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Heavy Metals Phytoremediation and Its Impact on Photosynthetic Pigments and Metabolic Content in Some Plant Species Grown in the Streets of Jeddah Governorate, Saudi Arabia

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Abstract

In Jeddah governorate, increased industrialization, urbanization and vehicular traffic may raise levels of heavy metals in the air and soil, threatening food safety and human health. Roadside vegetation traffic barriers might be an effective way to enhance roadside air quality and reduce human exposure to vehicular pollution. This study was conducted in order to uncover the best-cultivated plant species for purifying polluted air in terms of environmental parameters. The samples for this study were obtained from several locations throughout Jeddah governorate streets. The main causes of air pollution in the study area are traffic and automobile emissions. Photosynthetic pigments, soluble sugars, soluble protein, amino acids, and proline in plant extracts were investigated in the plant species used in this study. Also, the ionic composition (K, Na Ca and Mg), as well as the heavy metals (Zn, Cr, Ni, Cd, Pb, Co and Ba) in the sampling sites, as well as roots and leaves of the collected plant samples were all assessed. Plant examination revealed that *I. coccinea* possessed the highest value of amino acid, prolin, soluble proteins and sugars, while *T. stans* exhibited the highest amount of Chl a, carotenoids. Furthermore, the most common contaminants in all sites were Zn, Ba, and Ni, with Zn and Ba being the most actively accumulated in the leaves of the studied plants. The findings revealed that the root of *C. lancifolius* is a powerful phytoaccumulator of Zn, Ni, and Co. In addition, *C. lancifolius*, *I. coccinea*, *Z. spina-christi*, and *B. spectabilis* were shown to exhibit high accumulating potential of various polluting metals in their roots. Also, Zn, Ba, Ni, and Cr were the most efficiently transmitted metals to the leaves of the studied plants. Consequently, these plant species can be employed in phytoremediation approaches at contaminated sites.

Keywords

Air Pollution, Phytoremediation, Street Trees, Metabolic Content, Metal Accumulation

1. Introduction

Increased industrialization, urbanization, and vehicular traffic in Jeddah governorate potentially boost toxic metals levels in the air and soil, imposing higher environmental constraints upon living organisms and posing a risk to food safety and human health [1]. One of the most important challenges of atmospheric pollution is urban air pollution, which is growing as the urban population, traffic density, and industrialization expand [2]. The conventional tactics for eradicating heavy metals from contaminated soil and water are extremely expensive, time-consuming, and detrimental to the environment [3]. Transportation is one of the most significant contributors to urban air pollution worldwide [4]. Roadside vegetation traffic barriers could be a good way to improve roadside air purity and minimize human exposure to motor pollution. Plant species selection could perhaps be generally regarded as a key planning component for vegetative traffic barriers considering different plant species have differential levels of resistance toward air pollutants [5]. It has been established that trees and other plants can reduce municipal exhaust emissions by gathering up airborne particles or absorbing volatile air pollutants through their leaf surfaces [6] [7].

Plants form an important component in bringing down environmental pollutants [8]. They can also be utilized as environmental pollution biological indicators [9]. Heavy metals over-accumulation in soil and water has resulted from the enormous growth of industrial pollution. Metal pollution is among the most significant environmental challenges to plants' physiological performance and metabolic activities [10]. Traditional metal remediation approaches have a direct deleterious impact on soil fertility and the environment, as well as they are typically prohibitively expensive. Plants and related rhizospheric microorganisms immobilize, decompose, or sequester metal contaminants in the soil and water, making phytoremediation an environmentally friendly, sustainable and cost-effective technique [11] [12]. Over 500 plant species were identified to thrive in metal- contaminated soils. Most of them are obligatory metallophytes, but some are also facultative metallophytes. By hyperaccumulating metal ions in the aerial parts or removing them from the roots, they can thrive on normal, non-metalliferous, and metalliferous soils [10]. Phytoremediation was reported to be an effective method for decreasing the implication of heavy metals on all living organisms [13] [14]. Many physiological, biochemical, molecular and ecological responses are associated with plants' adaptive mechanisms to metal-contaminated circumstances. These adaptation techniques allow particular plants to acclimatize, detoxify, or hyperaccumulate heavy metals in their tissues [15].

Heavy metals accumulation in plant tissues substantially causes profound alterations at the morphological, metabolic and molecular levels, occasionally contributing to phytotoxicity [16]. Phytotoxicity can harm plant yield and performance by disrupting critical processes like photosynthesis, cell division, and water and nutrients uptake [17]. Because of rising industrialization and excessive traffic, Jeddah governorate suffers from environmental pollution. This study was carried out to investigate the potential of some street trees grown in streets to decontaminate the air and soil from pollution through their phytoremediation properties. The study also attempted to determine the implication of these contaminants on plant performance in terms of photosynthetic pigments and some metabolic attributes. This study supports the need for careful selection of grown plants used for phytoremediation in roadways, as well as the association between these plants' capacity to remove pollutants and accumulate heavy metals, as well as the implications of the accumulated metals on the metabolic profile of these plants.

2. Materials and Methods

2.1. Study Area

For the current investigation, plant and soil samples were collected from various localities throughout Jeddah governorate. Road traffic and exhaust emissions are the main causes of air pollution in the study area. Heavy metal contamination was mostly prevalent in the upper 20 cm at the study sites (**Figure 1**).

2.2. Plant and Soil Samples Collection

The study focused on eight plant species allocated in the streets of the stydied area. Soil (0 - 30 cm depth) and plant samples were taken from each study site throughout the winter season of 2021 (December to February). Root and leaf samples of the investigated plant species (**Table 1** and **Figure 2**) were acquired manually, packed in polythene bags with sample site labels, and kept in an ice-box before being transported to the laboratory. The soil samples were drawn up to a depth of 30 cm using a hand auger as sampling equipment. The obtained samples were thoroughly mixed on clean paper, sealed in paper bags, and transported to the laboratory for further analysis.

2.3. Plant Analyses

The soil and dust particles were removed from the plant leaf and root samples by washing them multiple times with tap water and then twice with deionized water. A subset of the fresh leaves was utilized immediately to determine photosynthetic pigments, while the remaining root and leaf samples were wrapped in paper bags and placed in an air-forced oven at 65˚C until they reached a constant weight (eight days). After complete dryness, leaf and root samples were mashed into a fine powder using an electric mixer, then passed through a 0.2 mm stainless steel sieve and kept in paper bags for subsequent analyses.

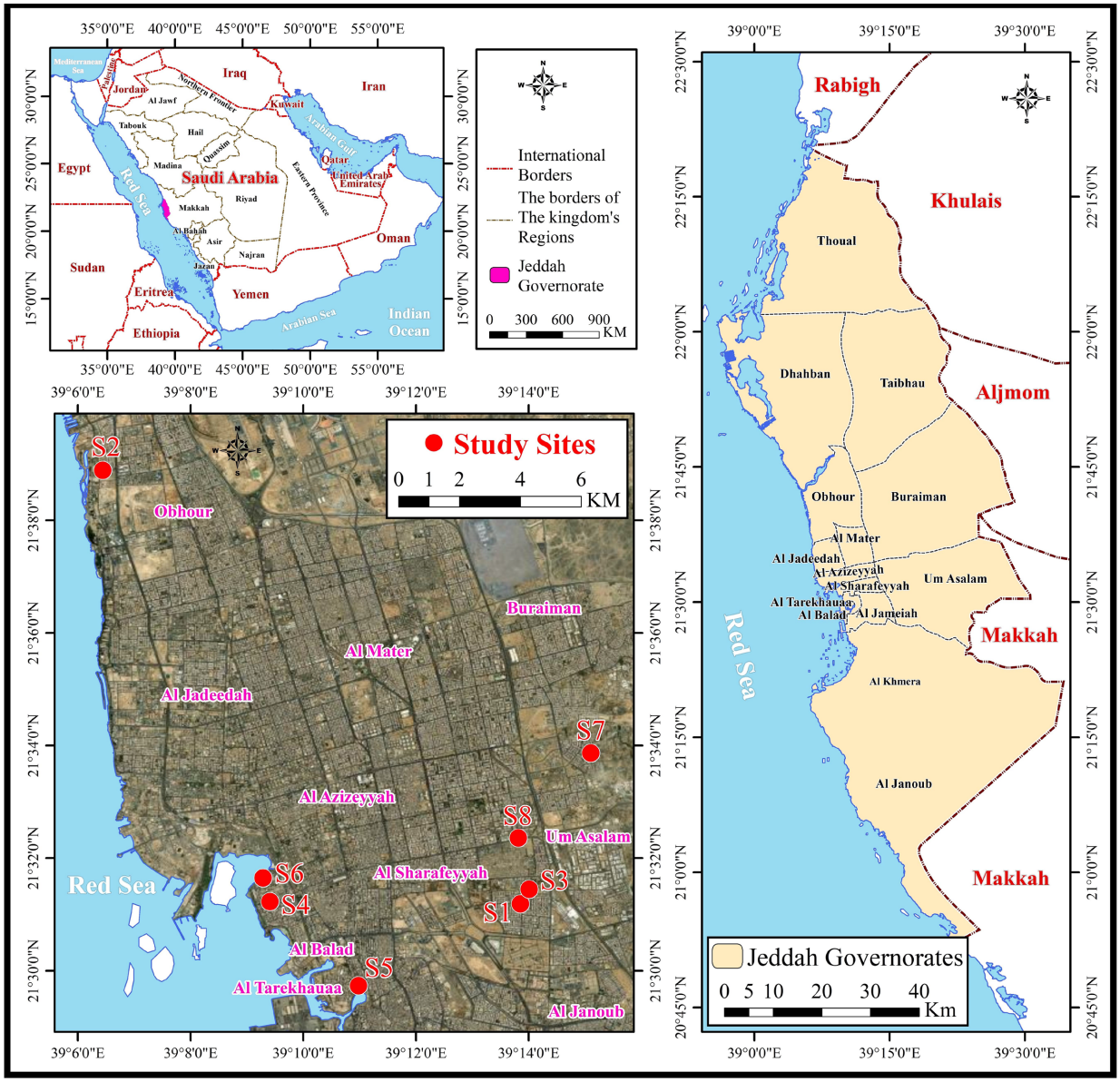

Figure 1. Location of the study area; (a) map of Kingdom Saudi Arabia, (b) Jeddah governorate, and (c) sampling sites (S1 - S8).

Table 1. List of plants studied, with site coordinates, Latin and family name, and growth habits.

No.	Plant location & coordinates	Latin Name	Family	Habit
1	21.519779 N, 39.230934 E	*Azadirachta indica* A.juss.	Meliaceae	Evergreen tree
2	21.648157 N, 39.107403 E	*Senna sulfurea* (DC.ex Colled.) H.S. Irwin & Barneby	Fabaceae	Evergreen shrub
3	21.524105 N, 39.233532 E	*Ziziphus spina-christi* (L.) Desf	Rhamnaceae	Deciduous tree
4	21.520454 N, 39.156849 E	*Cordia sebestena* L.	Boraginaceae	Deciduous tree
5	21.495596 N, 39.183075 E	*Tecoma stans* (L.) Kunth	Bignoniaceae	Evergreen shrub
6	21.527479 N, 39.154835 E	*Bougainvillea spectabilis* Willd.	Nyctaginaceae	Evergreen shrub
7	21.564419 N, 39.251770 E	*Conocarpus lancifolius* Engl.	Combretaceae	Evergreen shrub
8	21.539310 N, 39.230343 E	*Ixora coccinea* L.	Rubiaceae	Evergreen shrub

Figure 2. Plant images for this investigation. Photos were taken using Apple's mobile camera iPhone XS.

The photosynthetic pigments in the leaves of the collected samples were extracted and analyzed based on the technique adopted [18]. Leaf samples were powdered in liquid nitrogen with a mortar and pestle before being extracted in 80% aqueous acetone. The extracts were centrifuged at 5000 rpm for 10 min and the absorbance of the resultant supernatant was measured at 663, 646 and 470 nm, respectively. Photosynthetic pigments [chlorophyll a (Chl a), chlorophyll b (Chl b) and carotenoids] were assessed as mg/g FW.

For the determination of soluble sugars 0.4 ml of plant extract mixed with 3.6 ml of carbohydrate reagent (1% Tetrazolium blue with 0.3 sodium hydroxide) and immediately put in a boiling water bath covered with pulp for 30 seconds. Then it cools down in an ice bath. 4 ml of toluene is added and stirred in a vortex. The measurement was taken at a wavelength of 570 nm and soluble sugars were quantified as mg glucose equivalent mg/g FW [19]. Coomassie brilliant blue G-250 reagent was mixed with an aliquot (0.1 ml) of the borate extract, mixed well and the absorbance was determined at 595 nm. Soluble proteins were assessed as mg/g FW with the aid of a pre-plotted standard curve using bovine serum albumin [20].

The free proline content of leaf samples was assessed spectrophotometrically using the ninhydrin approach. For proline extraction, 0.1 ml of the leaf was extracted with 3% aqueous sulfosalicylic acid solution, centrifugated at 7000 rpm for 20 min and the supernatant was employed for proline assessment. 1 ml extract was combined with 2 ml ninhydrin reagent and 2 ml glacial acetic acid, then subsequently incubated in a water bath for 1 h at 100˚C. After cooling, the absorbance of the samples was recorded at 520 nm, and proline was reported as mg/g FW using a preprepared calibration curve using proline [21].

Total free amino acids were extracted from the leaf of collected samples using 85% ethanol. A 0.1 ml aliquot of the extract was combined with 1.9 ml of citrate buffer glycerol reagent [1% ninhydrin solution in 500 mM citrate buffer pH 5.5 (0.5 ml), 55% glycerol (1.2 ml) and 500 mM citrate buffer pH 5.5 (0.2 ml)]. The mixture was boiled in a water bath for 12 min, cooled immediately, and the absorbance was measured at 570 nm. With the help of a glycine-blotted standard curve, free amino acids were estimated as mg/g FW [22].

2.4. Mineral Analysis of Plant and Soil Samples

Visible plant materials were eliminated from air-dried soil samples before they were milled into smaller particles. For digestion, the samples were ground to a fine powder in an agate mortar and pestle, then sieved through a 0.2 mm stainless steel sieve. [23], wet digestion was performed on the collected plant and soil samples. In a 50 ml Taylor tube, 10 ml of 65% nitric acid was added into 0.5 g of soil or 0.1 g of plant material, and the mixture was allowed to stand overnight. After being heated for 4 h at 125˚C, the mixture was allowed to cool. The digestion mixture was completed into 12.5 ml using nitric acid and the final volume was adjusted to 50 ml using distilled water. The concentrations of certain mineral ions (K, Mg, Ca, and Na) and heavy metals (Zn, Cr, Ni, Cd, Pb, Co, and Ba) in the digested samples were determined using inductively coupled plasma-optical emission spectroscopy (ICP-MS Nexion, PerkinElmer, USA)

2.5. Statistical Analysis

Microsoft Excel 2016 was used to process the data. All of the values are expressed as the average and standard deviation (SD) from three replicates. To separate means, one-way ANOVA was used with Tukey's multiple range (TMR) as posthoc with significance levels of $p \leq 0.05$ and 0.01. The SPSS 19.0 software package was used for all statistical analyses.

3. Results and Discussion

The results of photosynthetic pigments analysis showed a highly significant variation in their contents in the investigated plant species (**Table 2**). Variability in plant species resulted in a large variation in the concentration of the investigated photosynthetic pigments from a statistical standpoint. As shown from the results,

Table 2. Photosynthetic pigments concentrations in the leaves of the investigated plant species. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Photosynthetic pigments (mg/g FW)		
	Chl a	Chl b	Carotenoids
A. indica	5.52 ± 0.94^{bc}	2.42 ± 0.87^{bc}	1.34 ± 0.14^{ab}
S. sulfurea	7.48 ± 1.21^{ab}	2.20 ± 0.26^{bc}	1.90 ± 0.21^{a}
Z. spina-christi	9.31 ± 1.37^{a}	2.86 ± 0.07^{abc}	1.68 ± 0.29^{ab}
C. sebestena	5.04 ± 0.28^{bc}	2.95 ± 0.17^{abc}	1.68 ± 0.29^{ab}
T. stans	10.54 ± 1.02^{a}	3.67 ± 0.31^{ab}	1.92 ± 0.05^{a}
B. spectabilis	7.65 ± 2.18^{ab}	4.37 ± 1.19^{a}	1.38 ± 0.06^{ab}
C. lancifolius	7.19 ± 1.07^{abc}	3.16 ± 0.89^{abc}	1.34 ± 0.16^{ab}
I. coccinea	3.93 ± 0.21^{c}	1.77 ± 0.42^{c}	0.98 ± 0.17^{b}
Statistics			
F value	10.278**	4.930**	3.895*
LSD at 5%	3.363	1.828	0.805
LSD at 1%	4.176	2.270	1.000

* = Statistically significant at $p \leq 0.05$; ** = statistically significant at $p \leq 0.01$.

Chl a content showed different levels in the studied plant species, as the highest contents; 10.54, 9.31 and 7.65 mg/g FW, were recorded in *T. stans*, *Z. spina-christi* and *B. spectabilis*, respectively. *I. coccinea*, *C. sebestena*, and *A. indica*, on the other hand, exhibited the lowest concentration of Chl a (3.93, 5.04, and 5.52 mg/g FW, respectively). As for Chl b, the highest concentrations were found in *B. spectabilis* (4.37 mg/g FW), *T. stans* (3.67 mg/g FW) and *C. lancifolius* (3.16 mg/g FW). On the other hand, the lowest Chl b content was attained in *I. coccinea*, *S. sulfurea* and *A. indica* (1.77, 2.20, and 2.42 mg/g FW, respectively). Carotenoids, as an accessory pigment, varied considerably among the species tested. *T. stans* showed the maximum concentration (1.92 mg/g FW), whereas *I. coccinea* displayed the lowest concentration (0.98 mg/g FW).

The capacity of *T. stans* and *B. spectabilis* to tolerate the high levels of pollutants without being affected [24]. They considered plants with high chlorophyll content in the polluted areas as pollution tolerant species. The presence of high carotenoids in the leaves of *T. stans* supports its tolerance potential, as carotenoids possess high antioxidant and metal chelating capacity, which enables normal plant growth at stressful situations [25]. According to the findings of this study, *I. coccinea* exhibited the least photosynthetic pigments of all the species studied, indicating that it has a limited ability to thrive in areas with high levels of pollution. As a result, it can be employed as a bioindicator for determining pollution intensity.

Table 3 depicts the effect of air pollution intensity on free nitrogenous components (protein, proline, and amino acids) and free sugars in the leaves of eight

Table 3. Free nitrogenous compounds (protein, proline, amino acids and free sugars) concentrations in the leaves of the investigated plant species. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Metabolites concentration (mg/g FW)			
	Protein	Proline	Amino acids	Free Sugars
A. indica	0.37 ± 0.10^{d}	1.19 ± 0.04^{a}	0.065 ± 0.021^{b}	0.045 ± 0.003^{c}
S. sulfurea	0.64 ± 0.02^{cd}	1.04 ± 0.17^{a}	0.056 ± 0.012^{b}	0.082 ± 0.003^{ab}
Z. spina-christi	5.15 ± 0.17^{a}	0.48 ± 0.01^{bc}	0.080 ± 0.008^{b}	0.058 ± 0.004^{bc}
C. sebestena	0.24 ± 0.03^{d}	0.18 ± 0.07^{c}	0.085 ± 0.018^{b}	0.084 ± 0.020^{ab}
T. stans	1.44 ± 0.05^{bc}	0.26 ± 0.10^{bc}	0.102 ± 0.003^{b}	0.077 ± 0.017^{abc}
B. spectabilis	1.14 ± 0.13^{bcd}	0.20 ± 0.03^{c}	0.087 ± 0.006^{b}	0.077 ± 0.014^{abc}
C. lancifolius	2.14 ± 0.70^{b}	0.48 ± 0.03^{bc}	0.085 ± 0.013^{b}	0.082 ± 0.009^{ab}
I. coccinea	5.42 ± 0.73^{a}	0.54 ± 0.23^{b}	0.745 ± 0.035^{a}	0.105 ± 0.006^{a}
	Statistics			
F value	95.7**	34.6**	559.2**	7.2**
LSD at 5%	1.041	0.316	0.049	0.033
LSD at 1%	1.293	0.392	0.061	0.041

** = Statistically significant at $p \leq 0.01$.

plant species collected from the study sites. Significant ($p \leq 0.01$) changes in the free nitrogenous compounds and sugars levels were associated with plant species variance, according to the statistical analysis results. The richest species in terms of free soluble protein content were *I. coccinea* and *Z. spina-christi* (5.42 and 5.15 mg/g FW, respectively). *C. sebestena* and *A. indica*, on the other hand, exhibited the lowest protein content (0.24 and 0.37 mg/g FW, respectively) among the studied species. The lower protein content of *C. sebestena* and *A. indica* could be due to a higher rate of protein breakdown and a reduction in de novo protein biosynthesis as affected by the pollution levels in the surrounding environment. The decrease in protein concentration in polluted areas is consistent with the findings of many other researchers [25] [26] [27].

In terms of proline content, *A. indica* and *S. sulfurea* had the highest free proline concentration (1.19 and 1.04 mg/g FW, respectively), whereas *C. sebestena* and *B. spectabilis* had the lowest concentration (0.18 and 0.20 mg/g FW, respectively) among the studied species. The elevated levels of proline in some plant species in polluted areas was thought to be owing to the activation of defensive mechanisms in these plants under pollution stress, as well as physiological adaptations made by the plants to accommodate for this stress [28]. Proline functions as a water homeostasis molecule, an osmoregulator, and a suppressor of protein breakdown by sustaining its structure and biological activity. It also stabilizes protein biosynthetic enzymes [29].

The highest levels of free amino acids were found in *I. coccinea* and *T. stans*

species (0.745 and 0.102 mg/g FW, respectively), while the lowest levels were found in *S. sulfurea* and *A. indica* (0.056 and 0.65 mg/g FW, respectively). Both free proline and amino acids can offer protection from cellular damage by acting as osmoprotectants, metal chelators, oxygen radicals quenchers, and peroxidation inhibitors [30]. As a result, elevated amino acid levels in the leaves of *I. coccinea* and *T. stans* could be employed as a biological indicator of pollution intensity in their growth environments.

In terms of free soluble sugars, *I. coccinea* and *C. sebestena* accumulated the most (0.105 and 0.084 mg/g FW, respectively), whereas *A. indica* and *Z. spina-christi* accumulated the least (0.045 and 0.058 mg/g FW) content in their leaves. The decrease in soluble sugar concentration in the leaves of *A. indica* and *Z. spina-christi* is consistent with the results of chlorophyll content, as both species had lower chlorophyll content in their leaves than the other plant species studied. Reduced CO_2 input, Rubisco activity, and water absorption, as well as increased stomatal resistance, pigment breakdown, and thylakoid destabilization, all contributed to the decrease in soluble sugars under stress circumstances.

The concentrations of some metal ions (K, Na, Ca and Mg) in the soil from which the investigated plant species were collected are reported in Table 4. The data showed that the sites where *C. lancifolius* and *Z. spina-christi* were collected exhibited the highest (K) concentrations (62.60 and 62.33 mg/l, respectively), whereas the sites where *T. stans* and *B. spectabilis* were collected showed the lowest K concentrations (3.22 and 3.80 mg/l, respectively). The sites of *I. coccinea*, *Z. spina-christi* and *C. lancifolius* collection were reported as being the most

Table 4. The concentration of certain mineral ions in the sampling sites of the plant species under investigation. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Mineral ions concentration (mg /l)			
	K^+	Na^+	Ca^{++}	Mg^{++}
A. indica	10.85 ± 0.13^{c}	49.40 ± 0.44^{e}	31.03 ± 0.26^{b}	12.27 ± 0.29^{e}
S. sulfurea	6.18 ± 0.08^{d}	29.22 ± 0.08^{f}	21.02 ± 7.43^{b}	11.65 ± 0.82^{e}
Z. spina-christi	62.33 ± 0.15^{a}	63.82 ± 0.75^{b}	177.50 ± 1.07^{e}	126.40 ± 0.54^{a}
C. sebestena	56.82 ± 0.19^{b}	17.18 ± 0.19^{g}	110.8 ± 0.10^{c}	98.17 ± 0.25^{c}
T. stans	3.22 ± 0.16^{f}	51.23 ± 0.15^{d}	9.05 ± 0.05^{a}	7.67 ± 0.08^{f}
B. spectabilis	3.80 ± 0.13^{e}	62.73 ± 0.15^{c}	5.92 ± 0.28^{a}	5.37 ± 0.25^{g}
C. lancifolius	$62.60 \pm 0.13_{a}$	66.40 ± 0.17^{a}	126.70 ± 0.53^{d}	61.88 ± 0.47^{d}
I. coccinea	56.73 ± 0.18^{b}	66.63 ± 0.21^{a}	122.20 ± 8.38^{d}	106.10 ± 0.13^{b}
	Statistics			
F value	114496**	9007**	827**	43546**
LSD at 5%	0.417	0.956	11.263	1.190
LSD at 1%	0.518	1.187	13.984	1.478

** = Statistically significant at $p \leq 0.01$.

polluted with (Na), with levels exceeding 63 mg/l, but the fewest accumulation of Na was detected at the site of *C. sebestena* collection (17.18 mg/l). As an essential macronutrient required by all plant species, Ca showed a peak content in the soil where *Z. spina-christi* and *C. lancifolius* were collected (177.50 and 126.70 mg/l, respectively). The least (Ca) content, on the other hand, was reported in the sites of *B. spectabilis* and *T. stans* collection (5.92 and 9.05 mg/l, respectively). Notwithstanding, the sites where *Z. spina-christi* and *I. coccinea* were collected represented the highest (Mg) abundance in their soil (126.40 and 106.10 mg/l, respectively), but the sites of *B. spectabilis* and *T. stans* collection were the poorest in (Mg) (5.37 and 7.67 mg/l, respectively). As a general observation, the site of *Z. spina-christi* collection was found to be enriched with the important macronutrients studied in this study, with a comparatively high (Na) concentration.

Table 5 shows the variability in the concentration of some mineral ions (K, Na, Mg, and Ca) in the roots of the plant species collected from the study sites. According to statistical analysis, the different ions exhibited significant ($p \leq 0.01$) differences in the various plant species roots. (K) as a macronutrient was highly abundant in the roots of *C. lancifolius* and *B. spectabilis* species (110.40 and 106.70 mg/l, respectively). However, *T. stans* and *I. coccinea* showed the least content (62.20 and 66.30 mg/l, respectively) of this nutrient ion in their roots. As a non-essential ion, (Na) accumulation reached its maximum level in the roots *of C. lancifolius and I. coccinea* (2579.40 and 548.00 mg/l, respectively), but the lowest (Na) accumulation was reported in the roots of *T. stans* and *S. sulfurea* (20.58 and 21.63 mg/l, respectively).

Table 5. The concentration of certain mineral ions in the roots of the plant species under investigation. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Mineral ions concentration (mg /l)			
	K^+	Na^+	Ca^{++}	Mg^{++}
A. indica	76.10 ± 0.50^{e}	100.80 ± 0.25^{c}	932.1 ± 0.72^{a}	62.02 ± 0.20^{e}
S. sulfurea	105.55 ± 0.05^{c}	21.63 ± 0.08^{f}	134.4 ± 0.13^{e}	71.98 ± 0.79^{c}
Z. spina-christi	82.65 ± 0.05^{d}	65.60 ± 0.27^{d}	100.9 ± 0.47^{h}	66.25 ± 0.05^{d}
C. sebestena	105.55 ± 0.28^{c}	66.08 ± 0.03^{d}	110.7 ± 0.14^{g}	56.10 ± 0.13^{f}
T. stans	62.20 ± 0.05^{g}	20.58 ± 0.20^{g}	117.4 ± 0.13^{f}	56.48 ± 0.43^{f}
B. spectabilis	106.70 ± 0.06^{b}	54.22 ± 0.24^{e}	157.7 ± 0.12^{d}	107.60 ± 0.03^{a}
C. lancifolius	110.40 ± 0.32^{a}	2579.40 ± 0.25^{a}	210.8 ± 0.03^{c}	107.70 ± 0.08^{a}
I. coccinea	66.30 ± 0.09^{f}	548.00 ± 0.23^{b}	611.8 ± 0.10^{b}	76.67 ± 0.15^{b}
		Statistics		
F value	21060**	53582159**	2818426**	11918**
LSD at 5%	0.670	0.592	4.896	0.942
LSD at 1%	0.832	0.735	1.113	1.169

** = Statistically significant at $p \leq 0.01$.

Concerning (Ca) ion, the highest concentrations were found in the roots of *A. indica* and *I. coccinea* (932.1 and 611.8 mg/l, respectively), while the lowest concentrations were found in the roots of *Z. spina-christi* and *C. sebestena* (100.9 and 110.7 mg/l, respectively). Likewise, *C. lancifolius* and *B. spectabilis* exhibited the highest (Mg) ion accumulation in their roots (107.70 and 107.60 mg/l, respectively). However, the minimum concentration of (Mg) ions was exhibited by *C. sebestena* and *T. stans* species (56.10 and 56.48 mg/l, respectively). These ions are taken up by roots via non-selective cation channels or specific transporters. In addition to giving the wall matrix stability through (Ca) crosslinks, (Ca) preserves consistency by electrostatically attaching lipids' negative groups. In addition to being a transition metal in the porphyrin ring of chlorophylls, which is essential for photosynthesis, cellular Mg also stabilises the structure of nucleic acid polymers by anchoring to negative carboxyl groups and prevents the accumulation of a negative thylakoid potential during photosynthesis-driven H^+ extrusion [31]. In addition, (K) is an imperative macronutrient for plants because it contributes with protein biosynthesis, charge homeostasis, leaf movement, and turgidity maintenance. It has been established that an H^+/K^+ symporter mechanism actively mediates the accumulation of (K) in the root cells, enabling K+ accumulation in opposition to the concentration gradient from the soil to the root cells [32]. (Na) uptake, on the other hand, into the root cells occurs mostly through nonselective cation channels, where it is then compartmentalised into vacuoles by Na^+/H^+ antiporters [33]. The accumulation of toxic levels of (Na) in root cells can exert detrimental effects such as the stimulation of cytosolic (K) efflux, which creates an ionic imbalance, oxidative stress, impairment of (Ca) and (K) activities, disruption of protein synthesis, and reduced plant growth [34].

The metal ions transmission from the roots to the leaves of the investigated plant species, which were collected from the study sites, is summarized in **Table 6**. *B. spectabilis* and *T. stans* had the highest rates of (K) ion accumulation in their leaves (1157.50 and 111.90 mg/l, respectively), whereas *Z. spina-christi* and *S. sulfurea* showed the lowest rates of (K) ion accumulation (5.72 and 6.68 mg/l, respectively). The maximum limit of (Na) concentration in the studied plant species was recorded in the leaves of *A. indica* (548.30 mg/l) *C. sebestena* (135.90 mg/l) and *I. coccinea* (135.60 mg/l), however, its least concentration was reported in the leaves of *T. stans* and *S. sulfurea* (12.68 and 26.48 mg/l, respectively).

(Ca) ion was characteristic in its higher level of accumulation in the leaves of *B. spectabilis* and *T. stans*, where it reached its peak in those species (1860.90 and 306.90 mg/l, respectively). However, like (K and Mg), (Ca) accumulation was the lowest in the leaves of *Z. spina-christi* and *S. sulfurea* (11.02 and 28.22 mg/l, respectively). In terms of (Mg) ions accumulation in the leaves of the investigated plant species, *B. spectabilis* and *C. sebestena* species showed the maximum potential (1657.6 and 125.80 mg/l, respectively), while *Z. spina-christi* and *S. sulfurea* represented the lowest rate of (Mg) accumulation (11.05 and

Table 6. The concentration of certain mineral ions in the leaves of the plant species under investigation. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Mineral ions concentration (mg /l)			
	K^+	Na^+	Ca^{++}	Mg^{++}
A. indica	11.42 ± 0.33^f	548.30 ± 0.13^a	44.27 ± 0.08^f	67.57 ± 1.10^d
S. sulfurea	6.68 ± 0.08^g	26.48 ± 0.25^f	28.22 ± 0.11^g	33.17 ± 0.08^f
Z. spina-christi	5.72 ± 0.10^h	135.60 ± 0.11^b	11.02 ± 0.16^h	11.05 ± 0.15^g
C. sebestena	66.52 ± 0.28^e	135.90 ± 0.38^b	111.40 ± 0.79^d	125.80 ± 0.17^b
T. stans	111.90 ± 0.19^b	12.68 ± 0.12^g	306.90 ± 0.56^b	56.53 ± 0.26^e
B. spectabilis	1157.50 ± 0.17^a	33.88 ± 0.16^e	1860.90 ± 0.26^a	1657.6 ± 0.08^a
C. lancifolius	110.80 ± 0.15^c	38.22 ± 0.08^d	127.70 ± 0.76^c	111.30 ± 1.06^c
I. coccinea	106.65 ± 0.13^d	49.18 ± 0.12^c	68.20 ± 0.17^e	56.45 ± 0.30^e
	Statistics			
F value	11673545**	2609129**	5804439**	2991730**
LSD at 5%	0.560	0.541	1.280	1.597
LSD at 1%	0.696	0.672	1.589	1.982

** = Statistically significant at $p \leq 0.01$.

33.17 mg/l, respectively). Overall, the leaves of *B. spectabilis* possessed substantial quantities of (K, Mg, and Ca), with a relatively moderate magnitude of (Na).

The concentrations of various heavy metal contaminants in soil sampled from the sites where the investigated plants were collected are shown in Table 7. In this concern, (Zn), (Ba) and (Ni) were the most prevalent pollutants, however, (Cd) and (Pb) were the least common pollutants in all sites. The site where *A. indica* was collected was heavily polluted with Zn, (Cr), Cd and (Co), as it possessed the greatest concentrations of these metals (60.95, 16.65, 0.75 and 10.60 µg/l, respectively). However, the soils of *Z. spina-christi*, *C. sebestena*, and *T. stans* exhibited the highest concentrations of Ni (22.92 µg/l), Pb (10.67 µg/l), and Ba (56.12 µg/l), respectively.

The *A. indica* sampling site, on the other hand, demonstrated the lowest concentrations of (Ni and Ba) as soil pollutants (11.28 and 17.5 g/l, respectively). However, the least existence of (Zn) (36.65 µg/l), Cr (6.17 µg/l), (Cd) (0.10 µg/l), (Pb) (3.00 µg/l) and (Co) (5.22 µg/l) was reported in the sampling sites of *C. lancifolius*, Z. *spina-christi*, *I. coccinea*, *S. sulfurea* and *S. sulfurea*, in that order. The electroplating industry, metal processing, mining, volcanic eruptions, landfill, weathering of soils, household appliances, surgical devices, metal alloys, automobile batteries, forest fire, coal, peat and wood burning, sludge, industrial effluent, paints, herbicides, and industrial effluents are the primary contributors of heavy metals in the soil [35] [36]. Jeddah governorate as an urban community is subjected to the majority of these pollution sources, which have a negative impact on all living creatures in the area. This fact necessitates collaboration between

Table 7. Heavy metals concentration in the sampling sites of the plant species under investigation. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Heavy metals concentration (µg/l)						
	Zn^{++}	Cr^{+++}	Ni^{++}	Cd^{++}	Pb^{++}	Co^{++}	Ba^{++}
A. indica	60.95 ± 0.05^{a}	16.65 ± 0.15^{a}	11.28 ± 0.11^{d}	0.75 ± 0.05^{a}	3.12 ± 0.08^{e}	10.60 ± 0.13^{a}	17.50 ± 0.05^{g}
S. sulfurea	51.63 ± 2.05^{b}	12.70 ± 0.13^{c}	11.85 ± 0.13^{d}	0.60 ± 0.05^{b}	3.00 ± 0.05^{e}	6.20 ± 0.10^{d}	26.13 ± 0.15^{e}
Z. spina-christi	45.68 ± 0.16^{c}	6.17 ± 0.08^{f}	22.92 ± 3.33^{a}	0.68 ± 0.03^{ab}	9.12 ± 0.03^{b}	6.67 ± 0.15^{c}	18.23 ± 0.16^{f}
C. sebestena	46.22 ± 0.18^{c}	11.17 ± 0.15^{d}	19.73 ± 0.21^{ab}	0.72 ± 0.11^{ab}	10.67 ± 0.11^{a}	5.22 ± 0.06^{f}	27.72 ± 0.13^{d}
T. stans	49.80 ± 0.13^{b}	15.72 ± 0.20^{b}	22.55 ± 0.05^{a}	0.08 ± 0.03^{d}	7.10 ± 0.05^{d}	8.08 ± 0.08^{b}	56.12 ± 0.08^{a}
B. spectabilis	44.30 ± 0.05^{c}	11.30 ± 0.05^{d}	16.20 ± 0.10^{c}	0.20 ± 0.05^{cd}	7.53 ± 0.08^{c}	5.73 ± 0.06^{e}	30.43 ± 0.16^{c}
C. lancifolius	36.65 ± 0.10^{d}	15.75 ± 0.20^{b}	16.78 ± 0.11^{bc}	0.25 ± 0.05^{c}	7.70 ± 0.05^{c}	6.65 ± 0.18^{c}	38.15 ± 0.09^{b}
I. coccinea	46.18 ± 0.19^{c}	6.72 ± 0.08^{e}	11.78 ± 0.08^{d}	0.10 ± 0.00^{d}	7.67 ± 0.08^{c}	5.92 ± 0.03^{de}	17.65 ± 0.05^{g}
Statistics							
F value	267.5**	2449.3**	48.8**	90.2**	4697.1**	739.7**	37937.7**
LSD at 5%	2.079	0.398	3.342	0.150	0.191	0.311	0.330
LSD at 1%	2.582	0.494	4.150	0.186	0.238	0.386	0.410

** = Statistically significant at $p \leq 0.01$.

many organizations in order to develop an appropriate response, considering phytoremediation techniques, to find an immediate and appropriate solution to this challenge.

The accumulation of various heavy metal ions in the root tissues of the plant species collected from the study sites is shown in Table 8. According to the findings, *C. lancifolius* is a robust phytoaccumulator of (Zn, Ni, and Co), with the largest amounts of these metal ions in its roots (94.83, 3.32, and 2.13 µg/l, respectively). *I. coccinea*, on the other hand, was demonstrated to be a powerful (Cr and Ba) phytoaccumulator in its root tissues (6.18 and 13.03 µg/l, respectively). In this context, the highest concentrations of (Cd) (0.75 µg/l) and Pb (5.93 µg/l) were attained in the root tissues of *Z. spina-christi* and *B. spectabilis*, respectively. Interestingly, (Zn) presented the highest heavy metal concentration in the root tissues of the collected samples, with concentrations ranging from 31.05 to 94.83 µg/l in *T. stans* and *C. lancifolius*, respectively. On the other hand, the least heavy metal detected in the roots of the collected samples was (Cd), which non-significantly varied among the tested samples, as its concentrations ranged from 0.67 µg/l in *T. stans* and *A. indica* to 0.75 µg/l in *Z. spina-christi*. Therefore, *C. lancifolius*, *I. coccinea*, *Z. spina-christi*, and *B. spectabilis* were shown to be potent hyperaccumulators in this study, with a high capacity for accumulating substantial amounts of various polluting metals in their root systems, resulting in a greater capacity for remediating contaminated sites.

The concentrations of heavy metals translocated from the roots to the leaves of the plant species under investigation are depicted in Table 9. The data revealed that the most actively accumulated metals in the leaves of the tested plant

Table 8. Heavy metals concentration in the roots of the plant species under investigation. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Heavy metals concentration (µg/l)						
	Zn^{++}	Cr^{+++}	Ni^{++}	Cd^{++}	Pb^{++}	Co^{++}	Ba^{++}
A. indica	70.92 ± 0.38^{c}	2.28 ± 0.10^{d}	1.73 ± 0.08^{e}	0.67 ± 0.10^{a}	3.57 ± 0.08^{e}	0.85 ± 0.05^{de}	10.13 ± 0.06^{c}
S. sulfurea	55.28 ± 0.20^{e}	1.65 ± 0.05^{e}	1.07 ± 0.08^{f}	0.72 ± 0.03^{a}	3.62 ± 0.03^{e}	0.75 ± 0.05^{e}	7.22 ± 0.03^{e}
Z. spina-christi	66.55 ± 0.23^{d}	3.25 ± 0.10^{c}	7.62 ± 0.10^{a}	0.75 ± 0.05^{a}	4.85 ± 0.13^{b}	1.23 ± 0.15^{b}	12.57 ± 0.08^{b}
C. sebestena	76.18 ± 0.13^{b}	5.18 ± 0.08^{b}	2.60 ± 0.05^{c}	0.73 ± 0.03^{a}	4.85 ± 0.05^{b}	0.93 ± 0.06^{de}	12.88 ± 0.03^{a}
T. stans	31.05 ± 0.05^{h}	1.90 ± 0.13^{e}	2.15 ± 0.05^{d}	0.67 ± 0.06^{a}	4.33 ± 0.08^{c}	1.07 ± 0.08^{bcd}	7.20 ± 0.13^{e}
B. spectabilis	52.67 ± 0.15^{f}	3.25 ± 0.13^{c}	2.08 ± 0.06^{d}	0.70 ± 0.05^{a}	5.93 ± 0.08^{a}	1.17 ± 0.08^{bc}	7.82 ± 0.08^{d}
C. lancifolius	94.83 ± 0.15^{a}	3.20 ± 0.13^{c}	3.32 ± 0.08^{b}	0.70 ± 0.05^{a}	3.60 ± 0.05^{e}	2.13 ± 0.08^{a}	6.37 ± 0.03^{f}
I. coccinea	42.47 ± 0.19^{g}	6.18 ± 0.08^{a}	2.28 ± 0.16^{d}	0.73 ± 0.06^{a}	4.00 ± 0.10^{d}	1.00 ± 0.05^{cd}	13.03 ± 0.03^{a}
Statistics							
F value	28704.3**	688.1**	1581.4**	0.857**	326.7**	86.27**	5425.8**
LSD at 5%	0.583	0.296	0.250	0.163	0.225	0.227	0.189
LSD at 1%	0.724	0.367	0.310	0.203	0.280	0.282	0.235

** = Statistically significant at $p \leq 0.01$.

Table 9. Heavy metals concentration in the leaves of the plant species under investigation. The results represent the average of three replicates ± SD. Similar superscript letters in the same column demonstrate non-significant differences.

Plant species	Heavy metals concentration (µg/l)						
	Zn^{++}	Cr^{+++}	Ni^{++}	Cd^{++}	Pb^{++}	Co^{++}	Ba^{++}
A. indica	$85.55^{a} \pm 0.05$	$4.30^{h} \pm 0.13$	$18.17^{c} \pm 0.15$	$0.75^{a} \pm 0.05$	$2.80^{e} \pm 0.05$	$6.27^{d} \pm 0.12$	$6.05^{h} \pm 0.05$
S. sulfurea	$71.85^{b} \pm 0.22$	$19.38^{d} \pm 0.03$	$37.30^{a} \pm 0.10$	$0.00^{d} \pm 0.00$	$2.68^{e} \pm 0.08$	$8.07^{a} \pm 0.03$	$54.0^{b} \pm 0.05$
Z. spina-christi	$65.32^{e} \pm 0.08$	$21.07^{c} \pm 0.08$	$14.83^{g} \pm 0.16$	$0.00^{d} \pm 0.00$	$8.63^{a} \pm 0.03$	$4.75^{g} \pm 0.05$	$58.53^{a} \pm 0.08$
C. sebestena	$63.13^{f} \pm 0.08$	$14.17^{f} \pm 0.10$	$15.40^{f} \pm 0.13$	$0.08^{cd} \pm 0.03$	$8.70^{a} \pm 0.10$	$5.62^{f} \pm 0.13$	$27.67^{d} \pm 0.08$
T. stans	$66.18^{d} \pm 0.08$	$28.08^{a} \pm 0.10$	$16.72^{d} \pm 0.18$	$0.75^{a} \pm 0.05$	$7.18^{b} \pm 0.08$	$8.13^{a} \pm 0.03$	$26.12^{e} \pm 0.16$
B. spectabilis	$71.20^{c} \pm 0.09$	$26.18^{b} \pm 0.10$	$26.13^{b} \pm 0.18$	$0.12^{c} \pm 0.03$	$5.33^{c} \pm 0.19$	$6.65^{c} \pm 0.05$	$21.15^{g} \pm 0.13$
C. lancifolius	$62.93^{f} \pm 0.31$	$15.60^{e} \pm 0.13$	$15.97^{e} \pm 0.26$	$0.17^{c} \pm 0.03$	$3.32^{d} \pm 0.13$	$7.60^{b} \pm 0.10$	$24.28^{f} \pm 0.03$
I. coccinea	$66.03^{d} \pm 0.23$	$12.67^{g} \pm 0.15$	$13.17^{h} \pm 0.17$	$0.47^{b} \pm 0.06$	$3.60^{d} \pm 0.13$	$5.98^{e} \pm 0.08$	$29.30^{c} \pm 0.13$
Statistics							
F value	6075.7**	14619.2**	7187.5**	224.9**	1679.9**	688.6**	91454.0**
LSD at 5%	0.468	0.312	0.469	0.104	0.307	0.227	0.280
LSD at 1%	0.581	0.388	0.582	0.129	0.381	0.282	0.347

** = Statistically significant at $p \leq 0.01$.

species were (Zn, Ba, Ni, and Cr), whereas (Cd) was the least accumulated among the metals studied. The highest concentrations of (Zn) (85.55 µg/l) and (Cd) (0.75 µg/l) were detected in *A. indica* leaves, Cr (28.08 µg/l) and Co (8.13

μg/l) in *T. stans* leaves, (Ni) (37.30 μg/l) in *S. sulfurea* leaves, (Pb) (8.70 μg/l) in *C. sebestena* leaves, and (Ba) (58.53 μg/l) in *Z. spina-christi* leaves. Like in roots, the least heavy metal detected in the leaves of the collected samples was (Cd), which significantly varied among the tested samples, as its concentrations ranged from 0.00 μg/l in *Z. spina-christi* and *S. sulfurea* to 0.75 μg/l in *A. indica* and *T. stans*. Furthermore, (Zn and Ba) were detected to be the most actively accumulated metals in the studied plant species leaves. Plant roots absorb and transport metal contaminants from the soil to the plants' above-ground portions in a process known as phytoextraction. Phytoextraction provides an innovative, low-cost, and effective approach that has the potential to dramatically improve the chances of purifying metal-contaminated places, thereby tackling an intractable worldwide problem [37]. According to the findings of this study, street-grown trees in the studied area can be harnessed in the extraction of toxic heavy metals such as (Zn, Ba, Ni, and Cr) from the contaminated sites.

4. Conclusions and Recommendations

This study concentrated on the issue of urban environmental pollution in Jeddah governorate, Kingdom of Saudi Arabia. Some plant species, such as *I. coccinea* and *T. stans*, demonstrated normal growth and metabolic performance despite ambient pollution circumstances, according to the results of the study. What's more, (Zn, Ba, and Ni) were the most typically accumulated pollutants in the leaves of the investigated plants, indicating their high accumulation potential. In addition, the roots of *C. lancifolius*, *I. coccinea*, *Z. spina-christi*, and *B. spectabilis* were proven to be significant phtoextractors to numerous heavy metals. Consequently, these plant species can be employed in phytoremediation approaches at contaminated sites. According to the study's final conclusion, Saudi Arabia government needs to expand the use of these species as environmental refineries, which can purify urban areas from pollutants. However, more in-depth scientific studies on different pollutants in the air, water, and soil throughout the selected site ecosystem are being required to monitor environmental pollution in urban sectors. Future approaches for similar studies include expanding the research area all through the Saudi Arabia Kingdom's metropolitan areas, which will highlight correlations and patterns while also offering a deeper knowledge of urban pollution. The Saudi biosphere as a whole should be included in ongoing studies, with a comprehensive emphasis on the plant species that can be used in the phytoremediation of organic pollutants.

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Conflicts of Interest

The authors declare that they have no competing interests in this research work.

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