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Usability of several species for monitoring and reducing the heavy metal pollution threatening the public health in urban environment of Ankara

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Abstract

In the last century, the pollution in the atmosphere significantly increased due to anthropogenic effects including industrial activities and traffic and reached a level threatening human and environmental health. Among these pollution factors, heavy metals that do not easily degrade in nature, tend to bioaccumulate in living organisms, and can be toxic, carcinogenic, and lethal even at low concentrations are among the most important threats in terms of human health. Thus, it is very important to reduce the heavy metal pollution in air, especially in urban areas where the traffic activities that are among the important heavy metal sources are intense. The most effective, affordable, environment-friendly, and sustainable method to be used in monitoring and reducing the heavy metal pollution in air is the use of plants. However, for this purpose, the most suitable species should be determined first. Within the scope of this study, it was aimed to determine the accumulation of Ba, Na, and Ca, which are very common, in the leaves, seeds, and branches of *Acer negundo, Aesculus hippocastanum, Tilia platyphyllos, Prunus ceracifera,* and *Ailanthus altissima* that are frequently used in landscaping in urban areas. The results achieved here showed that the concentration of Ba, which is very harmful to human health and compounds of which are toxic, increased with increasing traffic density. It was determined that, among the species examined here, the most effective ones to be used in reducing the Ba concentration were *Aesculus hippocastanum* and *Tilia platyphyllos*.

Keywords: Air Pollution; Biomonitor; Heavy metal; Urban Areas; Public Health

1. Introduction

The growth of world population in the recent century and the concentration of population in urban areas necessitated more people to live in unit areas, especially in large cities [1-3]. This also brought many problems with itself and the most important problem in urban areas is the environmental problem [4, 5]. In urban areas, soil, water, and air are remarkably polluted because of anthropogenic factors including domestic wastes, human activities, and traffic especially [6-8]. Particularly, air pollution reached very significant levels such that it became a global problem causing the deaths of more than 7 million individuals worldwide [9-13].

Among the components of air pollution, the most harmful and lethal one is the heavy metal pollution because many heavy metals are toxic, carcinogenic, and lethal for humans even when at low concentrations [14-16]. It was reported that even the heavy metals that are necessary as a nutrient element for people and plants might be harmful when at

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high concentrations [17-19]. Moreover, the intake of heavy metals, which are necessary as nutrient elements, into the human body through respiration might cause severe medical problems [20-22]. Besides that, the concentrations of heavy metals, which do not easily degrade or decompose in nature, in the air constantly increase [23].

Thus, heavy metals pose a significant threat to public health in urban areas. Since there are more human activities in urban environment [24] and pollutant factors in urban areas, air pollution increases and the larger population causes more individuals to be affected by the air pollution [25]. For this reason, the studies particularly focusing on monitoring the changes in heavy metal concentrations in air in urban areas, where the population density is high, and reducing these concentrations are among the primary research subjects [26].

The most effective method used in monitoring the heavy metal pollution in the air is biomonitors. Biomonitors are the organisms living in a place for a long time, accumulating pollution factors in their different organs but not die of the pollution factor, thus providing information about the levels of that specific pollutant in the air [27]. Nowadays, the most frequently used biomonitor in monitoring the heavy metal pollution is the plants [28]. Plants are useful biomonitors since they live fixed in a place, are exposed to heavy metal pollution constantly, can accumulate heavy metals in their organs, and can survive heavy metals and since it is known how long various organs have been exposed to heavy metal pollution [29].

Moreover, accumulating heavy metals in their organs, plants reduce the heavy metal pollution and they are the most effective instrument used for this purpose [30-32]. However, different heavy metals accumulate in different organs at different levels. Thus, in order to monitor the change of each heavy metal's concentration in the air and to reduce the air metal pollution effectively, it is necessary to determine which heavy metals more heavily accumulate in which organs and plants [33]. In the present study, it was aimed to determine the change of Ba, Na, and Ca concentrations in leaves, seeds, and branches of five plants, which are widely used in landscaping, by traffic density in Ankara, which is the capital and second-largest city of Türkiye.

2. Material and methods

2.1. Material

The research was conducted on the samples collected from the city center of Ankara. Within the scope of this study, the samples were collected from *Acer negundo, Aesculus hippocastanum, Tilia platyphyllos, Prunus ceracifera,* and *Ailanthus altissima* species, which are widely used in landscaping and were grown at high-traffic, low-traffic, and no-traffic (no motorway at min. 100m distance). The samples were collected by cutting from the last year's shoot using pruning shears. Then, they were taken to the laboratory after labeling.

2.2. Method

The samples taken to the laboratory were laid on the cardboards and separated. Then, the samples were crushed for achieving better drying and they were labeled after placing them into glass Petri dishes. The samples prepared were kept for 15 days in order to dry them under room conditions and the laboratory was ventilated on daily basis during this process. The air-dried samples were further dried in a drying oven for 1 week at 45^{o}C until completely dried.

In the next stage, the plant samples were crushed into powder. Then, 0.5g of powdered samples were put into tubes specifically designed for microwave and then added with 10 ml 65% HNO_3. These procedures were carried out using fume a cupboard. Then, the samples were combusted in a microwave at 280 PSI pressure and 180 ºC temperature for 20 minutes. After the combustion process, the tubes were taken out of the microwave and left for cooling. Cool samples were added with deionized water to 50ml of volume and filtered through filter paper. The samples prepared in this process were scanned using ICP-OES device at suitable wavelengths.

2.3. Statistical analyses

The data obtained from the study were entered into Excel software and analyzed using SPSS 22.0 statistical package software. The data were subjected to variance analysis and the data with differences at p<0.05 or the minimum confidence level of 95% were tested using Duncan's test and homogeneous groups were obtained. The data obtained were simplified and interpreted using tables.

3. Results

For the species, the changes in Ba concentrations in high-traffic, low-traffic, and no-traffic areas were determined and the homogeneous groups obtained from Duncan's test and importance level, *F* value obtained from variance analysis, and mean values are presented in Table 1.

Table 1 The change of Ba (ppm) concentration by species, organ, and washing condition

Species	Organ	Vehicle density- Intensely state			*F* value
		Low	Medium	High	
Acer negundo	Leaf	5.56 Ab	38.00 Be	51.70 Ch	32946.8***
	Seed	9.00 Ad	8.96 Aab	8.86 Ab	2.60 ns
	Branch	16.06 Bh	4.80 Aa	29.50 Ce	13318.3***
Aesculus hippocastanum	Leaf	36.66 Ck	18.13 Abc	19.50 Bd	5760.42***
	Seed	59.26 Al	125.40 Bg	156.53 Cl	63.16***
	Branch	11.83 Af	12.36 Bab	14.80 Cc	1350.60***
Tilia platyphyllos	Leaf	36.63 Ak	63.06 Bf	91.83 Ck	21437.3***
	Seed	3.90 Aa	4.30 Ba	5.06 Ca	237.25***
	Branch	13.43 Ag	13.86 Aab	40.43 Bg	549.09***
Prunus ceracifera	Leaf	15.43 Ah	16.70 Bbc	33.36 Cf	5102.71***
	Seed	30.46 Ai	33.00 Bde	65.76 Cj	7811.73***
	Branch	32.53 Bj	30.46 Ade	58.03 Ci	26520.8***
Ailanthus altissima	Leaf	7.40 Ac	25.70 Bcd	30.50 Bef	9.98*
	Seed	10.30 Ae	13.76 Bab	15.83 Cc	4221.60***
	Branch	9.50 Ade	13.56 Bab	29.30 Ce	29525.20***
F value		2390.3***	103.84***	959.14***	

The letters are groups formed as a result of the Duncan test, capital letters are values in rows although lower case letters are groups of values in columns, ns: not significance, *signifcant at 0.05 level, **signifcant at 0.01 level, ***signifcant at 0.001 level.

As a result of the variance analysis, it was determined that the change of Ba concentration was found to be statistically significant in organs for all traffic densities and in all traffic densities for all organs except for *Acer negundo* seeds. This difference was significant at the confidence level of 95% for *Ailanthus altissima* seeds and 99.9% for all other factors. Given the values, it can be seen that Ba concentration increased with increasing traffic density. Besides that, another attention-grabbing point is that the highest values were obtained generally from *Aesculus hippocastanum* seeds and *Tilia platyphyllos* leaves. The changes in Na concentration are presented in Table 2.

Given the changes in Na concentration, it was determined that the change in Na concentration was statistically significant in all traffic densities by all organs at the confidence level of 99.9% but the change by traffic densities was found not to be statistically significant in most organs (p>0.05). Besides that, another interesting point is that the concentrations obtained were generally at very low levels. The highest values were obtained from *Acer negundo* seeds and no increase by traffic density could be observed in other organs in general. This finding might suggest that Na concentration changed depending on organ rather than traffic density. The changes in Ca concentration are presented in Table 3.

As a result of the variance analysis, it was determined the changes in Ca concentration was statistically significant in all organs for all traffic densities and in all traffic densities for all organs at the confidence level of 99.9%. Given the data, it can be seen that the highest value was obtained from *Prunus ceracifera* seeds. Besides that, the highest values were generally obtained from the branches in all species and the values obtained from leaves were generally at very low levels. It can be stated that there was no direct relationship between traffic density and Ca concentration.

Table 2 The change of Na (ppm) concentration by species, organ, and washing condition

Species	Organ	Vehicle density- Intensely state			*F* value
		Low	Medium	High	
Acer negundo	Seed	1.70 c	3.70 cd	1.76 a	0.689 ns
	Branch	3.90 Af	106.26 Bi	208.63 Ci	8883.24***
	Leaf	0.66 Aa	4.53 Bd	17.46 Cf	7741.03***
Aesculus hippocastanum	Seed	1.70 c	1.73 ab	1.73 a	0.985 ns
	Branch	3.50 Ce	0.80 Aa	2.30 Bab	34.31**
	Leaf	2.20 Bd	10.43 Cf	1.46 Aa	3346.35***
Tilia platyphyllos	Seed	2.26 d	2.33 b	2.30 ab	0.485 ns
	Branch	8.10 Bg	17.33 Cg	3.50 Abc	337.52***
	Leaf	13.80 l	5.80 e	4.60 c	0.687 ns
Prunus ceracifera	Seed	1.13 Ab	1.70 Bab	1.70 Ba	72.25***
	Branch	2.20 Ad	3.43 Bc	3.43 Bbc	124.45***
	Seed	9.03 Bh	3.36 Ac	84.16 Cg	140835.8***
Ailanthus altissima	Branch	10.80 j	4.46 d	13.50 e	1.57 ns
	Leaf	9.73 i	9.70 f	9.76 d	0.947 ns
	Seed	12.50 Ak	21.43 Bh	93.70 Ch	87755.27***
F value		4276.7***	7765.6***	17223.7***	

The letters are groups formed as a result of the Duncan test, capital letters are values in rows although lower case letters are groups of values in columns, ns: not significance, *signifcant at 0.05 level, **signifcant at 0.01 level, ***signifcant at 0.001 level.

Table 3 The change of Ca (ppm) concentration by species, organ, and washing condition

Species	Organ	Vehicle density- Intensely state			*F* value
		Low	Medium	High	
Acer negundo	Seed	1694.46 Ac	3720.50 Bh	1695.63 Ab	64242.40***
	Branch	3892.83 Af	5685.93 Bj	7479.06 Ci	37400.36***
	Seed	8045.30 Cm	7957.20 Bo	7657.53 Aj	9229.49***
Aesculus hippocastanum	Seed	1688.70 Ac	1690.60 Bc	1701.00 Cb	39.57***
	Branch	5440.33 Bi	3461.63 Ag	5610.73 Cg	3649.14***
	Seed	7897.23 Cl	7807.20 Bn	7599.43 Aj	3409.90***
Tilia platyphyllos	Seed	1357.13 b	1357.10 b	1355.96 a	1.50 ns
	Branch	948.56 Aa	2985.76 Cf	1897.16 Bc	25936.97***
	Seed	3055.80 Ae	6113.50 Bk	6257.76 Ch	2508613.6***
Prunus ceracifera	Seed	1695.23 Ac	1755.63 Bd	7481.80 Ci	168842.31***
	Branch	7367.10 Aj	7629.06 Am	32513.66 Bk	31442.79***
	Seed	7609.86 Ak	7611.40 Al	7705.63 Bj	746.28***
Ailanthus altissima	Seed	3994.76 Bg	976.26 Aa	4358.30 Ce	12464.14***
	Branch	2178.00 Ad	2207.60 Ce	2191.80 Bd	2056.62***
	Seed	4406.76 Bh	4389.83 Ai	4469.43 Cf	3588.43***
F value		31088.1***	581415.5***	44939.5***	

The letters are groups formed as a result of the Duncan test, capital letters are values in rows although lower case letters are groups of values in columns, ns: not significance, *signifcant at 0.05 level, **signifcant at 0.01 level, ***signifcant at 0.001 level.

4. Discussion

As a result of the study, it was determined that Na and Ca concentrations varied depending on species and organ rather than traffic density. It might suggest that the main source of Ca and Na was the soil. Heavy metals penetrate trees in three ways. They are either absorbed by roots or taken from air directly via leaves or stems. Previous studies showed that many heavy metals are absorbed by the roots [34]. As a result of the study, this finding was corroborated by the result that Ca and Na concentrations didn't vary by the traffic density.

Ba, the other element examined here, plays a key role in the production of many products in the industry and it is widely used. Besides that, Ba also is one of the most dangerous heavy metals and all of its compounds are toxic [35]. Being one of the heavy metals threatening the public health, Ba is one of the risk factors for cancer, which is considered as the disease of the time [36]. Moreover, it was found that Ba exposure caused renal, neurological, cardiovascular, mental, and metabolic disorders [37]. As a result of the study, it was found that Ba concentrations increased with traffic density in almost all organs of the plant. Heavy metals can be spread to the atmosphere from different sources. But, the most important heavy metal sources were reported to be mining facilities, industrial facilities, and traffic [38-40]. Hence, it was reported in previous studies that the heavy metal concentrations in plants grown near the heavy metal sources were higher [41]. Studies revealed that Ba is one of the elements spread to the atmosphere by traffic and that Ba concentration in various organs of plants grown in high-traffic areas was higher [42].

As a result, the highest Ba concentrations were generally obtained from *Aesculus hippocastanum* seeds and *Tilia platyphyllos* leaves. Given this finding, it can be recommended to use especially these two species in order to reduce these concentrations and it can also be recommended to plant these two species in locations with a high level of Ba pollution. However, one should be careful especially about *Tilia platyphyllos* plantations because *Tilia* species are species examined in "edible landscaping" studies and flowers and leaves of these species are consumed as food. Thus, collecting the leaves of *Tilia* grown in high-traffic areas and consuming them as food might cause severe medical problems. Similar results were reported in previous studies [43-45].

As a result pf of the study, it was found that all the elements accumulated in the organs of different species at different levels. In many of previous studies, it was emphasized that heavy metal concentrations varied significantly by species and organs [46]. Accumulation of heavy metals in the organs of plants is affected by the mutual interaction between many factors [47]. The most important one among them is plant habitus and development which is shaped by the mutual interaction between genetic structure and environmental conditions [48]. Since genetic structures of plants vary significantly between plant species, it is normal for plants belonging to different species but grown in the same location to have different heavy metal concentrations in their same organs and it was emphasized in many of previous studies [49].

Another factor influencing the heavy metal pollution in plants is the plant habitus [50]. The plant habitus is shaped by various factors including plant's genetic structure and various climatic and edaphic factors [51-54]. Hence, heavy metal penetration and accumulation in plant body are shaped by the mutual interactions between numerous factors. Thus, it is very important to diversify the future studies on this subject in order to protect and improve public health and monitor and reduce the pollution.

5. Conclusion

In future studies, samples can be collected from locations with different land use patterns. Various polluting sources can be identified and suggestions can be made for urban planning. In addition, research on species selection in urban landscape planning can be developed. In summary, the results of this research can guide decision makers in terms of urban public health and quality of life.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they no conflict of interest. The none of the authors have any competing interests in the manuscript.

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