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A comparative study on capability of different tree species in accumulating heavy metals from soil and ambient air

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HIGHLIGHTS

- Fourteen different tree species in terms of their capability to accumulate four airborne and soilborne HMs.
- BCF, (CBCI) and MAI were applied to compare bioaccumulation ability.
- Based on CBCI and MAI, had the highest bioaccumulation capacity of HMs, respectively.

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ABSTRACT

Heavy metals (HMs) in the urban environment can be bio-accumulated by plant tissues. The aim of this study was to compare fourteen different tree species in terms of their capability to accumulate four airborne and soilborne HMs including; zinc (Zn), copper (Cu), lead (Pb), and cadmium (Cd). Samplings were performed during spring, summer, and fall seasons. To compare bioaccumulation ability, bio-concentration factor (BCF), comprehensive bio-concentration index (CBCI), and metal accumulation index (MAI) were applied. Species with the highest accumulation for single metal which shown using BCF did not have the highest CBCI and MAI. Based on CBCI and MAI, *Pinus eldarica* (7.74), *Wistaria sinensis* (8.82), *Morus alba* (8.7), and *Nigral morus* (27.15) had the highest bioaccumulation capacity of HMs, respectively. Therefore, these species can be used for phytoextraction of HMs pollution and green and buffer zone in the urban.

1. Introduction

The unorganized and rapid urbanization and industrialization has caused considerable environmental problems in the urban areas, especially in developing countries (Kumar, 2013; Miri et al., 2016b). Air pollution is the most important challenge facing most urban areas throughout the world. In addition to gaseous pollutants, urban transportation and industrial activities release

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particulate matter containing heavy metals into an urban atmosphere. Heavy metals are commonly adsorbed by organic matters, carbonates, minerals in the soil (Liptzin and Ashton, 1999). Therefore, the composition of soil and air could be affected by emissions from automobile exhaust and industrial facilities (Sawidis et al., 2011; Hu et al., 2014; Miri et al., 2016a). With respect to the above, it can be concluded that people not only through polluted air but also through other part of polluted environment such as soil are exposed with heavy metals. Heavy metals concentration should be monitored in environmental media because they can impact human health (Jiang et al., 2017; Sarwar et al., 2017).

Two problems with direct monitoring methods of heavy metals in the ambient are high cost and their unreliable information about the impact of atmospheric pollutants on ecosystems. Therefore, researchers have shown an increased interest in indirect monitoring methods such as the response of living organisms to pollutants during recent years (Abril et al., 2014; Boquete et al., 2014).

Although lichens and mosses are considered as good bioindicators for HMs contamination (Gerdol et al., 2014), trees are also used to evaluate the HMs pollution in the urban areas where their presence is widespread. The leaves of the tree have large surface area and can act as a natural filter to remove substantial amount of airborne particles and subsequently enhance the quality of air in polluted areas (Fourati et al., 2017). In addition, needles and barks, the other parts of trees, can adsorb HMs and other airborne pollutants (El-Hasan et al., 2002; Oliva and Mingorance, 2006; Sawidis et al., 2011; Miri et al., 2016a).

There are some evidences that trees play a crucial role in air pollution control through air filtering and can be considered as useful and cost-effective mitigation plan to protect vulnerable urban areas and to reduce human exposure to the anthropogenic pollutants (Zhan et al., 2014) (Dzierżanowski et al., 2011) (Speak et al., 2012).

The estimation of environmental pollution using the chemical composition of plants is the most applicable aspect of trees in air pollution control. HMs accumulation by trees can provide beneficial information for monitoring networks and can simplify analytical determination of HMs. In addition, trees can reflect the cumulative impacts of HMs contamination on ambient air and soil because transported pollutants through their roots and leaves can be accumulated during the time (Sawidis et al., 2012).

Although, many studies have been done in developed countries about the ability of trees for HMs monitoring (Ghosh and Singh, 2005; Zhan et al., 2014), information about the suitable trees is limited in Iran. This study will focus on the following topics:

- To assess the concentrations of certain HMs (Zn, Cu, Pb and Cd) in the leaf and bark of fourteen common tree species in the Yazd city, Iran.
- To select the best tree species for single HM accumulation in the leaf and bark suing bio-concentration factor (BCF).
- To evaluate the total accumulation capacities of HMs for selected tree species using comprehensive bio-concentration index (CBCI), and metal accumulation index (MAI).
- To provide qualified data for further investigations of HMs phytoremediation in the urban areas.
- To propose suitable tree species for soil and atmospheric phytoremediation in the urban areas.

2. Material and methods

2.1. Location, trees, and HMs selection

Fourteen common tree species (*Wistaria sinensis*, *Callistemon citrinus*, *Nigral morus, Salix babylonica*, *Fraxinus excelsior*, *Alnus glutinosa*, *Populous deltoids*, *Ulmus umbraculifera*, *Citriobatus pauciflorus*, *Robinia pseudoacacia*, *Pinus eldarica*, *Olea europaea*, *Cupressus arizonica*, and *Morus alba)* in the study are were 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 leaf and bark of trees because they are typical pollutants in the urban air and soil (Anagnostatou, 2008; Sawidis et al., 2011).

To conduct better comparison and to reduce probable confounders, sampling conditions (meteorological, air and soil characteristics) should be similar for all of tree species. Therefore, the samples were taken from trees located in the same location. Sampling region with surface area of 5000 m^2 was located in the southeast of Yazd city (latitude 31.84222° and longitude 54.3396°).

2.2. Sampling and analysis

Sampling was conducted three times during late spring, summer, and autumn after 10-day rainless periods. The steel knife was applied as a sampling instrument. Nearby 50 g of leaves and barks of different species were taken and kept in the plastic bags. There were no any defections (insect infestation and other additional waste) in the samples. The samples were taken from the different side of same age trees (about 10 years old) at a height of 1.5–2 m above the ground. All samples were dried in laboratory temperature (about 25 °C) and all the concentrations were reported based on dry weigh.

The details about digestion process and heavy metal measurement techniques have been fully explained elsewhere (Miri et al., 2016a). In brief, the soil, leaf, and bark samples were cleaned, sieved, and dried. Afterward, concentrated HNO_3 were added to 1.0 g prepared samples and mixed for 1 h at room temperature. After two warming (2 h at 50 °C) and heating (4 h at 140 °C) stages, concentrated H_2O_2 was added to the sample. Finally, the sample were filtered and its HMs concentration were measured according to the methods recommended by Lu (1999) (Lu, 1999) using graphite furnace atomic absorption spectrophotometer (GF-AAS) (Varian spectrAA.20, Australia). Only the elements with given certified values and mean recoveries in the range of 80–120% were included in the data analysis. The detection limit for each element was considered as three times the standard deviation of eight replicate blank measurements.

2.3. Comparing indices

2.3.1. Bio-concentration factor (BCF)

Bio-concentration factors (BCF) is defined as the ratio of total metal concentrations in sampled tissue (leaves and barks) and soil in which the tree has been cultivated. In many previous study, BCF has been used to estimate the ability of plants to accumulate a certain HMs from soil (Xiaohai et al., 2008; Shi et al., 2011). BCF is calculated using the following equation.

$$BCF = \frac{C_{harvested\ tissue}}{C_{soil}} \tag{1}$$

where $C_{\text{harvested tissue}}$ is the metal concentration in harvested tissues and C_{soil} is the metal concentration in soil.

2.3.2. Comprehensive bio-concentration index (CBCI)

Comprehensive bio-concentration index (CBCI) were developed by Zhao et al. (2014) and was applied to assess the capability of trees for comprehensive accumulation of multiple HMs. To calculate CBCI, the membership function of fuzzy synthetic evaluation method is used as follows:

A. Firstly, the fuzzy set or the factor set U, U= (u_1, u_2, u_3 …… u_i), was calculated. U is the level of comprehensive accumulation ability for tree, and u_i are various metal pollution factors.

B. Secondly, the value of fuzzy membership function was calculated using the following equation:

$$\mu(x) = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (2)$$

where x is the BCF of a certain metal, x_{min} and x_{max} are the minimum and maximum value of the BCF for the given metal, respectively. The maximum and minimum values can be one and zero, respectively, which reflect the highest and lowest comprehensive accumulation factors of various HMs.

C. And finally, CBCI was calculated as follows:

$$CBCI = \frac{1}{N}\sum_{i=1}^{N}\mu_i \quad (3)$$

where N is the total number of HMs, and μ_i is μ(x) of metal *i*.

2.3.3. Metal accumulation index (MAI)

Metal accumulation index (MAI) introduced by Liu et al. (2007). Different trees species have different ability to accumulate atmospheric HMs. Therefore, MAI was used to associate and compare the ability of different tree species for HMs accumulation. MAI was calculated as follows:

$$MAI = \left(\frac{1}{N}\right)\sum_{j=1}^{N} I_j \quad (4)$$

Where the MAI index represents the metal accumulation, N is the total number of HMs, and I_j is the sub-index for variable *j*. I_j was obtained by the division the mean concentration value (x) of each HM on their standard deviation (Δx) as follows:

$$I_j = \frac{x}{\Delta x} \quad (5)$$

3. Result and discussion

3.1. Leaf and bark heavy metal concentrations

The heavy metals concentrations in the leaf and bark of fourteen tree species in spring, summer, and autumn were presented in Figs. (1)–(4). The mean (with standard deviations) of HMs concentrations in the leaf and bark and their MAI and CBCI values along with HMs concentrations in soil were shown in Tables 1 and 2.

As can be seen from Figs. (1)–(4), the maximum HMs concentrations in the leaf and bark of most species were observed in summer. These results may be related to the more atmospheric precipitations in spring and autumn which can wash out the particulate matters from the surfaces of the leaves and barks. Moreover, the mean of HMs concentrations in the barks were significantly more than those for leaves. The most probable explanations for this difference are these facts that barks can retain their structure against the pollutants for a longer time, they are widely available without affecting the health of the trees, and porosity structure of bark is very high (Mandiwana et al., 2006; Berlizov et al., 2007; Sawidis et al., 2011).

As shown in Tables 1 and 2, the minimum seasonal mean concentrations of Zn in the leaf and bark were found in *Populous deltoids* and *Ulmus umbraculifera*, and its maximum were measured in *Pinus eldarica* and *Morus alba* species, respectively. Zinc plays an

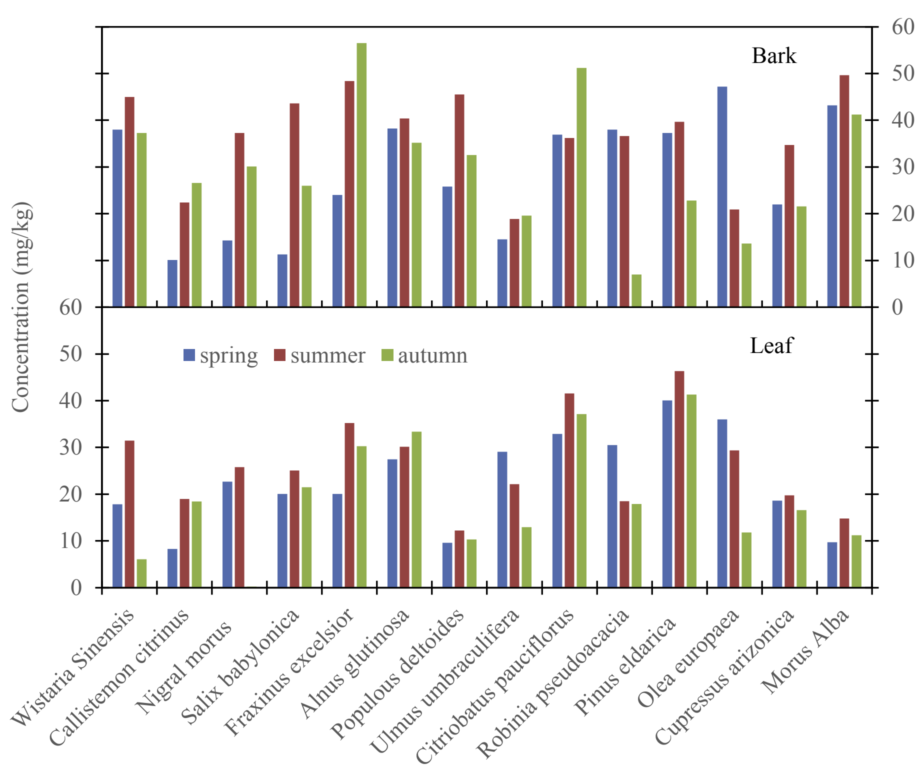

Fig. 1. Zn concentration in leaf and bark of different trees collected from study area.

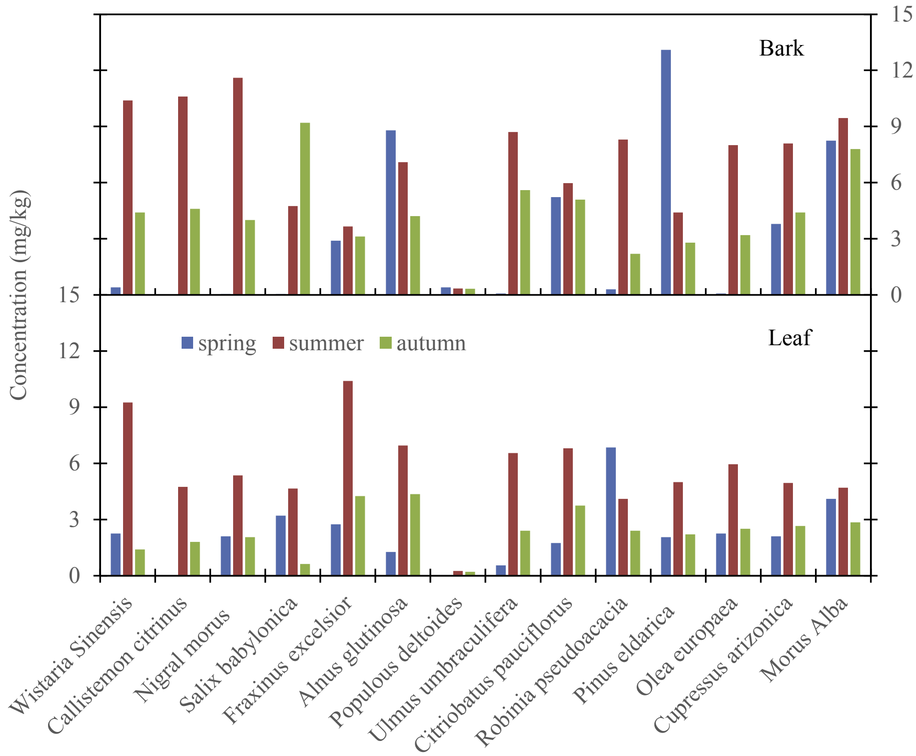

Fig. 1. (*continued*).

important role in biosynthesis and it is an essential element for all organisms (Serbula et al., 2012). The conventional Zn concentration in plants is in the range of 10–150 mg kg^{-1} (Padmavathiamma and Li, 2007; Hu et al., 2014). In present study, none of tree species have Zn concentration outside of the normal range.

Most of the plant species can accumulate considerable amounts of copper under natural and anthropogenic condition (Padmavathiamma and Li, 2007; Serbula et al., 2012). The seasonal

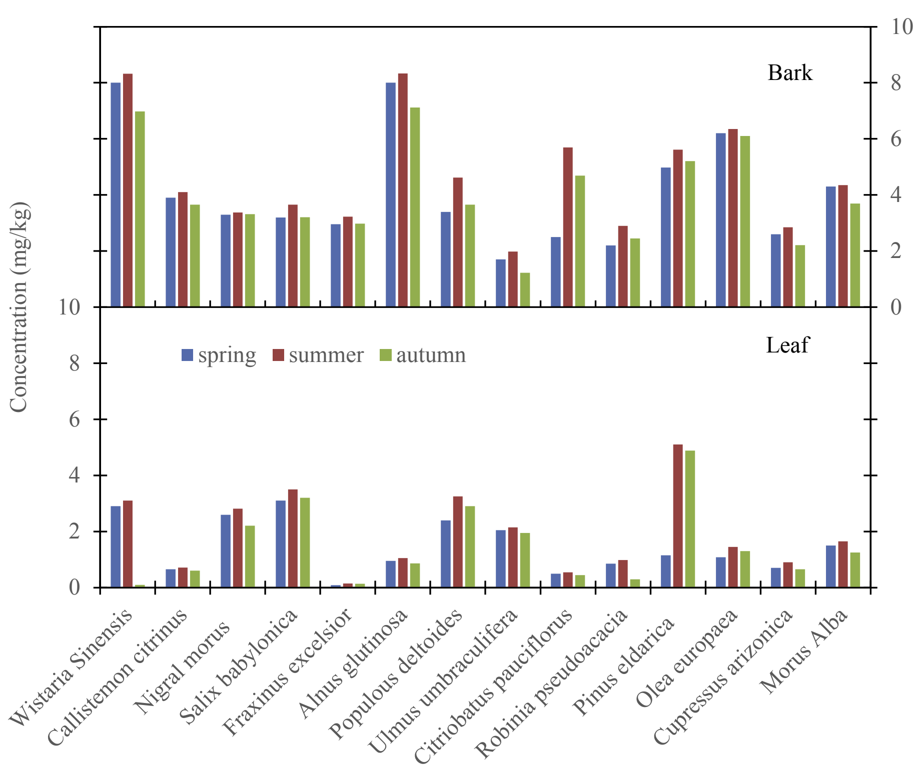

Fig. 2. Cu concentration in leaf and bark of different trees collected from study area.

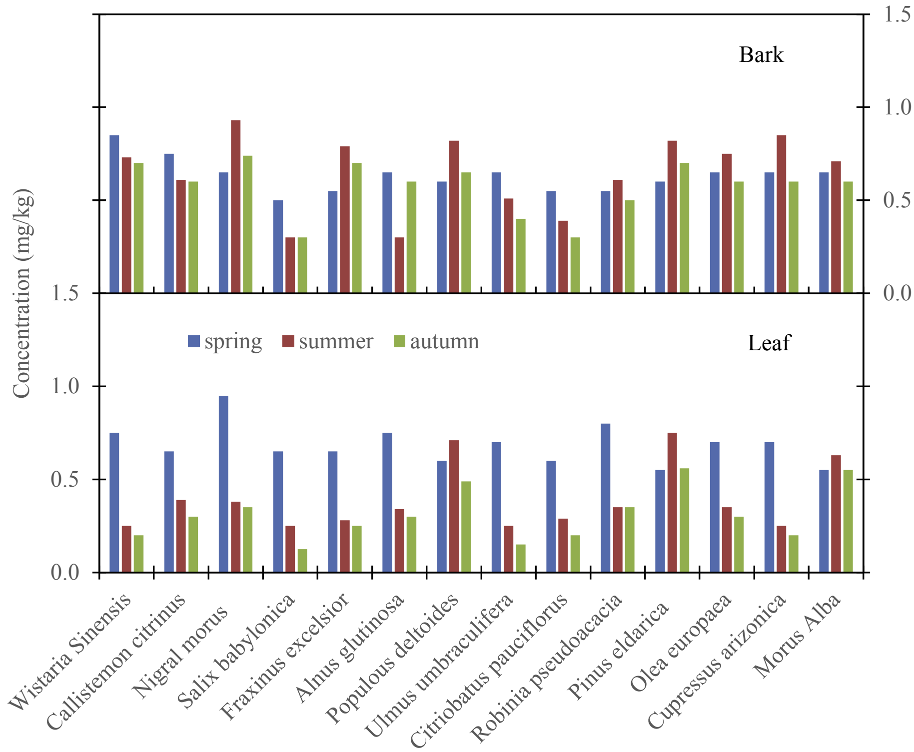

Fig. 3. Pb concentration in leaf and bark of different trees collected from study area.

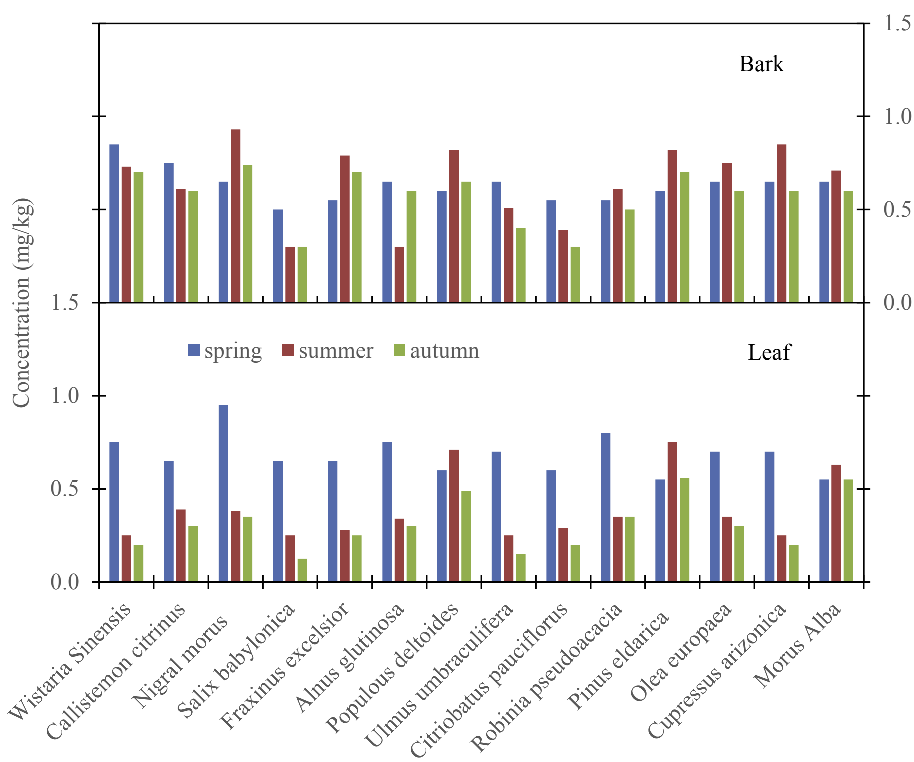

Fig. 4. Cd concentration in leaf and bark of different trees collected from study area.

mean concentrations of Cu were from 0.165 to 5.8 mg kg^{-1} in leaves and from 0.36 to 8.5 mg kg^{-1} in barks (Tables 1 and 2). The maximum seasonal mean concentrations of Cu in leaf and bark were related to *Fraxinus excelsior* and *Morus alba*, respectively while the leaf and bark of the *Populous deltoids* have minimum seasonal mean concentrations of Cu. The normal range of Cu concentrations in the plants is 3–30 mg kg^{-1} (Kabata and Pendias, 2001), but its phytotoxic concentrations range is 20–100 mg kg^{-1}

Table 1
Mean (standard deviation) of heavy metal concentration in the leaf of different tree species and their metals accumulation index (MAI) and comprehensive bio-concentration index (CBCI).

Tree species	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	MAI	CBCI
Wistaria sinensis	18.46(10.35)	4.3(3.51)	2.03(1.36)	0.4(0.24)	1.52	4.35
Callistemon citrinus	15.25(4.91)	2.19(1.94)	0.65(0.04)	0.44(0.14)	5.8	4.55
Nigral morus	16.25(11.38)	3.16(1.54)	2.54(0.24)	0.56(0.27)	3.93	5.86
Salix babylonica	22.21(2.12)	2.82(1.66)	3.26(0.16)	0.34(0.22)	8.22	3.66
Fraxinus excelsior	28.51(6.32)	5.8(3.3)[a]	0.126(0.02)	0.39(0.18)	3.31	4.175
Alnus glutinosa	30.31(2.41)	4.18(2.32)	0.95(0.07)	0.46(0.2)	7.23	4.9
Populous deltoides	10.72(1.11)	0.165(0.08)	2.85(0.34)	0.6(0.08)	6.58	6.17[a]
Ulmus umbraculifera	21.38(6.59)	3.16(2.5)	2.05(0.08)	0.36(0.23)	7.78	3.86
Citriobatus pauciflorus	37.2(3.53)	4.1(2.07)	0.5(0.04)	0.36(0.17)	6.71	3.88
Robinia pseudoacacia	22.3(5.8)	4.45(1.83)	0.71(0.29)	0.5(0.21)	2.75	5.23
Pinus eldarica	42.57(2.72)[a]	3.08(1.35)	3.71(1.81)[a]	0.62(0.09)[a]	6.66	6.72[a]
Olea europaea	25.71(10.2)	3.56(1.68)	1.27(0.15)	0.45(0.17)	3.89	4.73
Cupressus arizonica	18.33(1.3)	3.23(1.23)	0.75(0.1)	0.38(0.22)	6.32	3.95
Morus alba	11.92 ± 2.12	3.88(0.77)	1.46(0.16)	0.57(0.03)	8.7[a]	5.97[a]
Soil	65.789(8.25)	15.25(3.68)	16.35(4.36)	0.958(0.24)	-	-

[a] Maximum concentration of HMs and highest value of indexes.

Table 2
Mean (standard deviation) of heavy metal concentration in the bark of different tree species and their metals accumulation index (MAI) and comprehensive bio-concentration index (CBCI).

Tree species	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Pb(mg kg^{-1})	Cd(mg kg^{-1})	MAI	CBCI
Wistaria sinensis	40.1(3.47)	5.06(4.1)	7.76(0.57)	0.76(0.06)	9.52	8.42[a]
Callistemon citrinus	19.7(7.0)	5.07(4.32)	3.88(0.18)	0.65(0.06)	8.62	6.98
Nigral morus	27.23(9.6)	5.21(4.79)	3.33(0.03)	0.77(0.11)[a]	27.15[a]	8.25[a]
Salix babylonica	26.96(13.2)	4.66(3.37)	3.35(0.2)	0.36(0.09)	5.79	4.01
Fraxinus excelsior	42.96(13.81)	3.22(0.31)	3.05(0.12)	0.68(0.09)	11.24	7.32
Alnus glutinosa	37.95(2.13)	6.703(1.89)	7.81(0.51)[a]	0.51(0.15)	9.99	5.92
Populous deltoides	34.63(8.16)	0.36(0.02)	3.89(0.52)	0.69(0.09)	7.79	7.33
Ulmus umbraculifera	17.66(2.25)	4.79(3.56)	1.63(0.3)	0.52(0.1)	4.88	5.46
Citriobatus pauciflorus	41.43(6.91)	5.43(0.38)	4.29(1.3)	0.41(0.1)	6.8	4.66
Robinia pseudoacacia	27.2(14.29)	3.6(3.41)	2.51(0.28)	0.55(0.04)	5.98	5.88
Pinus eldarica	33.25(7.45)	6.76(4.52)	5.27(0.26)	0.706(0.08)	8.43	7.74[a]
Olea europaea	27.23(14.42)	3.76(3.25)	6.21(0.1)	0.66(0.06)	18.56[a]	7.24
Cupressus arizonica	26.1(6.08)	5.43(1.9)	2.55(0.26)	0.7(0.1)	5.83	7.45
Morus alba	44.68(3.6)[a]	8.5(0.69)[a]	4.11(0.3)	0.65(0.04)	13.2[a]	7.26

[a] Maximum concentration of HMs and highest value of indexes.

(Padmavathiamma and Li, 2007). In present study, the concentrations of Cu in the plants were in safe range.

According to Kabata-Pendias and Pendias (2001) study (Kabata and Pendias, 2001), the sufficient or normal Pb concentration in the plants can be in the range of 5–10 mg kg^{-1} and its toxic concentrations is from 30 to 300 mg kg^{-1}. While Markert (1994) (Markert, 1994) reported the toxic Pb range for plants to be between 3 and 20 mg kg^{-1}. In present study, the minimum seasonal mean Pb concentration in the leaf (0.12 mg kg^{-1}) and bark (1.63 mg kg^{-1}) were related to *Fraxinus excelsior* and *Ulmus umbraculifera*, respectively, and its maximum in leaf (3.71 mg kg^{-1}) and bark (7.81 mg kg^{-1}) were associated in *Pinus eldarica* and *Alnus glutinosa*, respectively. The Pb concentrations in plants are typically less than 10 mg kg^{-1} (Kabata and Pendias, 2001; Padmavathiamma and Li, 2007; Hu et al., 2014). Plants can readily uptake Pb from atmosphere after deposition on the their leaves, but Pb translocation from plant roots to leaves is not a main pathway for Pb accumulation (Turer et al., 2001; Hu et al., 2014).

The seasonal mean concentration of Cd was in the range of 0.34–0.62 mg kg^{-1} for leaves, and 0.36–0.77 mg kg^{-1} for barks. The maximum mean Cd concentrations for leaf and bark were observed in *Pinus eldarica* and *Nigral morus*, respectively. For both leaf and bark, the minimum concentration was found in *Salix babylonica.* Generally, the Cd concentrations in plants are less than 10 mg kg^{-1} (Tomašević et al., 2004). Particulate matters have low concentration of Cd (Hu et al., 2014), which is the major reason why Cd concentrations in the plant samples are low. Vehicle tires, combustion of fossil fuels, municipal solid waste incineration, and the combustion of vehicle lubricating oils are considered to be the major man-made sources of Cd (Hu et al., 2014).

Generally, 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 (Satpathy and Reddy, 2013; Ipeaiyeda and Dawodu, 2014).

3.2. Bio-concentration factor (BCF)

The values of bio-concentration factor (BCF) for the leaf and bark samples are shown in Fig. 5. 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 0.163–0.647, 0.005 to 0.281, 0.007 to 0.227, and 0.356 to 0.647 for leaves, and 0.268 to 0.679, 0.011 to 0.280, 0.1 to 0.478, and 0.382 to 0.807 for barks, respectively. Bark showed higher accumulation ability than leaf. Therefore, bark was more suitable organ to monitor the contamination of HMs. According to the obtained values of BCF, the capability of tree species for accumulation of HMs was in the order of Cd>Zn>Pb>Cu, which can be confirmed by previous researches (Zhan et al., 2014; Zhai et al., 2016).

The maximum BCF of Zn in leaves (0.647) and barks (0.679) were observed to be related to *Pinus eldarica* and *Morus alba*, respectively. For Cu, the maximum BCF values of both leaves (0.28) and barks (0.281) were found in *Morus alba*. *Pinus eldarica* and

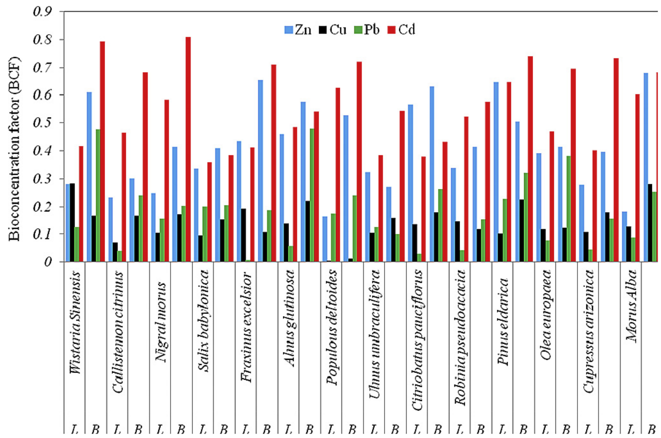

Fig. 5. Bio-concentration factor (BCF) of leaf and bark of 14 tree species (L: leaf, B: bark).

Buxushyrcana showed the maximum BCF of Pb in leaves (0.227) and barks (0.478), respectively. For Cd, *Pinus eldarica* and *Nigral morus* had the maximum BCF value for leaves (0.647) and barks (0.807), respectively. According to the calculated BCF values, although *Pinus eldarica* has the maximum ability to accumulate single heavy metal, it has not the maximum capability to accumulate multi HMs.

The best option for every region is to select native plant species even with lower ability instead of non-native plant species with higher ability for HMs extraction. Native plant species with the ability to accumulate large quantities of HMs are the best options for greening urban areas (Mok et al., 2013).

According to the obtained results, the following species can be suggested for phytoextraction of HMs due to their considerable accumulating ability; *Pinus eldarica* and *Morus alba* for Zn, *Fraxinus excelsior* and *Morus alba* for Cu, *Pinus eldarica* and *Alnus glutinosa* for Pb, and *Pinus eldarica* and *Nigral morus* for Cd.

3.3. Comprehensive bio-concentration index (CBCI)

Comprehensive bio-concentration index (CBCI) was applied to evaluate the capability of different tree species in accumulating multi HMs from soil. The maximum CBCI in leaves samples were related to *Pinus eldarica* (6.72), *Populous deltoids* (6.17) and *Morus alba* (5.97), (Table 1) and in barks samples were related to *Wistaria sinensis* (8.42), *Nigral morus* (8.25) and *Pinus eldarica* (7.74), (Table 2).

In this study, most CBCI values in leaves and barks were observed to be more than those reported by Zhao et al. (2014). Many previous studies have reported that young trees with fast growth rate can accumulate more HMs from soil through phytoremediation (Puschenreiter et al., 2010; Zhao et al., 2014). In this study, all of the samples were taken from the young trees (8–12 years old). This is an important finding in terms of long-term phytoremediation because it suggests that substantial HMs accumulation could be expected during a remediation period from seedlings to fully grown (Baker et al., 2000). Therefore, tree species with high CBCI values identified in this study can be used for soil phytoremediation in the future.

3.4. Metal accumulation index (MAI)

The MAI values for the leaves and barks were summarized in Tables 1 and 2. The minimum MAI values for leaf and bark were found in *Wistaria sinensis* (1.52) and *Ulmus umbraculifera* (4.88), respectively. *Salix babylonica* and *Olea europaea* have the maximum MAI values for leaves (8.2) and for barks (18.56), respectively. Obtained MAI values in present study are more than those reported previously by Hu et al. (2014) (Hu et al., 2014), but they are in agreement with Liu et al. (2007) findings. There are several possible explanations for these results. Firstly, these differences can be explained in part by the difference in local atmospheric chemistry and meteorology properties. Moreover, the other factors, such as sampling altitude, sampling time, and plant characteristics can also influence on the capacity of air pollutants removal by urban plants (Yin et al., 2011; Hofman et al., 2013).

The leaves of tree species with slow growth rate are exposed to the soil splash more than those from fast growth rate trees (Dzierżanowski et al., 2011; Hu et al., 2014). It should be noted that *Morus alba* with the large surface leaves and *Salix babylonica* with leaves near to the ground level, had higher MAI values than *Pinus eldarica*, *Cupressus arizonica* and *Robinia pseudoacacia* with needle like leaves which their growth is more in higher elevation in contrast to the ground surface (Table 1). The morphology of leaf surface and especially the dense of its trichomes can increase its potential to trap airborne pollutants and to uptake HMs from the epidermis stomata. Several reports have shown that as the surface of the leaves gets rougher, the HMs accumulation are increased due to their greater ability to trap in the particles (Sawidis et al., 2001, 2011). MAI values in all bark samples were more than leave samples. This fact can be confirmed that bark is better than leaves to be used as bio-indicator for HMs pollution. In Zhai et al. study (Zhai et al., 2016), MAI in all of leaf samples was less than bark. Many studies have reported that plant leaves are very good bioindicator for atmospheric HMs pollution and they can be used also for removal of air pollutants (Tomašević et al., 2004; Yang et al., 2005; Nowak et al., 2006; Serbula et al., 2012; Mok et al., 2013), but the other parts of trees such as bark have received less attention in atmospheric assessment standpoint. The bark of trees can give reliable results for estimation of long term air pollution because its structure retains HMs pollutants for a long period of time (Berlizov et al., 2007). On the other hand, leaves are periodically shed whereas bark lasts for longer time. According to the above content, the species with high MAI values have better HMs accumulation properties and as they can grow in contaminated environments, they can be used as bioindicator or biomonitor for HMs contamination in the urban environment. Thus, present study proposes that these plants should be used more frequently as barriers between contaminated and vulnerable areas, such as parks, schools, hospitals, and residential areas.

The coniferous trees are considered to be more useful in particulate matter (PM) accumulation than broad-leaved ones. Sæbø et al. (2012) reported that pine species should be used more in urban areas because of their ability to uptake large amount of PM particularly during winter when the concentrations of pollutants are higher. However, conifers are less tolerant to high concentrations of pollutants related to traffic and they are not often recommended for roadside plantings (Dzierżanowski et al., 2011). Furthermore, Beckett et al. (2000) (Beckett et al., 2000) stated that evergreen conifers could not be suitable to remove air pollutants because the needles of these plants are kept for a considerable long time. Therefore, there is no opportunity to recycle the accumulated and stored pollutants. So, present study suggests that *Morus alba* and *Salix babylonica* according to MAI values of their leaf and *Nigral morus* and *Olea europaea* in terms of obtained MAI values of their bark, can be suggested to be commonly used in urban large green area including the schools and parks where they can create a considerable greening landscapes and also remove the air pollutants.

Beside the direct adsorption processes, trees can reduce the air temperature through shading and evapotranspiration in the summer. This can reduce air pollutant emissions from indoor cooling processes and decrease the rate of chemical reactions responsible for secondary air pollutants production in urban areas (Yang et al., 2005; Hu et al., 2014). According to the obtained results, some suggestions can be proposed for future screening trials of urban tree species. It has been reported that trees and forests are the significant sinks for aerosol, particulate matters, and gaseous and rain-born pollutants (Fowler et al., 1989). However, there are some limitations with urban greening programs. The most important problem is related to the lack of land space in urban environments (Speak et al., 2012). Plants that can tolerate high HMs concentrations and have rapid growth rates, should be studied comprehensively to increase the overall uptake of contaminants and harvesting cycles (Laidlaw et al., 2012; Sæbø et al., 2012). The capability of trees to remove air pollutants cannot be the only screening factor, trees should also be assessed for their suitability to grow in urban surroundings (Yang et al., 2005). This suitability can be described as high tolerance to urban soils properties (Craul, 1994), the ability to survive and grow without consistent watering (Whitlow et al., 1992), the longevity and sustainability (Nowak et al., 2006), the aesthetic value and limited volatile organic compound emissions (Yang et al., 2005), and little or no production of pollen (Beckett et al., 2000).

4. Conclusion

HMs accumulation ability in leaf and bark of fourteen tree species with the same HMs concentrations were investigated. CBC was used to estimate the ability of plants to accumulate a certain HMs from soil. CBCI and MAI were applied for comparing different tree species in multi HMs accumulation form soil and ambient air. Based on CBCI, *Pinus eldarica* and *Wistaria sinensis* had the highest ability to accumulate HMs from soil, and MAI values indicated that *Morus alba* and *Nigral morus* had the highest ability to accumulate HMs from ambient air. The maximum BCF values of Zn, Cu, Pb and Cd for leaves were found in *Pinus eldarica* then *Morus alba,* and for barks the maximum BCF values of Zn, Cu, Pb and Cd were found in *Morus alba*, *Buxushyrcana* and *Nigral morus* species. Therefore, these species can be used as a good bioaccumolator for mentioned HMs. Their high accumulation capacity can also indicate their application potential for the bio-monitoring of the HMs contaminations in the urban environment. Finally, according to present results, cultivation of suitable plants in urban area can help to remediate the soils and atmospheric pollution due to HMs.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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