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Original Article

Comparative assessment of phytoremediation potential of four Ficus spp. under Semi-arid environmental conditions

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Abstract

Heavy metals have been recognized as a prominent hazard in today's world, causing pollution in the air environment. Woody tree species can play a significant role in the extraction and remediation of metal pollutants from the air, therefore promoting the air quality index. This study investigated the potential of four species of the Ficus genus (F. benjamina, F. microcarpa, F. religiosa, and F. virens) to remediate varying levels of heavy metal contamination in industrial, residential, and highway areas of Faisalabad City, Pakistan. For this purpose, six heavy metals (cadmium, chromium, copper, lead, zinc, and manganese) were assessed in young leaves (YL) as well as old leaves (OL) of subjected tree species at selected study sites. Eight fully expanded leaves were selected from each tree species: two from each cardinal direction from the shoot of the current year (young leaves, YL), as well as from the shoot of the previous year (old leaves, OL). The results showed that the same genus has different capabilities to accumulate different heavy metals, and the overall trend was in the following order: F. virens > F. religiosa > F. benjamina > F. microcarpa at all study sites. The heavy metal contents in both YL and OL of selected tree species decreased in the order of Manganese (Mn)> Zinc (Zn)> Copper (Cu) > Chromium (Cr) > Lead (Pb) > Cadmium (Cd) at all study sites. The metal accumulation index (MAI) values ranged between 2.14-5.42 for F. benjamina, 2.09-3.89 for F. microcarpa, 3.61-7.01 for F. religiosa and 4.77-6.48 for F. virens across all study sites. Among the studied tree species, it has been determined that F. virens and F. religiosa are well-suited for urban areas with significant heavy metal contamination and can be strategically planted in barrier areas to effectively combat atmospheric pollution.

Keywords: Atmospheric pollution, Bio-concentration factor, Heavy metals, Ficus species, Metal accumulation index

1. Introduction

The ongoing advancements and progress in our standard of living have led to a noticeable increase in the issue of urban air quality, which has emerged as a significant subject of interest for researchers. As a consequence of this advancement, many different kinds of pollutants have been generated. The issue of pollution in urban areas is increasingly recognized as a significant problem [1, 2], and it is presently regarded as one of the primary environmental health concerns [3]. Comprehending urban air pollution is essential for municipal governance and urban planning. In this regard, the adoption of biological monitoring has proven to be a more effective approach [4, 5]. However, the response of species and ecosystems is more important than the concentration of some pollutants in the air [6, 7].

Heavy metals (HMs) have gained significant attention among the various airborne contaminants due to their non-biodegradable and pervasive features and their toxic and detrimental effects on living things, even at low levels [8]. In recent decades, there has been noteworthy global interest among researchers in utilizing vegetation for monitoring pollution caused by different heavy metals [9-13]. The utilization of plants as passive samplers in biomonitoring offers several advantages, including extensive spatial and temporal coverage, as well as cost-effectiveness [14, 15]. Therefore, it has been observed that higher plants with long-term survival capabilities can be employed for bio-

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monitoring air quality [16, 17]. In recent times, trees have become the primary choice for bioindicators in air quality biomonitoring studies across the globe [18, 19]. A few studies have been conducted to assess the phytoremediation potential of woody vegetation in urban areas across the country. For example, a study conducted by [3] examined the phytoremediation ability of *Eucalyptus camaldulensis* and *Morus alba* in different urban and rural areas. Similarly, [20] examined the phytoremediation potential of four tree species (*M. alba*, *V. nilotica*, *A. ampliceps*, and *A. indica*) in different urban areas.

The genus *Ficus* L., commonly referred to as figs, is a type of angiosperm belonging to the Moraceae family. Figs are native to tropical and subtropical regions, and some species are present in semi-warm temperate zones [21]. The genus contains approximately 800 species that are distributed worldwide [22]. Among them, 120 species are found in the Americas, 105 species in Africa, and 367 species are distributed throughout the Asian-Australasian region [23]. In Pakistan, several *Ficus* species, such as *F. virens*, *F. religiosa*, *F. benjimina*, *F. elastica*, *F. microcarpa*, etc, have been widely planted along the roads, in and around the industrial as well as residential areas of many big cities like Faisalabad.

The accumulation of heavy metals in plants is primarily affected by specific plant organs (such as leaves or bark) and species characteristics, which encompass factors such as growth rate and biomass [24, 25]. Metals are acquired by plants through their root system from the soil and subsequently transported to different plant tissues [26-28]. The climate change and pollution issue in central Punjab, Pakistan, specifically in Faisalabad City, has been intensifying for a considerable period. The urban environment in Faisalabad is confronted with substantial difficulty concerning the absorption of heavy metals, which presents potential hazards to both the ecology and public health. The industrial and urban activities in the region result in the emission of heavy metals into the atmosphere, soil, and water, causing their buildup in the ecosystem.

This accumulation raises concerns about the long-term impacts on flora, fauna, and human inhabitants[29, 30]. The limited research on heavy metal uptake in the urban landscape of Faisalabad poses challenges to the development of successful methods of mitigation and safety regulations. Hence, this study aimed to examine the capacity of four distinct species of Ficus: *F. virens*, *F. religiosa*, *F. benjimina*, and *F. microcarpa*, to accumulate and withstand heavy metals in their leaves within the industrial hub of the country. The levels of heavy metals such as Cd, Cu, Cr, Pb, Zn, and Mn were analysed in both mature and young leaves of four different Ficus species. These species were collected along roads with high traffic flow, and industrial and residential areas of the city in order to highlight the usefulness of these species as a bioindicator of air metallic pollution.

2. Materials and Methods

2.1. Study area and sampling sites

The research was carried out in a metropolitan city, Faisalabad, the industrial hub and the third largest city in the Punjab Province of Pakistan, having an estimated population of 3.7 million in 2023 with a growth rate of 2.37%. The city is located at a longitude of 73°5′28″ East, a latitude of 31°25′0″ North, and has an elevation of approximately 186 m above mean sea level. The city of Faisalabad is subject to a semi-arid climate, which is defined by an average annual rainfall of around 375 millimeters (14.8 in). The precipitation exhibits a pronounced seasonality, with approximately 50% of the total rainfall concentrated in the monsoon season, specifically during July and August. The summer season experiences high temperatures, ranging from 26.9 to 45.5°C, while in winter, the temperatures range from 4.1°C to 19.4°C. In this particular region, the winds are generally light.

The city is home to a variety of industrial activities, including the textile industry, ceramic tile manufacturing, and pipe manufacturing industries. The vehicular traffic volume in the city is extremely high and different kinds of vehicles, such as trucks, coaches, rickshaws, motorcycles, tourism vehicles, and road tractors, move across the city daily. Congestion is observed on all the major roads passing through the city, and it is in close proximity to economic zones and industrial states. Samples were collected from 3 sites: roads with heavy traffic flow, industrial area, and residential area. Overall, 15 sampling points, 5 for each site, were randomly selected for leaf sampling of selected *Ficus* species (Figure 1).

2.2. Leaf sampling

Leaf sampling was conducted in November 2022 following nearly 60 days of rainfall. This ensures that heavy metals are not released from the leaf surface. Sampling was conducted from the lower one-third of the canopy of each tree species. Eight fully expanded leaves were selected from each tree species: two from each cardinal direction. These leaves were taken from the shoot of the current year (young leaves, YL), as well as from the shoot of the previous year (old leaves, OL). A total of 120 samples were collected across the entire study area, with 40 samples taken from each site and 60 samples from each age class. Special attention was taken to ensure that no flaws, like insects, bird droppings, or pesticide residue, were gathered. The leaves were meticulously transported to the laboratory for further analysis, following the required procedures of washing, drying, and grinding.

2.3. Sample digestion

The leaf samples were initially subjected to wet digestion using the procedure outlined by [17]. In a 100 mm volumetric flask, 0.2 grams of leaf sample and 4 mm of nitric acid (HNO_3) were added and mixed well. Before heating, the solution was incubated for a few hours. After this, the solution was meticulously heated using a water bath until the red fumes emitted from the flask were eliminated. Then, the solution was cooled to room temperature, and 4 mL of perchloric acid was added to the flask. Filtration was carried out with the help of Whatman filter paper no. 42. By adding the purified water, the volume was adjusted to the desired level.

The atomic absorption spectroscopy technique was employed to assess heavy metals in the leaf samples. For the evaluation of the presence of heavy metals like copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), and manganese (Mn), air acetylene was utilized as fuel, while the radiation source utilized hollow cathode lamps [3, 31]. Furthermore, the prescribed solutions for each trace element under investigation were utilized, and their retrieval rates were calculated to validate and ensure the effectiveness of the methodology used in identifying heavy metals from the leaf samples of ficus tree species. Moreover, to ensure quality standards, the materials, solutions, and acids utilized were of analytical grade and highly purified. In order to ensure quality control, reagent blanks, as well as standard reference materials (namely SRM 1515 and 1573a for plants), were included in the analysis. These materials were replicated, and 10% of the entire specimen population was used to check purities and detect any potential inaccuracies or biases in the analytical method. During the complete digestion process, the recovery rates used for most trace metals were 78 to 120% in standard reference materials [32].

2.4. Heavy metals assessment

An atomic absorption spectrophotometer (Shimadzu AA-6800) was used to evaluate the amount of different HMs such as zinc, copper, cadmium, chromium, manganese, and lead in old and new leaf samples collected from four different ficus tree species and were described as mg kg^{-1} [1].

2.5. Bio-concentration factor

The Bio-concentration factor (BCF) indicates the ratio of all the metal content in the leaves to the soil concentration. Bio-concentration factor (BCF) also indicated the enrichment and intensification of various HMs. The approach explained by [6] was employed to measure the deposition of specific HMs in plants, as indicated by the following formula:

$$BCF = \frac{C_{harvested\ tissue}}{C_{soil}}$$

Where $C_{harvested\ tissue}$ indicates metal contents in leaf samples and C_{soil} represents soil metal concentration.

2.6. Comprehensive bio-concentration index (CBCI) and metal accumulation index (MAI)

The comprehensive bio-concentration index (CBCI) designates the aptitude of trees to amass multiple metals and was estimated by adopting the relationship explained by [33].

$$\mu(x) = \frac{X - X_{min}}{X_{max} - X_{min}}$$

The accumulation of various types of substances in the leaves of trees occurs simultaneously. An accumulation index was calculated based on the data gathered during this study to estimate the general effectiveness of the tree species in terms of metal accumulation. This index is known as the metal accumulation index (MAI) and measures the metal accumulation. MAI was computed by following the formula developed by [34].

$$MAI = \left(\frac{1}{N}\right)\sum_{j=1}^{N} Ij$$

2.7. Statistical analysis

Following the assessment of data normality, the difference in leaf heavy metal data across species of selected sites were examined using a one-way analysis of variance (ANOVA) with the assistance of Statistica version 10 tool, developed by StatSoft, Inc. Statistically significant differences were identified using LSD test, with a significance level of $p < 0.05$.

3. Results

3.1. Heavy metals in tree leaves

3.1.1.Copper (Cu)

Copper (Cu) is considered a heavy metal, but it is also an essential micronutrient required for chlorophyll and seed production and for several enzymatic activities. Cu accumulation beyond the permissible limit (>1 mg/m^3) causes several oxidative toxic effects on plants and humans. In the present study, we revealed the Cu accumulation index in younger and older leaves of *Ficus* species (*F. benjamina*, *F. microcarpa*, *F. religiosa*, and *F. virens)* grown at three different sites: residential, industrial, and highways, as demonstrated in Figure 2. The results of our study showed a maximum accumulation of Cu in older leaves of all subject species as compared to younger leaves. In addition to that, it is also obvious from the results of the current study that the site also plays a significant role in Cu accumulation, as trees located in industrial areas had the maximum concentration of Cu, followed by trees present alongside highways. A minimum concentration of Cu (5.72 mg kg^{-1}, 7.75 mg kg^{-1}, 7.89 mg kg^{-1}, 8.45 mg kg^{-1}) was reported in trees located in residential areas. For instance, *F. virens,* alongside highways and in residential areas, accumulated 21.68 % and 15.98 % lower Cu in their leaves (both younger and older) as compared to corresponding species in industrial areas. Likewise, *F. benjamina* in industrial areas accumulated 6.15 % and 60.93 % higher copper as compared to the corresponding species in highway and residential areas, respectively. Similarly, *F. religiosa* in industrial sites accumulated 15.84% and 53.71 % higher Cu in their leaves than those in highway and residential areas, respectively. Although all species of *Ficus* showed a significant potential to accumulate Cu in their leaves in all study sites, but overall Cu-accumulation trends for all subjected tree

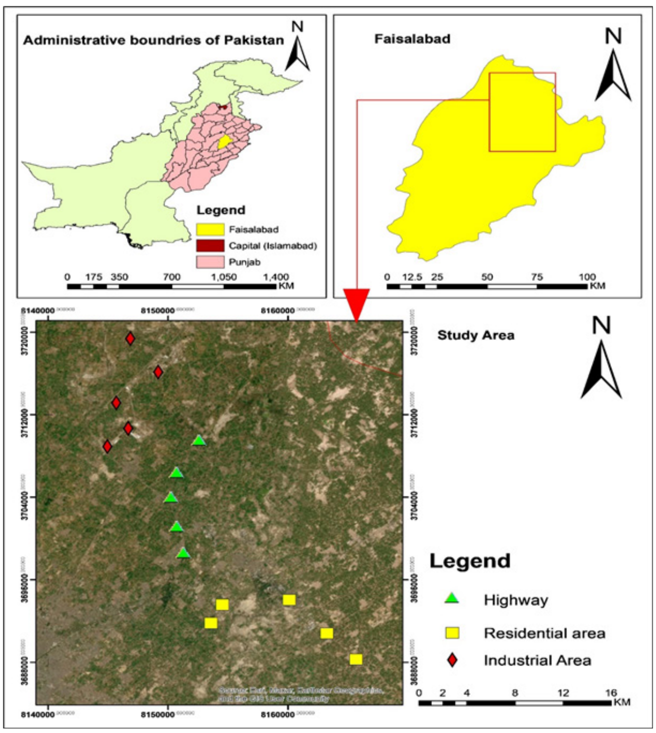

Fig. 1. Study area map showing the sampling point distribution within selected sites.

species was *F. virens* > *F. religiosa* > *F. microcarpa*. For instance, in industrial areas, *F. virens* accumulated 64.29 % and 60.71% higher Cu than *F. microcarpa* and *F. Religiosa*, respectively, as depicted in Figure 2.

3.1.2. Cadmium (Cd)

Cadmium (Cd) is a very toxic heavy metal due to its non-degradable nature and high persistency in nature and causes detrimental effects on the environment. Chronic exposure to Cd can cause severe morphological, physiological, and biochemical effects on plants and cause kidney and lung damage in humans. In the present study, we revealed the Cd accumulation index in younger and older leaves of *Ficus* species (*F. benjamina*, *F. microcarpa*, *F. religiosa*, and *F. virens)* grown at three different sites: residential, industrial, and highways, as demonstrated in Figure 3. The results demonstrated that species types and study sites significantly influenced Cd accumulation percentage, as Cd accumulation was maximum (0.58 mg kg^{-1}, 0.37 mg kg^{-1}, 0.80 mg kg^{-1}, 0.88 mg kg^{-1}) in all subjected tees in the industrial site as compared to the other two areas, and the overall Cd-accumulation trend in all subjected trees was *F. virens* > *F. religiosa* >. *F. benjamina* > *F. macrocarpa.* Moreover, the results of this study revealed that older leaves have accumulated more concentration of cadmium than younger leaves. For instance, younger leaves of *F. benjamina*, *F. microcarpa*, *F. religiosa*, and *F. virens* in industrial areas accumulated 0.49 mg/kg, 0.33 mg/kg, 0.67 mg/kg, and 0.79 mg/kg of Cd respectively whereas older leaves have accumulated 0.68, 0.42, 0.93 and 0.97 mg/kg cadmium.

Among sites, it can be observed that trees in residential areas have accumulated a minimum concentration of Cd for all selected species, while the maximum amount of Cd was reported in trees located in Industrial areas. For instance, *F. virens* in highway and residential areas accumulated 10.23% and 16.87% less Cd in their older leaves as compared to the correspondence species in industrial areas. Likewise, *F. microcarpa* in industrial areas accumulated 10.53% and 20.00% higher Cd than the corresponding species in highway and residential sites. *F. benjamina* also showed statistically significant results for different sites as it appeared that leaves of *F. benjamina* in industrial areas accumulated 21.43 % and 30.77 % higher Cd than in corresponding species in highway and residential areas, as demonstrated in Figure 3.

3.1.3. Chromium (Cr)

Chromium is the second most common metal pollutant in the soil, sediment, groundwater, and atmosphere, and its excessive amount can be detrimental to human beings. The Cr accumulation pattern in younger and older leaves of selected *Ficus* species grown at three different sites: residential, industrial, and highway was represented in Figure 4. The results demonstrated that minimum accumulation of Cr (1.44 mg kg^{-1}, 1.69 mg kg^{-1}, 1.99 mg kg^{-1}) was reported in younger leaves of *F. microcarpa* followed by *F. benjimina* and *F. religiosa*, respectively across all study sites. Meanwhile, the maximum accumulation of Cr (3.45 mg kg^{-1}, 4.52 mg kg^{-1}, 4.59 mg kg^{-1}) was estimated in older leaves of *F. virens*. Overall, among all subjected samples of selected tree species, older leaves showed a significantly higher accumulation of Cr as compared to younger leaves, as demonstrated in Figure 4. Cr accumulation with respect to the study sites was considerably higher in both younger and older leaves of all subjected tree species on highways, followed by industrial areas and residential areas. For example, *F. religiosa* alongside highway accumulated 1.53 % more Cr in their leaves as compared to industrial areas, whereas *F. virens* alongside highway areas accumulated 3.40 % more Cr in their leaves as compared to industrial areas. On the other hand, *F. microcarpa* species at industrial sites accumulated 8.99% and 46.97 % more Cr in their leaves (both younger and older) than the corresponding trees on highways and residential sites, respectively. Furthermore, *F. benjamina* in industrial areas accumulated 4.5 % and 28.51 % higher Cr in their leaves

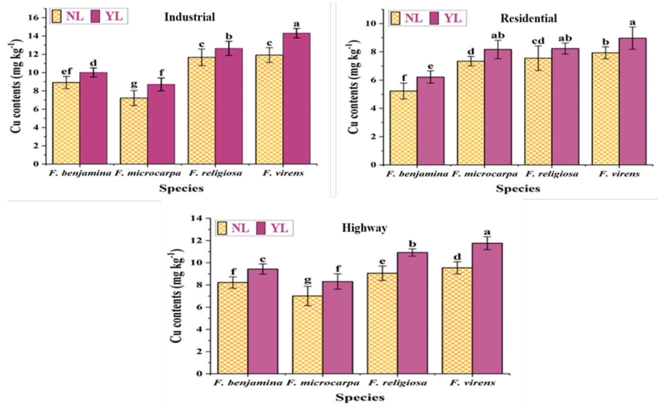

Fig. 2. Mean values ± SD of Cu (mg kg^{-1}) in new and old leaves of *Ficus* species at three different studied sites.

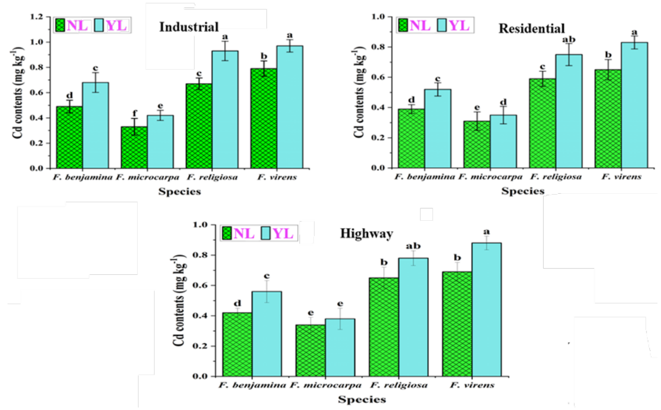

Fig. 3. Mean values ± SD of Cd (mg kg^{-1}) in new and old leaves of *Ficus* species at three different studied sites.

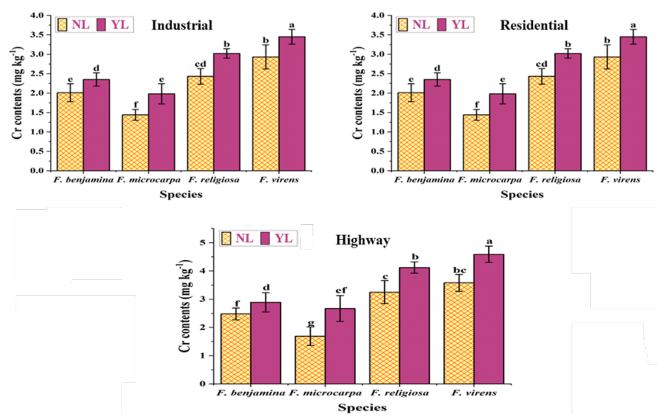

Fig. 4. Mean values ± SD of Cr (mg kg^{-1}) in new and old leaves of *Ficus* species at three different studied sites.

than in the corresponding species in highway and residential areas, as demonstrated in Figure 4.

3.1.4. Lead (Pb)

Lead (Pb) is an important heavy metal that has a lot of industrial uses, but its higher accumulation causes several toxicity effects in plants and humans. In the present study, the Pb accumulation pattern in younger and older leaves of various *Ficus* species grown at three different sites (residential, industrial, and highway) was revealed (Figure 5). The results demonstrated that a minimum accumulation of Pb (1.55 mg kg^{-1}) was reported in *F. benjamina*, followed by *F. microcarpa* (1.74 mg kg^{-1}) and *F. religiosa* (2.61 mg kg^{-1}), respectively at residential areas. Meanwhile, the maximum accumulation of Pb was reported in older leaves of *F. virens*. Overall, among all subjected samples of selected tree species, older leaves showed a significantly higher accumulation of Pb than younger leaves, as demonstrated in Figure 5. Pb accumulation with respect to the study sites was considerably higher in both younger and older leaves of all subjected tree species in industrial areas, followed by highways and residential areas (Figure 5). For instance, *F. virens* tree plants accumulated 20.50% and 34.26 % lower Pb in their leaves in highway and residential areas, respectively, as compared to corresponding tree plants in industrial areas. Likewise, *F. macrocarpa* species at industrial sites accumulated 22.11% and 29.95% higher Pb in their leaves (both younger and older) than the corresponding trees on highways and residential sites, respectively. Similarly, *F. religiosa* at industrial sites showed 21.93 % and 35.93 % higher accumulation of Pb in their leaves as compared to the corresponding species at highway and residential sites. Additionally, *F. benjamina* in industrial areas accumulated 21.43 % and 32.34 % higher Pb in their leaves than in the corresponding species in highway and residential areas, as demonstrated in Figure 5.

3.1.5. Zinc (Zn)

The results regarding the Zinc accumulation pattern in younger and older leaves of selected *Ficus* species grown at three different sites: residential, industrial, and highway were demonstrated in Figure 6. The results of this study indicated that minimum accumulation of Zn (11.54 mg kg^{-1}) was reported in younger leaves of *F. microcarpa* in residential areas followed by *F. benjimina* (12.54 mg kg^{-1}) and *F. religiosa* (16.65 mg kg^{-1}), respectively. Meanwhile, the maximum accumulation of Zn (31.01 mg kg^{-1}) was estimated in older leaves of *F. virens* at industrial sites. Overall, among all subjected samples of selected tree species, older leaves showed a significantly higher accumulation of Zn as compared to younger leaves, as demonstrated in Figure 6. Zn accumulation with respect to the study sites was considerably higher in both younger and older leaves of all subjected tree species in industrial areas, followed by highway and residential areas. For instance, *F. virens,* alongside highway and residential areas, accumulated 7.82 % and 25.50 % less Zn in their leaves (both younger and older) than the corresponding trees in industrial areas. Likewise, *F. microcarpa* grown in industrial areas accumulated 11.93 % and 17.64 % more Zn than the highway and residential areas. Furthermore, *F. benjamina* accumulated 11.93 % and 17.64 % more Zn in industrial areas as compared to highway and residential areas, respectively (Figure 6).

3.1.6. Manganese (Mn)

Manganese is also an essential micronutrient and has many industrial applications. Its excessive amount can be a cause of serious environmental hazards and health risks to human health. In the present study, the Mn accumulation pattern in younger and older leaves of selected *Ficus* species grown at three different sites: residential, industrial, and highway was represented in Figure 7. The results demonstrated that minimum accumulation of Mn (24.56 mg kg^{-1}) was reported in younger leaves of *F. microcarpa* at highway sites followed by *F. benjimina* (25.71 mg kg^{-1}) and *F. religiosa* (27.65 mg kg^{-1}), respectively. Meanwhile, the maximum accumulation of Mn (51.43 mg kg^{-1}) was estimated in older leaves of *F. virens* at industrial sites. Overall, among all subjected samples of selected tree species, older leaves showed a significantly higher accumulation of Mn as compared to younger leaves, as demonstrated in Figure 7. Mn accumulation with respect to the study sites was considerably higher in both younger and older leaves of all subjected tree species in industrial areas, followed by residential areas and highways. For instance, *F. virens,* alongside highway and residential areas, accumulated 24.14% and 12.27% less Mn in their leaves as compared to industrial areas. Likewise, *F. religiosa* present in industrial sites accumulated 27.79 % and 13.36 % more Mn than the corresponding species in highway areas and residential areas. Furthermore, *F. benjamina* present in industrial areas has accumulated 23.68 % and 1.51 % more Mn than in highway and residential areas, as demonstrated in Figure 7.

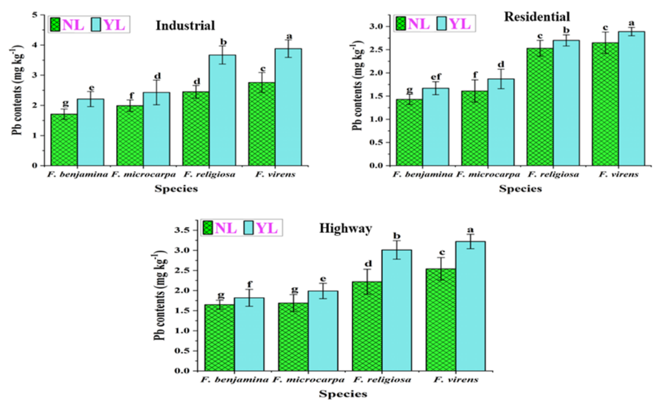

Fig. 5. Mean values ± SD of Pb (mg kg^{-1}) in new and old leaves of *Ficus* species at three different studied sites.

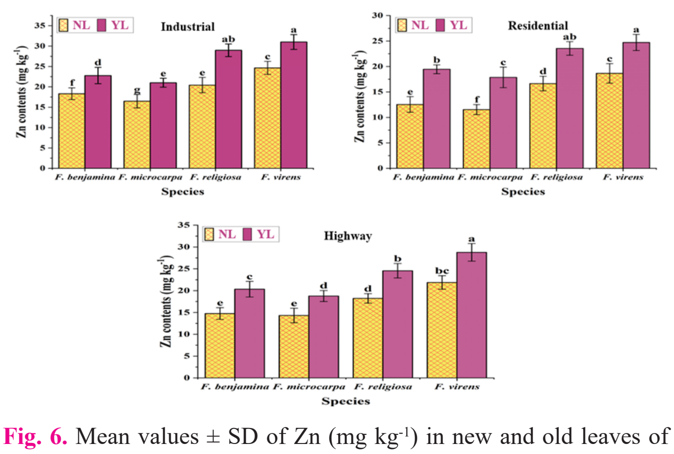

Fig. 6. Mean values ± SD of Zn (mg kg^{-1}) in new and old leaves of *Ficus* species at three different studied sites.

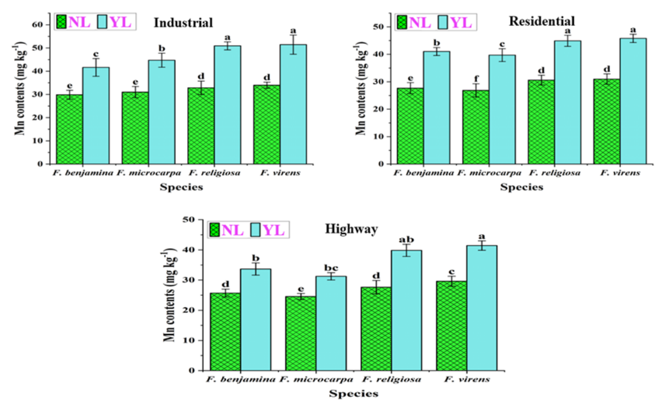

Fig. 7. Mean values ± SD of Mn (mg kg^{-1}) in new and old leaves of *Ficus* species at three different studied sites.

3.2. Comprehensive bio-concentration index (CBCI) and metal accumulation index (MAI)

Comprehensive bio-concentration index (CBCI) and metal accumulation index (MAI) in leaf samples of four selected *Ficus* species were measured for three different selected sites, i.e., industrial areas, highway areas, and residential areas. CBCI and MAI for all selected sites and species are summarized in Table 1. For the industrial area, the maximum MAI (7.01) was calculated for *F. religiosa* leaves, whereas the minimum MAI (2.33) was estimated for the leaves of *F. microcarpa*. In highway areas, *F. virens* showed a different trend as maximum MAI (6.48) was observed in the leaves of *F. virens* as compared to *F. religiosa*. *F. benjamina* showed a minimum MAI (2.14) in residential areas, whereas *F. religiosa* showed the maximum MAI in residential areas. The selected tree species were tested for their ability to store various multi-heavy metals from the soil by measuring their CBCI. In industrial areas, CBCI was present in the range of 0.39-1.09. In highway areas, CBCI was found in the range of 1.16-0.62. In residential areas, CBCI was found in the range of 0.38-0.56 for all studied *Ficus* species, as depicted in Table 1.

3.3. Bio-concentration Factor (BCF)

Table 2 displays data regarding the bio-concentration factor values for various aged leaf samples of chosen *Ficus* species at all three selected sites. Results of the current study indicate that various heavy metals have shown a wide range of BCF for selected species. Moreover, newer leaves have shown less BCF content than older ones. At industrial sites, BCF contents ranged from 0.13 to 0.82 for newer leaves and 0.19 to 0.98 for older leaves. Minimum BCF contents of chromium were found in the newer leaves of *F. microcarpa,* whereas maximum BCF contents of Cupper were found in *F. virens*. At the highway site, BCF contents ranged from 0.12 to 0.67 for newer leaves and 0.17 to 0.83 for older leaves. In residential areas, BCF contents ranged from 0.12 to 0.72 for newer leaves and 0.17 to 0.81 for older leaves. The results of the current study reveal that all selected species of *Ficus* have accumulated cadmium, but minimum BCF contents were observed in *F. microcarpa* for all the calculated heavy metals. *F. virens* showed the maximum potential to accumulate BCF contents for Cd, Cu, Pb, Cr, Zn, and Mn in its older leaves as compared to all other selected species (Table 2).

3.4.Principal component analysis and correlation

PCA analysis indicated that all the parameter variations were covered in the first two components, explaining 96.4% variation. The first factor contributed to 79.3% whereas the second factor contributed to 17.1% variation with maximum variation contribution by CBCI, Cd and Cu shown in Figure 8. Data loaded onto "PC 1" include *F. benjimina* (r = -3.66), *F. microcarpa* (r = -4.91), *F. religiosa* (r = 2.76), and *F. virens* (r = 5.81); while on "PC 2" included include *F. benjimina* (r = -0.50), *F. microcarpa* (r = 0.27), *F. religiosa* (r = 0.59), and *F. virens* (r = -0.36). Based on the qualitative data of various tree species, PCA plot indicated *F. virens* and *F. religiosa* were close to each other for various traits, while *F. benjimina* and *F. microcarpa* were highly diverse and varied from each other in terms of different traits as depicted in Figure 8.

The Pearson correlation analysis demonstrated that CBCI highly negatively correlated with the MAI, while negatively correlated with Cd, Cu, and Zn concentration and showed slightly negative correlation with Cr and no correlation with Pb, and Mn. Mantel's correlation analysis showed that *F. benjamina* and *F.virens* tree species showed significantly positive correlation with CBCI and negative

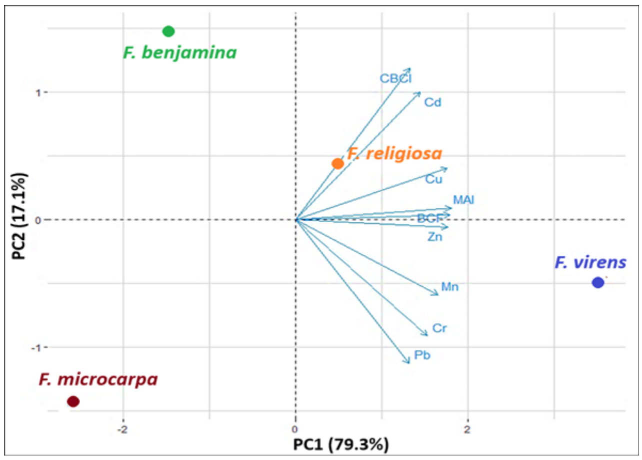

Fig. 8. Principle component analysis (PCA biplot) showing the relationship between various heavy metals and selected *Ficus* tree species.

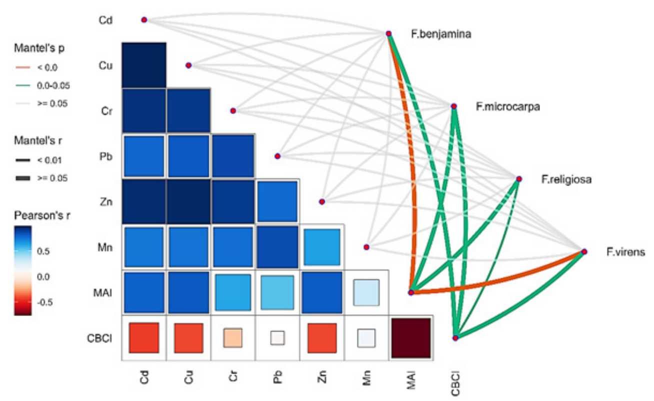

Fig. 9. Pearson interaction and mental test between different variables (heavy metals) and selected *Ficus* species. The heatmap indicates the pairwise correlations between the variables while the lines demonstrate mantel test results, and the color represents Pearson's correlation coefficient. Cd (cadmium), Cu (copper), Cr (chromium), Pb (lead), Zn (Zinc), Mn (Manganese), MAI (metal accumulation index), CBCI (comprehensive bio-concentration index).

Table 1. Leaf means (young+old) ± SD, metal accumulation Index (MAI), and Comprehensive bio-concentration Index (CBCI) OF Cd, Cu, Cr, Pb, Zn, and Mn of *Ficus* species in Industrial, Highway, and Residential Areas. *F.religiosa>F.virens>F.benjamina>F.microcarpa* for industrial areas, *F.virens>F.benjamina>F.religiosa>F.microcarpa* for highway areas, and *F.religiosa>F.virens>F.microcarpa>F.benjamina* for residential area.

Tree Species	Cd ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Cr ($mg\ kg^{-1}$)	Pb ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	MAI	CBCI
				Industrial Area				
F. benjamina	0.59 (0.13)	9.47 (0.77)	2.90 (0.16)	1.96 (0.35)	20.54 (3.14)	35.76 (4.33)	4.91	0.45
F. microcarpa	0.38 (0.06)	7.97 (1.05)	2.45 (0.65)	2.21 (0.31)	18.75 (3.19)	37.86 (2.98)	2.33	1.09
F. religiosa	0.80 (0.18)	12.2 (0.69)	3.50 (0.68)	3.06 (0.86)	24.70 (4.06)	41.89 (5.01)	7.01	0.39
F. virens	0.88 (0.12)	13.1 (1.70)	4.05 (1.57)	3.32 (0.79)	27.83 (4.49)	42.71 (4.82)	5.81	0.87
				Highway Area				
F. benjamina	0.49 (0.09)	8.83 (0.85)	2.69 (0.29)	1.74 (0.12)	17.55 (3.98)	29.69 (4.61)	5.42	1.16
F. microcarpa	0.36 (0.02)	7.66 (0.91)	2.18 (0.70)	1.84 (0.21)	16.54 (3.15)	27.89 (3.99)	2.09	0.67
F. religiosa	0.72 (0.08)	9.99 (1.31)	3.68 (0.62)	2.61 (0.55)	21.39 (4.16)	33.74 (4.01)	3.61	0.80
F. virens	0.79 (0.13)	10.66 (1.56)	4.10 (0.71)	2.88 (0.48)	25.32 (4.87)	35.52 (5.26)	6.48	0.62
				Residential Area				
F. benjamina	0.45 (0.09)	5.73 (0.70)	2.18 (0.24)	1.55 (0.16)	15.99 (4.88)	34.35 (3.29)	2.14	0.56
F. microcarpa	0.33 (0.04)	7.76 (0.58)	1.71 (0.38)	1.74 (0.18)	14.71 (3.46)	33.29 (4.11)	3.89	0.38
F. religiosa	0.67 (0.11)	7.89 (0.49)	2.72 (0.41)	2.62 (0.12)	20.09 (3.91)	37.76 (4.00)	6.92	0.51
F. virens	0.74 (0.08)	8.45 (0.74)	3.19 (0.75)	2.77 (0.20)	21.68 (4.48)	38.40 (3.90)	4.77	0.46

Table 2. Bio-concentration factor of heavy metals (Cd, Cu, Cr, Pb, Zn, and Mn) in new and old leaf samples of *Ficus* species in Industrial, Highway and Residential Areas.

Site	**Industrial Area**							
Leaf age	**YL**				**OL**			
Tree species	*F. benjamina*	*F. microcarpa*	*F. religiosa*	*F. virens*	*F. benjamina*	*F. microcarpa*	*F. religiosa*	*F. virens*
Cd	0.22	0.15	0.31	0.36	0.31	0.19	0.42	0.44
Cu	0.60	0.49	0.79	0.82	0.68	0.59	0.86	0.98
Cr	0.18	0.13	0.20	0.23	0.20	0.19	0.26	0.30
Pb	0.36	0.42	0.52	0.59	0.47	0.52	0.78	0.83
Zn	0.33	0.30	0.37	0.44	0.41	0.38	0.52	0.56
Mn	0.51	0.53	0.56	0.58	0.71	0.76	0.86	089
Site	**Highway Area**							
Leaf age	**YL**				**OL**			
Tree species	*F. benjamina*	*F. microcarpa*	*F. religiosa*	*F. virens*	*F. benjamina*	*F. microcarpa*	*F. religiosa*	*F. virens*
Cd	0.21	0.17	0.33	0.35	0.28	0.17	0.39	0.46
Cu	0.58	0.49	0.64	0.67	0.66	0.59	0.77	0.83
Cr	0.17	0.12	0.23	0.25	0.20	0.19	0.29	0.32
Pb	0.36	0.37	0.49	0.56	0.40	0.44	0.66	0.71
Zn	0.28	0.27	0.35	0.42	0.39	0.36	0.47	0.55
Mn	0.54	0.56	0.59	0.61	0.75	0.81	0.92	0.93
Site	**Residential Area**							
Leaf age	**YL**				**OL**			
Tree species	*F. benjamina*	*F. microcarpa*	*F. religiosa*	*F. virens*	*F. benjamina*	*F. microcarpa*	*F. religiosa*	*F. virens*
Cd	0.22	0.17	0.33	0.37	0.29	0.20	0.42	0.46
Cu	0.47	0.66	0.68	0.72	0.56	0.74	0.75	0.81
Cr	0.16	0.12	0.20	0.24	0.20	0.17	0.26	0.29
Pb	0.36	0.40	0.63	0.66	0.42	0.47	0.68	0.73
Zn	0.27	0.25	0.35	0.41	0.41	0.39	0.51	0.54
Mn	0.58	0.56	0.64	0.65	0.86	0.81	0.93	0.97

correlation with MAI, while *F. microcarpa* and *F. religiosa* tree species demonstrated significantly positive correlation with both MAI and CBCI (Figure 9).

4. Discussion

Heavy metal (HMs) toxicity causes several morphological, physiological and biochemical effects on plant species from reduced nutritive value and inhibited photosynthesis to retardation of plant growth, as reported in several previous studies [3, 35-37]. Additionally, HMs concentration in soil from multiple sources including sewage sludge, pesticides, gasoline and paints, fertilizers and wastewater irrigation can become the main constitute of the food chain and cause serious health problems like kidney dysfunction, immune system dysfunction, nervous system disorder, skin lesions, cancer and vascular damage [5, 16, 38]. Taking into account the harmful effects of HMs on plants and humans, the present study was aimed at phytoremediation HMs concentration from the air environment through tree species grown in different biological ecosystems. For this purpose, we selected four tree species *F. microcarpa*, *F. religiosa*, *F. benjamina* and *F.virens* grown in industrial, residential, and highway sites of study area to assess their phytoremediation potential against selected HMs (Cd, Cr, Cu, Mn, Pb, and Zn). The results revealed that all selected ficus species demonstrated great potential to accumulate heavy metals depending on study site and tree species, as demonstrated in Fig 2-7 and Tables 1-2. The observed variations suggest that these trees can serve as reliable bioindicators, offering valuable intuitions into the spatial dissemination of air metallic contamination in urban and residential areas.

Previous findings have strongly emphasized the biomonitoring and phytoremediation potential of tree species against HMs in soil, water and air environments [3, 16]. Trees as bioindicators, have the capacity to engross HMs in their different parts and improve air, water and soil quality. Woody trees usually phytoremediation HMs through various processes including HMs mobilization, root uptake, xylem loading, translocation from root to shoot, cellular compartmentation, sequestration, and extraction via salt trichomes [16, 39]. So, trees can be used as the most suitable candidates for phytoremediation. In the present study, our results emphasized the same conclusion where all tree species showed the ability to accrue different types of HMs (Figure 2-7). In our findings, different tree species demonstrated varying trends of HMs accumulation in their younger and older leaves at different sites (Fig. 2-7 and Tables 1-2), which was similar to the previous conclusions [40, 41]. In our finding, *F. virens* showed maximum accumulation of Cr, Cu, Cd, Mn, Zn and Pb concentrations in its younger and older leaves at industrial, residential, and highway sites followed by *F. religiosa* and *F. microcarpa*. The similar results were reported in pervious findings where *F. virens* efficiently phytoremediate Pb and Cu from the soils of Bareilly, India [42]. Similarly, Yeo and Tan (2011), reported that *F. virens* is a good candidate for the phytoextraction of Zn followed by Cd and Cu in wetlands. Additionally, our findings also indicate that the remaining two tree species are good bioindicators, bioextractors and biofiltrators against MHs. For instance, several studies have indicated that the leaves of *F. religiosa* can be used as suitable bio-indicators for air pollution with crystal violet dye and heavy metals [44]. *F. religiosa* is reported to be useful in tracking and amelioration of HMs contamination in urban localities [45, 46]. In this study, *F. microcarpa* and *F. benjamina* showed lower potential to accumulate HMs as compared to the other two species but they can also be used to alleviate heavy metals in polluted soils. As in a previous study, *F. microcarpa* was reported as an appropriate option for Cd phytoextraction and Cu, Hg, and Pb phytostabilization [47]. Another species of Ficus, *F. nitida* has also been reported to be a viable option for phytoremediation [1]. The study highlights the importance of considering different Ficus species, as their responses to heavy metal accumulation vary. Some species may exhibit higher tolerance or accumulation capacity, making them more suitable for specific monitoring purposes.

Metal accumulation index (MAI) and comprehensive bioconcentration index (CBCI) of heavy metals by urban trees have been used as an effective tool to monitor air pollution index in many previous studies [3, 5, 48]. In the present study, we calculated MAI and CBCI of all selected HMs for all species and reported different trends varying with tree species and study sites. For MAI, the trend was *F.religiosa*> *F.virens*> *F.benjamina*> *F.microcarpa* for industrial areas, *F.virens* > *F.benjamina*> *F.religiosa*> *F.microcarpa* for highway areas, and *F.religiosa*> *F.virens*> F.*microcarpa*> *F.benjamina* for residential area (Table 1). The same conclusion was reported in previous findings, where MAI depends on study sites and tree species [3, 5]. It has been reported in many previous studies that plants are species-specific to accumulate heavy metals. Different plant species have different tendency to accumulate heavy metals [16]. Plants accumulate heavy metals in different parts of their body but the most commonly used organelles are leaves [49-51]. The sub-species of same species have different potential to accumulate heavy metals [52]. The reason behind these differences is that the heavy metal accumulation process in plants is interlinked with plant anatomical structure. Overall, the MAI and CBCI results of our findings indicate that all tree species have greater potential to phytoremediation selected HMs, which was similar to previous findings. For example, *F. religiosa* has been reported as one of the best species to accumulate different types of heavy metals [18, 45, 53].

In plants, stomata also play an essential role in the accumulation of heavy metals [54]. The dimensions and arrangement of stomata play a crucial role in facilitating the exchange of gases within the leaves (Bradney *et al.* 2019). Furthermore, the anatomical and physiological structures, as well as the morphological traits, of plants have a substantial impact on the accumulation of heavy metals in any given species [55]. These characteristics of plants are formed by genetic and environmental attraction [56]. So, different plants not only react differently to heavy metal stress but also have different potentials to accumulate specific heavy metals [52]. So, species-specific variability is found in our study. In our study, *F. virens* have often shown the best results in accumulating different heavy metals. For all selected species in our study, older leaves have accumulated more heavy metals as compared to newer leaves. The phenomenon of metal sequestration in aged organs has been assumed to be a potential mechanism by which plants are able to survive in soils that are contaminated with pollutants. The plants growing in soils contaminated with heavy metals employ various mechanisms to ensure their survival. [57]. Among different mechanisms, one of the famous phenomena is the compartmentalization of metals [58, 59]. The plants effectively bind heavy metals using organic compounds within their tissues, operating at both cellular and sub-cellular levels to detoxify these harmful substances [60]. These heavy metals translocate to old leaves before shedding [61]. Accretion of HMs in older plant leaves, which are not very sensitive to toxic heavy metals, is considered a procedure for tolerating HMs stress in plants [62, 63]. This could be one of the possible reasons for the higher accumulation of heavy metals in older leaves of plants. Our findings align with the conclusions of prior research. For example, [64] reported that older leaves of *Calotropis procera* have demonstrated a better capacity to accumulate much larger quantities of certain metals compared to green leaves. Another study has explored the translocation of arsenic from roots to old leaves, suggesting it as a potential detoxification process [65, 66].

The findings of this study indicated that among different sites, trees present on residential sites accumulated fewer heavy metals. The influence of site on metal accumulation is almost consistent across most studied heavy metals (HMs). The maximum amount of HMs was reported in industrial areas, followed by highways and residential sites. The results of the present study provide valuable insights into the fact that heavy metal pollution is primarily caused by industrialization and heavy traffic. This is the reason why some species have accumulated different concentrations of heavy metals at different sites. Prior studies have documented the advantageous effects of bioaccumulation in industrial regions as trees present in these areas have the ability to capture heavy metals either on their leaves or within their internal tissues. This process allows trees to function as natural filters or accumulators of these toxic metals [1, 57, 67]. Our study is in accordance with previous studies as it is suggested in previous studies that industries are the key source of HMs accumulation in cultivated soils, resulting in poor soil health conditions [68]. For example, industrial production is identified as the primary source of heavy metal pollution in cultivated land in China. The main source of heavy metal pollution for cultivated land in China is reported to be industrial production [69, 70]. Another study was conducted in the Yangtze Delta of China to collect 230 surface soil samples from an industrializing area. The findings of the study indicated that heavy metal pollution in the area is primarily caused by industrial emissions [54]. In Tangshan City, China, industries pose serious health risks to children due to the accumulation of heavy metals [71]. The most dangerous cause of pollution in Pakistan is also industries that do not properly dispose of mechanisms [11].

Along with industrialization, trees present alongside highways have accumulated a maximum concentration of HMs in their leaves. Previously, various researchers have also suggested that trees present on sites with dense traffic accumulated more heavy metals as compared to those with less traffic or no traffic [55, 72]. High metal accumulation in trees alongside highways might be due to the high concentration of toxic metals in the fuel consumed [73]. The uptake of pollutants by leaves of certain species is directly linked to the presence of pollutants present in the atmosphere [74]. The accumulation of toxic HMs in plants is species- and site-specific [18]. For example, residential areas are the least polluted areas; therefore, the HM concentrations in the plant leaves of residential areas are the lowest compared to both industrial and highway areas.

5. Conclusion

Heavy metals (HMs) have attained substantial importance among the various airborne contaminants due to their non-biodegradable and pervasive features, along with their harmful and damaging impacts on plants and humans, even at low concentrations. It is imperative to measure and track the level of heavy metal concentration in the air and take laborious steps to remediate HMs from the air environment. For this purpose, researchers focused on trees as bioindicators for assessing the air quality across the globe as they remain fixed within the landscape, with certain species being perennial and consistently exposed to pollutants. In the current study, a comprehensive analysis of HMs concentration in air and their accumulation in new and older leaves of Ficus species in diverse urban environments was done to reveal their role as bioindicators and bioextractors of air metallic contamination. The results indicated that among selected tree species, , the general trend for HM accumulation was observed as *F. virens* > *F. religiosa* > *F. benjamina* > *F. microcarpa*. So, it is recommended to include *Ficus virens* and Ficus religiosa for urban landscape planning and also near industrial areas for phytoremediation purposes. Meanwhile, the HM concentrations in both the NL and OL of selected tree species were reduced in the order of Mn> Zn> Cu > Cr > Pb > Cd at all selected sites. The metal accumulation index (MAI) values in Ficus tree species ranged between 2.14-5.42 for *F.benjamina* (minimum) to 4.77-6.48 for *F. religiosa* (maximum) across all study sites. Overall, *F. virens* and *F. religiosa* accumulated maximum HMs in their old and new leaves, which emphasizes their affective phytoremediation role against all reported HMs. Based on our findings, we suggested that *F. virens* and *F. religiosa* are suitable plants for urban areas with significant HMs contamination and can be strategically planted in barrier areas to effectively mitigate atmospheric pollution.

Data availability statement

The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding authors.

Author contributions

GY, MTBY, MFA and DK conceptualized and wrote the main manuscript. GY and QZ helped to perform the lab analysis. AJM, GY, SAO and SUR reviewed and edited the manuscript in the present form. SUR supervised the work and approved the submission. Dr MJA and HSA provided funding and edited the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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