Li, Y.; Gao, Y.; Sun, Q. Effects of soil properties on heavy metal bioavailability and accumulation in crop grains under different farmland use patterns. *Sci. Rep.* **2022**, *12*, 9211. [CrossRef]
39. Ibrahim, A.T.A.; Omer, H.M. Seasonal variation of heavy metals accumulation in muscles of the African Catfish Clarias gariepinus and in River Nile water and sediments at Assiut Governorate, Egypt. *J. Biol. Earth Sci.* **2013**, *3*, 236–248.
40. Kabata-Pendias, H.A.; Mukherjee, A.B. *Trace Elements from Soil to Human*; Springer: Berlin/Heidelberg, Germany, 2007; pp. 14–27. [CrossRef]
41. Van der Ent, A.; Baker, A.J.M.; Reeves, R.D.; Pollard, A.J.; Schat, H. Hyperaccumulators of metal and metalloid trace elements: Facts and Fiction. *Plant Soil.* **2013**, *362*, 319–334. [CrossRef]
42. Coakley, S.; Cabill, G.; Enright, A. Cd hyper-accumulation and translocation in *Impatiens glandulifera*: From foe to friend. *Sustainability* **2019**, *11*, 5018. [CrossRef]
43. Chapman, D.F.; Caradus, J.R. Effects of improved, adapted white clover (*Trifolium repens* L.) germplasm on the productive properties of a hill pasture. *New Zealand J. Agric. Res.* **1997**, *40*, 207–221. [CrossRef]
44. Islam, M.S.; Ahmad, M.K.; Raknuzzaman, M. Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. *Ecol. Ind.* **2015**, *48*, 282–291. [CrossRef]
45. Rolli, N.M.; Gadi, S.B.; Giraddi, T.P. Bioindicators: Study on Uptake and Accumulation of Heavy Metals in Plant Leaves of State Highway Road, Bagalkot, India. *J. Agric. Ecol. Res. Int.* **2016**, *6*, 1–8. [CrossRef]
46. Al-Shayeb, S.M.; Seaward, M. Heavy metal content of roadside soils along the ring road in Riyadh (Saudi Arabia). *Asian J. Chem.* **2001**, *13*, 407–423.
47. Aydinalp, C.; Marinova, S. Lead in particulate deposits and in leaves of roadside plants in Turkey. *Polish J. Environ. Studies* **2004**, *13*, 233–235.
48. Grigorates, T.; Martini, G. Brake wear particle emissions: A Review. *Environ. Sci. Pollut. Res.* **2014**, *22*, 2491–2504. [CrossRef] [PubMed]
49. Amato, F. *Vehicle Non-Exhaust Emissions Impact on Air Quality Problem for Public Health*, 1st ed.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 21–65.
50. Iwegbue, C.; Bassey, F.; Tesi, G.; Nwajei, G.; Tsafe, A. Assessment of Heavy Metal Contamination in Soils around Cassava Processing Mills in Sub- Urban Areas of Delta State, Southern Nigeria. *Niger. J. Basic Appl. Sci.* **2013**, *21*, 96–104. [CrossRef]
51. Hjortenkrans, D.S.T.; Bergback, B.G.; Haggerud, A.V. Metal emissions from brake linings and tires: Case studies of Stockholm, Sweden 1995/1998 and 2005. *Environ. Sci. Technol.* **2007**, *41*, 5224–5230. [CrossRef] [PubMed]
52. Adamiec, E.; Jarosz-Krzemińska, E.; Wieszała, R. Heavy metals from non-exhaust vehicle emissions in urban and motorway road dusts. *Environ. Monit. Assess.* **2016**, *188*, 369. [CrossRef]
53. Christoforidis, A.; Stamatis, H. Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region. Greece. *Geoderma* **2009**, *151*, 257–263. [CrossRef]

54. Naveed, N.H.; Batool, A.I.; Rehman, F.U.; Hameed, U. Leaves of roadside plants as bioindicator of traffic related lead pollution during different seasons in Sargodha Pakistan. *Afr. J. Environ. Sci. Technol.* **2010**, *11*, 770–774.
55. Khan, S.; Khan, M.; Rehman, S. Lead and Cadmium Contamination of Different Roadside Soils and Plants in Peshawar City, Pakistan. *Pedosphere* **2011**, *21*, 351–357. [CrossRef]
56. Badr, N.; Fawzy, M.; Al-Qahtani, K. Phytoremediation: An ecological solution to heavy metal polluted soil and evaluation of plant removal ability. *World Appl. Sci. J.* **2012**, *16*, 1292–1301.
57. Pandey, V.C. Phytoremediation efficiency of Eichhornia crassipes in fly ash pond. *Int. J. Phytorem.* **2016**, *18*, 450–452. [CrossRef]
58. Cheng, S. Heavy metals in plants and phytoremediation. *Environ. Sci. Pollut. Res.* **2003**, *10*, 335–340. [CrossRef]
59. Sharma, P.K.; Agerwal, M.; Marshall, F.M. Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in Urban India: A case study in Varanasi. *Environ. Pollut.* **2008**, *154*, 254–263. [CrossRef] [PubMed]
60. Alexander, P.; Alloway, B.; Dourado, A. Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environ. Pollut.* **2006**, *144*, 736–745. [CrossRef] [PubMed]