Plant Archives Vol. 18 No. 2, 2018 pp. 2559-2566 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

TREE LEAVES AS BIOINDICATOR OF HEAVY METAL POLLUTION FROM SOIL AND AMBIENT AIR IN URBAN ENVIRONMENTAL

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Abstract

An air pollutant is a substance in the air that can have adverse effects on humans and the ecosystem. The aim of this study was to compare thirteen different tree species in capability to accumulate four airborne and soil borne heavy metals (Cu, Cd, Pb, and Zn) from Mansoura city, Egypt. Samples were conducted in the summer and winter seasons. To compare bioaccumulation ability, bioconcentration factor (BCF), comprehensive bio-concentration index (CBCI), and metal accumulation index (MAI) were applied. The results indicated that the trend for HMs uptake in the leaf is in this order of Zn>Cu>Pb>Cd and Zn>Pb>Cu>Cd in summer and winter, respectively. The maximum BCF values were observed in *Eucalyptus rostrate* for Zn (0.62) and Pb (0.95), *Nicotina glauca* for Cu (0.77) and *Tamarix nilotica* for Cd (1.31). The maximum CBCI in leaves samples were found in *Melia azedarach*, *Morus alba* and *Ficus benghalensis*. Finally, according to, the cultivation of appropriate plants in urban areas can help to remediate soil and air pollution resulting from HMs.

Key words: Phytoremediation, Heavy metals, Air, Soil, Metal accumulation index

Introduction

The present-day atmosphere is quite different from the natural atmosphere that existed before due to urbanization and rapid industrialization, which created major environmental problems in urban areas, particularly in developing countries (Miri *et al.*, 2016). An air pollutant is a substance in the air that can have adverse effects on humans and the ecosystem. The substance can be solid particles, liquid droplets, gases and biological molecules. It may cause diseases, allergies and also the death of humans (Chen *et al.*, 2008; Louwies *et al.*, 2013); it may also cause harm to other living organisms such as animals and food crops, and may damage the natural or built environment (Gehring *et al.*, 2010). Human activity and carbon monoxide gas from motor vehicle exhaust or the sulfur dioxide released from factories and natural processes (such as ash from a volcanic eruption) can both generate air pollution (Youning *et al.*, 2014).

There are a few evidence that trees play important role in ecosystems because they transfer elements from the abiotic environment to the biotic one and to reduce human exposure to the anthropogenic pollutants (Speak *et al.*, 2012; Martínez-López *et al.*, 2014). Urban vegetation plays an essential role in assessing and purification of the surrounding air by removing HMs (Dzierzanowski *et al.*, 2011; McDonald *et al.*, 2007; Youning *et al.*, 2014). Tree leaves, twigs and branches have a large surface area that is very effective for direct elimination of particulate matter and can act as a natural filter to remove a substantial amount of airborne particles and subsequently enhance the quality of air in polluted areas (Divan *et al.*, 2009; Fourati *et al.*, 2017). The concentration of heavy metals in environmental media should be monitored as they can affect human health (Jiang *et al.*, 2017; Sarwar *et al.*, 2017).

Although, many studies have been performed in developed countries on the potential of trees for HMs monitoring (Ghosh and Singh, 2005; Youning *et al.*, 2014; Zhan *et al.*, 2014), statistics on appropriate trees is limited in Egypt. Therefore, the goal of this study were: (1) to assess the concentrations of certain HMs (Pb, Cu, Cd and Zn) in the leaves of street tree in El-Mansoura city, Egypt (2) To select the best tree species for single and total accumulation capacities of HMs phytoremediation using bio-concentration factor (BCF), comprehensive bio-concentration index (CBCI), and metal accumulation

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index (MAI) and (3) To propose suitable tree species for soil and atmospheric phytoremediation in the urban areas.

Material and Methods

Description of sites and sampling procedure

The present study was conducted in Mansoura city (Dakahlia Governorate), it is located to the north east of the Delta region (31°03'N 31°23'E) and the east bank of the Damietta branch of the Nile (fig. 1) (El-Dardiry and El-Ghonaimy, 2009). El-Mansoura city represents the highest population densities among the fourteen Marakez of the governorate with a population density over 2000 person/km^2. Dakahlia governorate is located in the northeast of Nile Delta in Egypt as shown in (Figure 1). Dakahlia has a mild climate that tends to be warm in winter with some rain that increases on the coasts, and is hot in summer; where maximum temperature in the studied area varies from 35.3ºC in summer to 20.1ºC in winter. Minimum temperature ranges from 20.2ºC in summer and 7.5ºC in winter. Total precipitation varies from 29.2 to 72.3 mm (Elnaggar *et al.*, 2014).

Samples were taken from two seasons; summer (2017) and winter (2018). Thirteen common tree species (*Cupressus sempervirens, Eucalyptus rostrate, Ficus benghalensis, Ficus nitida, Jacaranda acutifolia, Melia azedarach, Morus alba, Nicotina, Poinciana regia, Salix subserrata, Tamarix nilotica, Tecoma stans* and *Ziziphus spina-christi*) in the study are selected and sampled for HMs concentrations. Four heavy metals including zinc (Zn), copper (Cu), cadmium (Cd) and lead (Pb) were selected to be analyzed in the tree leaves because they are typical pollutants in the urban air and soil (Anagnostatou, 2008; Sawidis *et al.*, 2011).

Each site had at least one woody species and each species had more than five adult trees. Leaves were collected randomly (about 80 g DW) from the whole tree canopy at a height of 1.5-2 m above the ground and mixed to a homogeneous sample. All samples were dried at

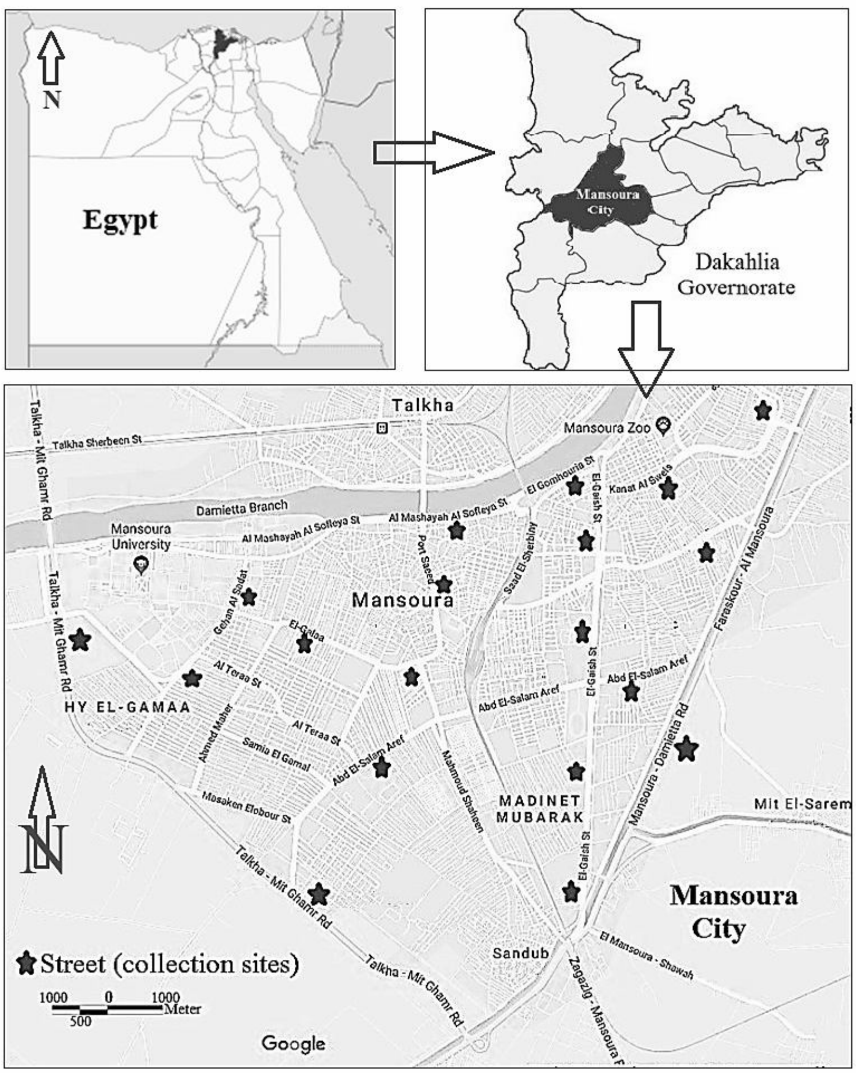

Fig.1: Map of sampling sites.

laboratory temperature (about 25ºC) and all the concentrations were reported based on dry weight. To conduct the better comparison, the samples were taken from trees located in the same location (Mansoura city) because sampling conditions (air and soil characteristics) should be similar for all of the tree species.

Analysis of plants and soil

In brief, the soil and leaf samples were cleaned, sieved, and dried. For metal analyses, 0.1 g (dry weight) of samples was added to Teflon beakers and digested with HNO_3/H_2O_2 (3:1, v/v) at 70 to 90°C until evolution of nitrous gas had stopped and the digest became quite clear. Finally, the sample was filtered and diluted with distilled water up to a known volume. HMs (Zn, Cu, Cd and Pb) concentration were measured according to the methods recommended by Allen *et al.* (1974) using Atomic Absorption Spectrometer (A Perkin-Elemer, Model 2380, USA).

Comparing indices

Bio-concentration factor (BCF)

Bio-concentration Factor (BCF) was used to determine the quantity of heavy metal absorbed by the plant from water. The higher the BCF value, the more suitable is the plant for phytoaccumulation (Blaylock *et al.*, 1997). This is an index used to measure the ability of the plant to accumulate a particular metal with respect to its concentration in the surrounding water medium. The BCF is calculated using the equation of Ghosh and Singh (2005) as follows:

$$BCF = \frac{Concentration\, of\ element\, in\ plant}{Concentration\, of\ element\, in\ soil}$$

Comprehensive bio-concentration index (CBCI)

In our study, we applied the membership function of fuzzy synthetic evaluation to assess the trees' comprehensive accumulation ability of multi-metals through several pollution influence factors such as Pb, Zn, Cd, Cu, etc. The CBCI was proposed to stand for comprehensive metal accumulation ability as follows:

1. The fuzzy set or the factor set U: U= (u_1, u_2, u_3 …… ui), where U is the trees' comprehensive accumulation ability level, and u_i are those various metal pollution factors.
2. Bio-concentration factors (BCF), also known as accumulation factors or enrichment factors, which are defined as the ratio between total metal concentration in leaves and soil, have been previously used to estimate the ability of plants to accumulate a certain heavy metal (Harada *et al.* 2011; Liu *et al.* 2008; Shi *et al.* 2011). The value of fuzzy membership function for trees' accumulation ability of each metal pollution factor (BCF) can be calculated by the formula as follows:

$$\mu ExF = \frac{x - x\_}{x\_ - x..}$$

Where *x* is the BCF of a certain metal pollution factor, x min is the minimum value of the BCF of the metal among the woody species investigated, and x max is the maximum value of the BCF of the metal among the woody species investigated. The maximum ì(*x*) is denoted as the fuzzy membership value 1, which has contributed most to the trees' comprehensive accumulation ability of various pollution factors. The minimum is denoted as the fuzzy membership value 0, which has contributed the least to the trees' comprehensive accumulation ability of various pollution factors, or low provision level.

$$CBCI = E_N^1 F\widehat{u}^{\mu i}$$

Metal accumulation index (MAI)

The metal accumulation index (MAI) was used to assess the overall performance of heavy metal accumulation in the plants.

$$MAI = E_N^1 F\widehat{u}^{I_j}$$

$$Ij = x / \delta x$$

N is the total number of metals analyzed and Ij is the sub-index for variable j. Ij can be further defined, where *x* is the mean concentration of an element and δ*x* is its standard deviation (Liu *et al.*, 2007; Monfared *et al.*, 2013).

Results and Discussion

Leaf metal concentrations

The concentrations of Zn, Cu, Cd and Pb ($mg.kg^{-1}$) in the leaf of thirteen tree species in summer and winter were presented in fig. 1-2. Mean (with standard deviations) of heavy metal concentrations in the leaf and their MAI and CBCI values of each plant species with HMs concentrations in soil were shown in Table 1.

As shown in Fig. 1-2, the maximum Zn and Cu concentrations in the leaf of most species were observed in summer, while the maximum concentration of Pb and Cd were observed in winter. These results may be related to the more atmospheric precipitations in winter which can wash out the particulate matters from the surfaces of the leaves. Moreover, the different plant species had varying metal concentrations, and no individual species had the highest concentrations for each of the heavy metals studied.

A general trend for HMs uptake in the leaf are in this order of magnitude Zn>Cu>Pb>Cd and Zn>Pb>Cu>Cd in summer and winter, respectively. This agrees with findings by other researchers working with metal uptake by deciduous street trees (Kim and Fergusson, 1994; Sawidis *et al.*, 2001; Piczak *et al.*, 2003; Youning *et al.*, 2014; Alahabadi *et al.*, 2017).

From table 1, the minimum seasonal mean concentrations of zinc (Zn) in the leaf was found in *Ficus benghalensis* and *Jacaranda acutifolia*, and its maximum was measured in *Eucalyptus rostrata* and *Ficus nitida* species, respectively. Zinc is an essential micronutrient that is involved in numerous aspects of cellular metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (Tisdale *et al.*, 1984; Classen *et al.*, 2011). The concentration of traditional zinc in plants in the range 10-150 mg kg^{-1} (Padmavathiamma and Li, 2007; Hu *et al.*, 2014). In the present study, none of the tree species have Zn concentration outside of the normal range.

Copper (Cu) is considered as a micronutrient for plant species that can accumulate considerable amounts under different natural and anthropogenic condition (Padmavathiamma and Li, 2007; Serbula *et al.*, 2012). The highest mean concentrations of Cu were present in *Nicotina glauca,* followed by *Ficus nitida, Morus alba* and *Poinciana regia*, while the lowest concentration was in *Ficus benghalensis*. In the present study, the concentrations of Cu in the plants were in safe range. The normal concentrations of Cu in the plants is 3-30 mg kg^{-1} (Kabata and Pendias, 2001), but its phytotoxic concentrations range is 20-100 mg kg^{-1} (Padmavathiamma and Li, 2007). Moreover, an excess of Cu in soil plays a cytotoxic role, induces stress and causes injury to plants. This leads to plant growth retardation and leaf chlorosis (Lewis *et al.,* 2001).

Lead (Pb) is one of the most toxic elements available everywhere distributed in soil. They have a negative impact on the formation, growth and photosynthesis of plants (Nagajyoti *et al.*, 2010). According to Kabata and Pendias (2001) study, the normal Pb concentration in the plants can be between 5 and 10 mg kg^{-1} and its toxic concentrations from 30 to 300 mg kg^{-1}. While Markert (1994) reported the toxic Pb range for plants to be between 3 and 20 mg kg^{-1}. In the present study, the minimum seasonal mean Pb concentration in the leaf (2.27 mg kg^{-1}) was related to *Ficus benghalensis*, and its maximum in leaf (10.86, 10.55 mg kg^{-1}) was associated in *Salix subserrata* and *Eucalyptus rostrata*, respectively. The plant might have absorbed Pb from other sources regardless of soil. It is possible that the Pb emitted into the atmosphere from the automobile exhaust penetrates through the intercellular spaces of the leaves and accumulates in the plant (Turer *et al.*, 2001; Hu *et al.*, 2014).

Cadmium (Cd) is a trace element and easily absorbed by plant roots and translocated to shoot system. The uptake of Cd by plant increases proportionally to increasing soil Cd when the rich soil contains concentrations of Cd salts (Smolders, 2001; Yao *et al.*, 2017). Cadmium, concentrations in the plants studied had arranged of 0.94–2.42 mg kg^{-1} (Figure 3). The highest mean concentrations of Cd was found in *Tamarix nilotica*, followed by *Cupressus sempervirens*, *Jacaranda acutifolia* and *Eucalyptus rostrata*, while the lowest concentration was in *Ficus benghalensis*. Typical concentrations of Cd in plants are less than10mg/kg^{-1} (Tomasevic *et al.*, 2004). Solid particles have a low concentration of Cd (Hu *et al.*, 2014), which is the major reason why Cd concentrations in the plant samples are low. According to our investigation, burning of fossil fuels, municipal solid waste, vehicle tires and burning of vehicle lubricants are the major man-made sources of Cd in air pollution (Hu *et al.*, 2014).

In general, heavy metal uptake and translocation in plants take place through roots and exposed surfaces (leaves) (Kabata and Pendias, 2001; Youning *et al.*, 2014), and it is difficult to distinguish the exact amount of

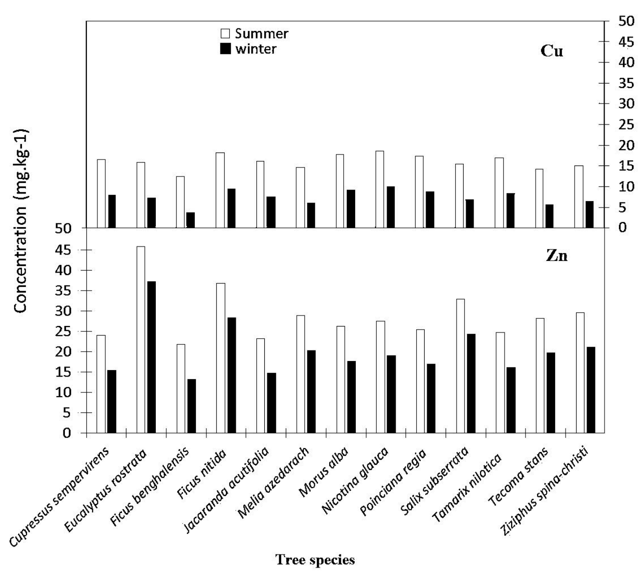

Fig. 2: Cu and Zn concentration in leaf of different trees collected from the study area.

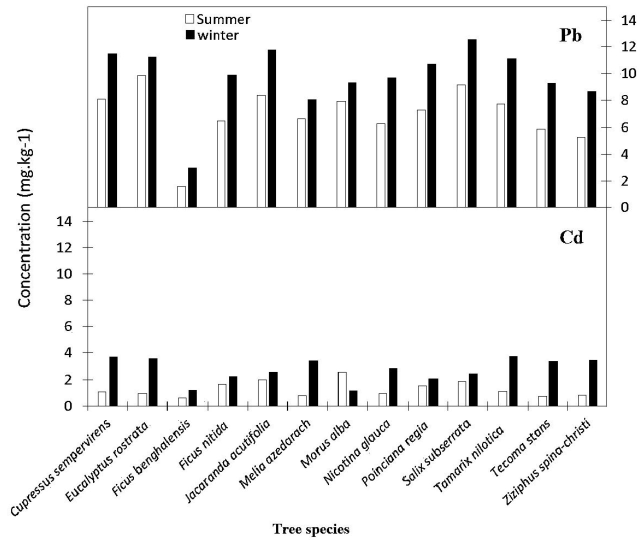

Fig. 3: Pb and Cd concentration in leaf of different trees collected from the study area.

accumulated elements that originated from the soil or air. HMs concentration in different plant parts is depended on the amount of HMs in the air and soil, and it is different within and between species of plants (Ipeaiyeda and Dawodu, 2014; Alahabadi *et al.*, 2017).

Bio-concentration factor (BCF)

The values of bioconcentration factor (BCF) for the leaf samples are shown in fig. 4. BCF refers to the ratio of HMs concentration in aerial parts of trees to that in the soil. It can reflect the ability of plants to uptake single HM. The average BCF of Zn, Cu, Pb, and Cd were in the range of 0.26 to 0.62, 0.44 to 0.77, 0.20 to 0.95 and 0.51 to 1.31 for leaves, respectively. According to the obtained values of BCF, the capability of tree species for the accumulation of HMs was in the order of Cd>Pb>Cu>Zn, which can be confirmed by previous researches (Zhan *et al.*, 2014; Zhai *et al.*, 2016; Alahabadi *et al.*, 2017).

The maximum BCF of Zn and Pb in leaves (0.62 and 0.95, respectively) were observed to be related to *Eucalyptus rostrata*. For Cu, the maximum BCF value of leaves (0.77) was found in *Nicotina glauca*. *Tamarix nilotica* showed the maximum BCF of Cd in leaves (1.31). Mok *et al.* (2013) reported that native plant species with the ability to phytoextraction large amounts of HMs are the best options for greening urban areas. Therefore, the best option for each region is to select native plant species even with low capacity rather than non-native plant species with the higher ability for HMs extraction.

Comprehensive bio-concentration index (CBCI)

This index can collect accumulation results of several metal pollution factors into one relative measurement index. The theory of fuzzy set has been used in various regions (Zadeh, 1996). To date, however, no attempts have been made to assess the metal accumulation potential of plants by this method. Here, we applied it in our study to assess the overall performance of the woody species in terms of multi-metal accumulation and proposed a CBCI. The maximum CBCI in leaves samples were related to *Melia azedarach* (9.27), *Morus alba* (9.16) and *Ficus benghalensis* (4.56), (table 1).

In this study, it was observed that most CBCI values in leaves were similar to those reported by Zhao *et al.* (2014), but lower than those reported by Alahabadi *et al.* (2017). Many previous studies have reported that young trees with fast growth rate can accumulate more HMs from the soil through phytoremediation (Puschenreiter *et al.*, 2010; Zhao *et al.*, 2014). In this study, all of the

Table 1: Concentrations of metals (mean ±SD, $mg.kg^{-1}$) in the leaf of different tree species and their metals accumulation index (MAI) and comprehensive bio-concentration index (CBCI).

Tree species	Metals				MAI	CBCI
	Zn	Cu	Cd	Pb		
Cupressus sempervirens	19.74(9.45)	12.31(2.27)	2.37(0.64)	9.78(1.87)	2.85	1.13
Eucalyptus rostrata	41.51(6.09)	11.56(2.68)	2.24(0.46)	10.55(2.39)	3.65	2.95
Ficus benghalensis	17.52(4.85)	8.12(2.01)	0.94(0.15)	2.27(1.07)	4.47	4.56
Ficus nitida	32.55(7.61)	13.85(3.14)	1.95(0.23)	8.29(1.24)	5.93	2.36
Jacaranda acutifolia	18.95(7.47)	11.89(4.20)	2.31(1.54)	10.08(2.84)	3.81	1.32
Melia azedarach	24.57(5.41)	10.35(3.51)	2.09(0.68)	7.34(1.02)	5.72	9.27
Morus alba	21.98(4.67)	13.46(3.94)	1.88(0.52)	8.62(1.40)	5.11	9.16
Nicotina glauca	23.24(13.35)	14.28(6.40)	1.99(0.68)	7.97(3.05)	2.38	1.07
Poinciana regia	21.18(6.63)	13.05(2.78)	1.82(0.63)	8.99(0.74)	3.34	2.08
Salix subserrata	28.62 (6.89)	11.18(3.72)	2.18(1.67)	10.86(3.72)	2.60	3.15
Tamarix nilotica	20.43(4.78)	12.7(3.26)	2.42(1.34)	9.41(2.78)	3.75	1.46
Tecoma stans	23.98(10.45)	9.97(1.81)	2.04(0.99)	7.59(1.48)	3.19	1.03
Ziziphus spina-christi	25.33(8.63)	10.74(2.69)	2.14(0.57)	6.97(1.77)	3.99	1.13
Soil	67.15(7.28)	18.47(3.22)	2.82(0.72)	14.23(2.11)	-	-

samples were taken from the young trees (8-12 years old). Therefore, tree species with high CBCI values identified in this study can be used for soil phytoremediation in the future.

Metal accumulation index (MAI)

The MAI values for the leaves were summarized in Table 1. The highest MAI values displayed in *Ficus nitida* (5.93), *Morus alba* (5.11), *Melia azedarach* (5.72) and *Ficus benghalensis* (4.47). The minimum MAI values for leaf was found in *Cupressus sempervirens* (2.85),

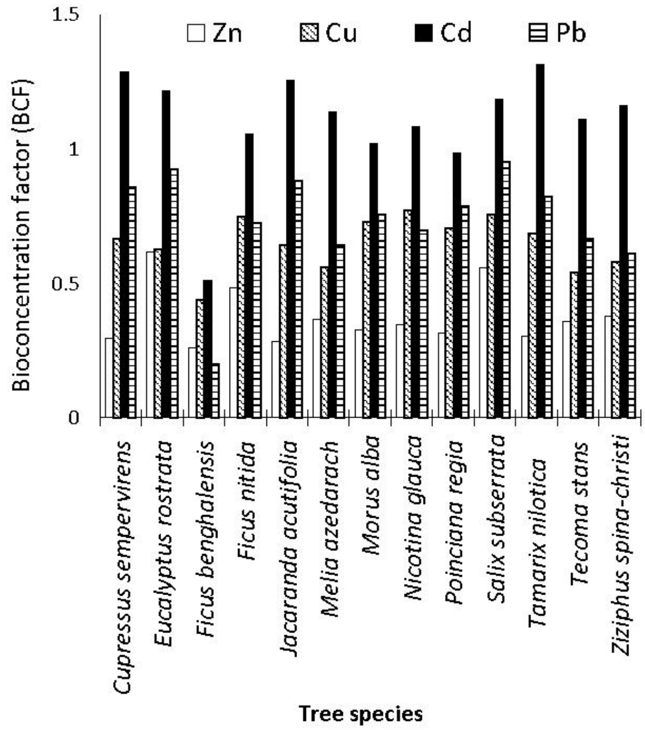

Fig. 4: Bio-concentration factor (BCF) of 13 leaf tree species.

Nicotina glauca (2.38) and *Salix subserrata* (2.60). Obtained MAI values in the present study are in agreement with Hu *et al.* (2014) findings, but less than those previously mentioned by Liu *et al.* (2007) and Alahabadi *et al.* (2017). This may depend mainly on the characteristics of local meteorology properties and atmospheric chemistry. Furthermore, other factors, such as sampling altitude and time as well as plant characteristics, affect the ability to remove air pollutants in urban vegetation (Yin *et al.*, 2011; Hofman *et al.*, 2013).

Several studies have reported that trees have been believed that the most efficient plant group for removing air pollution (Beckett *et al.*, 2000; Yang *et al.*, 2005; Mok *et al.*, 2013; Youning *et al.*, 2014; Alahabadi *et al.*, 2017). Leaves of low-growing plant species can be more exposed to soil splash than leaves of high-growing ones, particularly trees (Hu *et al.*, 2014). In our study, the MAI values of *Ficus nitida* and *Melia azedarach* (growing low to the ground) were always greater than those in *Eucalyptus rostrate*, *Poinciana regia* and *Salix subserrata* (growing high to the ground) (table 1). It should be noted that *Morus alba* and *Ficus benghalensis* with the large surface leaves had higher MAI values than *Cupressus sempervirens, Nicotina glauca, Salix subserrata* and *Tecoma stans* with small leaves (table 1). The abundance of trichomes and rough of leaf surface can increase their ability to capture airborne pollutants and to uptake HMs from the epidermis stomata (Sawidis *et al.*, 2011; Alahabadi *et al.*, 2017).

On the other hand, leaves are periodically disposed, but the other parts of trees last for longer time. Therefore, there is no opportunity to recycle the accumulated and stored pollutants. According to the above content, the species with high MAI values have better HMs accumulation properties and they can be used as a bioindicator for HMs contamination in the urban environment (Beckett *et al.*, 2000). The current study suggests that *Ficus nitida, Morus alba, Melia azedarach* and *Ficus benghalensis*, according to the MAI values of their leaves, can be cultivated in green urban areas such as parks, schools, hospitals, and residential areas, where they can remove air pollutants from a large green area.

Conclusion

HMs accumulation ability in leaf of thirteen tree species with the same HMs concentrations was investigated. Traffic emissions and coal combustion are the most important pollution sources in Mansoura city. CBCI and MAI were applied for comparing different tree species in multi HMs accumulation from soil and ambient air. In the present study, the maximum Zn and Cu concentrations in the leaf of most species were observed in summer, while the maximum concentration of Pb and Cd were observed in winter. The maximum BCF of Zn and Pb in leaves were observed in *Eucalyptus rostrata*. For Cu and Cd the maximum BCF value of leaves was found in *Nicotina glauca* and *Tamarix nilotica*, respectively. The maximum CBCI in leaves samples were related to *Melia azedarach*, *Morus alba* and *Ficus benghalensis*. Therefore, these species can be used as a good bioaccumolator for mentioned HMs. Finally, according to present results, cultivation of suitable plants in an urban area can help to remediate the soils and atmospheric pollution due to HMs.

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