http://www.balticforestry.mi.lt
ISSN 1392-1355
eISSN 2029-9230

Baltic Forestry 2023 29(2): 141–152
Category: Research article
https://doi.org/10.46490/BF661

Variation in Pb and Zn concentrations in different species of trees and shrubs and their organs depending on traffic density

DENIZ GUNEY [1], İSMAIL KOÇ [2]*, KAAN ISINKARALAR [3] AND RAMAZAN ERDEM [4]

[1] *Department of Forest Engineering, Karadeniz Technical University, 61080 Trabzon, Turkey; https://orcid.org/0000-0001-7222-6162*
[2] *Forestry Vocational School, Düzce University, 81620 Düzce, Turkey; https://orcid.org/0000-0001-5847-9155*
[3] *Faculty of Engineering and Architecture, Department of Environmental Engineering, Kastamonu University, 37150 Kastamonu, Turkey; https://orcid.org/0000-0003-1850-7515*
[4] *Kastamonu University, Arac Rafet Vergili Vocational School, Department of Forestry, Programs of Forestry and Forestry Products, 37800 Kastamonu, Turkey; https://orcid.org/0000-0002-5243-5685*

* *Corresponding author: ismailkoc@duzce.edu.tr; phone: +90 380 542 3309*

Guney, D., Koç, İ., Isinkaralar, K. and Erdem, R. 2023. Variation in Pb and Zn concentrations in different species of trees and shrubs and their organs depending on traffic density. *Baltic Forestry* 29(2): 141–152; https://doi.org/10.46490/BF661.

Received 19 August 2022 **Revised** 2 October 2023 **Accepted** 2 October 2023

Abstract

Global population growth and increasing urban population density together are responsible for many disruptions such as environmental pollution, especially air one. Trace metals are of specific prominence as air pollutants because they are conservative pollutants. They tend to accumulate biologically; some have poisonous or carcinogenic effects, even at small concentrations. Among toxic trace metals, lead (Pb) and zinc (Zn) can be harmful to human health in certain quantities. These trace metals were included in primary pollutant lists of the Agency for Toxic Substances and Disease Registry. Therefore, determining these trace metal concentrations in the air and monitoring the differences is very important for determining the risky districts and the level of risk. Biomonitors are the most important indicators of differences in trace metal concentrations in the atmosphere. The plants chosen as biomonitors intake several of the trace metals from the soil and/or the air into their bodies and determining the level of this accumulation might provide insight into the trace metal pollution of the atmosphere and soil. The present study aims to determine the variations of Pb and Zn concentrations in various landscaping plants growing in different districts of Kastamonu (Türkiye) depending on tree species, organs and traffic density. It was found that unwashed leaves of *Acer negundo* L. can be suggested as a good biomonitor for the presence of both analysed trace metals.

Keywords: biomonitor; air pollution; trace metal; lead; zinc; traffic

Introduction

The rapidly expanding human population in our world has resulted in negative impacts on ecosystems and the civilisation has been faced with many challenges, such as global climate change, global warming, severe droughts (Koç et al. 2022, Koç and Nzokou 2022), and air pollution (Isinkaralar et al. 2022a, Cobanoglu et al. 2023). Rapid economic development, industrialization, and urbanization increased needs in energy and raw materials the world during the last 200 years. As a result of the activities addressing these necessities, various pollutants spread throughout the atmosphere and deteriorated its quality. When combined with population growth, the global urbanization problem became one of the most critical irreversible challenges on the earth (Aricak et al. 2019, Ghoma et al. 2022, Koç 2022, Cetin et al. 2023).

As the density of people per unit area has increased, urban areas have become areas susceptible to air pollution. The World Health Organization (WHO) reported that, as of 2014, roughly 92% of the people worldwide live in low-air quality territories (Elsunousi 2020, Sevik et al. 2020a).

Among the factors playing a role in air pollution, trace metals have a specific status because they are conservative pollutants and do tend to accumulate biologically, and some of them show carcinogenic or poisonous effects even in small amounts (Koç 2021, Isinkaralar et al. 2022a, b). Some metals, such as As (arsenic), Cd (cadmium), Ni (nickel), Cr (chromium), Pb (lead), V (vanadium), and Zn (zinc), are mainly of industrial origin and carcinogenic. Among them, Pb, Cd, As, Hg (mercury), and Cr are poisonous metals, particularly in terms of their potential toxicity and effects on living beings (Sevik et al. 2019, Savas et al. 2021). As macronutrients, Zn, Mn (manganese), Fe (iron), Cu (copper), Cr, and Ni are essential as microelements for living beings, including animals and plants. However, they can also cause destructive outcomes in high amounts. Trace metal elements such as As, Cd, Hg, and Pb reveal their severe toxicity in the living body even at small doses (Ucun Ozel et al. 2020, Cesur et al. 2022, Çobanoğlu et al. 2022).

A complex mechanism shapes the intake of trace metals into plant bodies. Plant development and growth are shaped by genetic setup and environmental conditions (Sevik et al. 2020d, Yigit et al. 2021). Thus, the distinction between the trace metal accumulations in plant development in similar ecological conditions can be related to genetic differences. Previous studies pointed out that besides the differences between the genetic structures of diverse species, even the genetic codes of various origins, varieties, subspecies, and forms were different, and the anatomic, morphologic, and physiologic properties vary with the effect of gene structure (Canturk and Kulac, 2021, Imren et al. 2021, Ozel et al. 2021). Therefore, many factors such as a plant's genetic constitution, soil conditions and stress level significantly impact plant metabolism and the accumulation and assimilation of trace metals.

Although many organisms can be used as biomonitors in the monitoring of trace metal pollution, more studies have been carried out on the use of woody plants in recent years. Woody plants absorb the trace metals in their bodies, and they also contribute to decreasing air pollution. Besides their contribution to air pollution, these plant species also have numerous positive ecological, social, and economic roles (Kesik et al. 2014, Yigit et al. 2019, Varol et al. 2022). However, considering that each metabolism has a different metabolism and environmental interactions, more studies should be done on the use of plants for more targeted reasons, such as the mitigation of certain trace and toxic metals.

Among the trace metals, Pb and Zn are the elements coming to the forefront with their effects on human health and the environment. Pb is of particular importance among them. It is frequently found due to its great use in agricultural and industrial activities (Cetin et al. 2022). As a very lethal trace metal, Pb spreads in the air in compound form. Pb is among the trace metals damaging the ecologic system at most throughout anthropogenic activities, and it is among the trace metals based on traffic density at the utmost (Sevik et al. 2020b, c, Koç 2021). Zn is an element that is a necessity for animals, humans, and plants (Mossi 2018). In addition, Zn is a toxic element for humans and can cause nausea and vomiting, stomach cramps, anaemia, diarrhoea, liver failure, pancreatic complications, fatigue, kidney failure, epigastric pain, pancreatic damage, neutropenia, and immune system disorders (Vardhan et al. 2019, Briffa et al. 2020, Okereafor et al. 2020).

Moreover, it is stated that Zn-induced neurotoxicity can lead to neuronal damage and death associated with epilepsy, stroke, neurodegenerative disorders, and traumatic brain damage. The trace metal poisoning can cause metabolic syndrome, which is a co-occurrence of triggers that increase a person's risk of heart disease and diabetes (Alengebawy et al. 2021). The permissible level of Zn in drinking water suggested by the BIS (The Bureau of Indian Standards) is 5 ppm (5 mg/L or 5000 ppb) (Vardhan et al. 2019). However, since Zn in the air is taken into the lungs by respiration, it is stated that it can be harmful to humans at much lower concentrations in terms of human health and may even lead to death results (Savas et al. 2021, Ghoma et al. 2022). Thus, it is crucial to determine the Zn and Pb concentrations in the airborne and monitor the change to identify the risky region and the risk level.

Both Pb and Zn are highly harmful elements for humans. Maximum limits allowed in soils are 100,000 ppb (100 ppb) for Pb and 300,000 ppb (300 ppb) for Zn. The maximum allowable limits for the edible parts of plants are 1,000 ppb (1 ppb) for Pb and 50,000 ppb (50 ppb) for Zn (Khalid et al. 2017). Legal limits in different countries may differ, which the WHO and Chinese Ministry of Health and the National Standards accept the upper limits of Pb as 10 ppb for drinking water and 100–300 ppb for vegetables, while the National Environment Management Authority (NEMA, Kenya) with Kenya Bureau of Standards (KEBS), as well as the EPA (USA) accept it as 50 and 300 ppb, respectively (Kinuthia et al. 2020). Regarding human health, limit values for trace metal concentrations in the air have not yet been determined. The difficulty of measuring trace metal concentrations in the airborne can also be considered a factor. Because the direct measurement of trace metal pollution in the air is complex, costly and the direct effect of the results on the ecosystem is not known, it is considered meaningless (Key et al. 2022, Sulhan et al. 2022, Yayla et al. 2022).

Biomonitors are the most critical indicator of changes in air metal pollution levels. The plant species, especially ornamenting species used as biomonitors, collect several trace metals in air or soil within their bodies, and determining the level of this accumulation provides proof of the metal pollution in air and soil (Nowak et al. 2018, Aricak et al. 2020, Isinkaralar et al. 2023). However, plants vary in terms of collecting different trace metals and trace metal retention potential by their organs. Therefore, the most relevant plant species and organs used for monitoring should be selected for each trace metal individually.

Pb and Zn are trace metals which concentrations increase due to traffic (Turkyilmaz et al. 2018, Key and Kulac 2022). Studies to monitor and reduce the concentration of these trace metal elements in the airborne are of great prominence (Karacocuk et al. 2022). Although there are numerous studies on this subject, the studies have mainly evaluated trace metal concentrations in the species' leaves. However, the woody part of trees is the largest organ in terms of mass, and the bark has as much surface area as the leaf one. Therefore, trace metal accumulation should also be determined based on the plant species and organs. Also, the differences in the concentration of selected trace metal elements depending on the traffic intensity should be examined. The relationship between the trace metal concentrations determined in the organs and particulate matter should also be evaluated. The current research is aimed to reveal the differences in Pb and Zn concentrations in different organs of specific ornamenting plants grown in the city centre of Kastamonu depending on the traffic density. Thus, it aimed to determine the tree species and organs, which are suitable for biomonitoring of Pb and Zn concentrations.

Material and method

Study area

The current research was performed in the city of Kastamonu, Northern Türkiye. Within the study scope, the specimens were obtained from heavy traffic (HT), moderate traffic (MT), and low/no-traffic (LT). In the present study, HT samples were collected from the city centre of Kastamonu. There was a 4-lane motorway in this region, and the traffic density was very high all day. The samples were obtained from the area in the middle of the main road with heavy traffic. The samples' distance to the vehicles' transit route was less than 2 m, which was considered a source of pollution. The less-density areas were on the motorway route without traffic jams outside the city centre. The trees in this area were located on the pavement, and the distance of the vehicles to the crossing route was less than 2 m. Hence, the level of contamination is assumed to be significantly less than in the high-traffic area. The campus of Kastamonu University was selected as a low-non-traffic area, and the samples were collected from the points with no motorway at a 50 m distance (Figure 1).

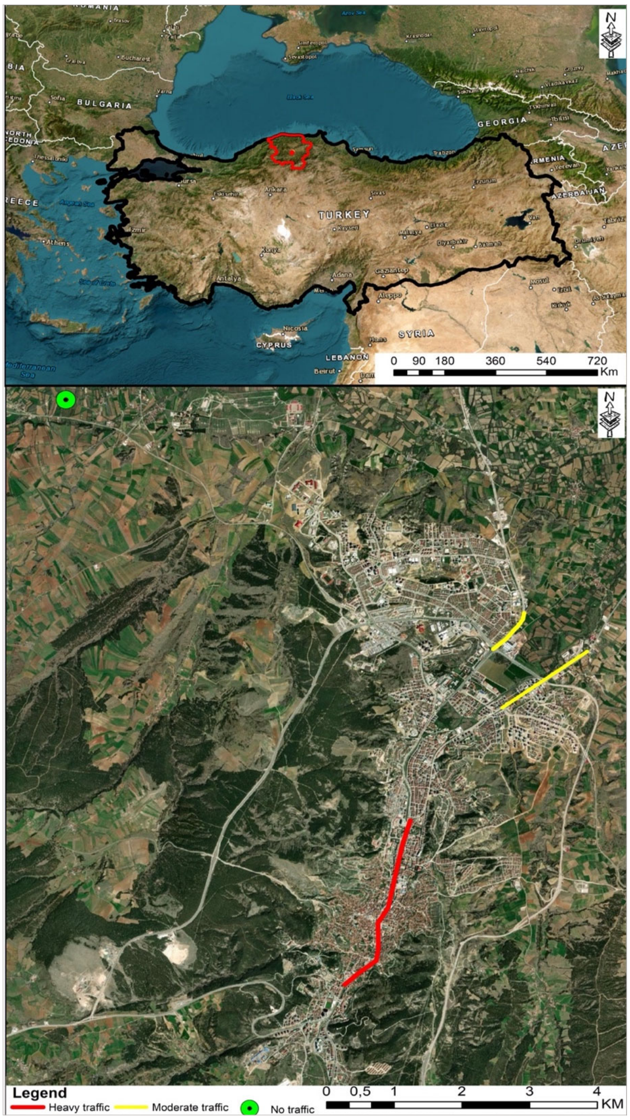

Figure 1. The sampling locations in Kastamonu city

Sampling and analysis

The samples were collected from *Ailanthus altissima* (Mill.) Swingle (AA), *Aesculus hippocastanum* L. (AH), *Acer negundo* L. (AN), *Tilia tomentosa* Moench. (TT), and *Euonymus japonica* 'Aurea' (EJ) that are frequently utilised in landscaping and greening projects. Three trees were selected from each point, and samples were collected from three branches of each tree. The specimens were taken from the last-year (1-year-old) shoots. Samples were collected in late October 2019 (end of vegetation season). The study was carried out in 3 repetitions, and branch samples were taken from the parts of the trees facing the road, roughly 2 m above the ground. Last-year growth was felled from each tree and approximately 1 kg of the leaf sample was taken.

The samples were collected, labelled, taken to the laboratory, and distinguished by spreading over cardboard. Some of the barks and leaves were washed and in the washing process, the samples were separated into branches and leaves and washed them separately. First, the samples were washed with running tap water until the visible dirt was removed. Afterward, the samples were placed in jars half filled with tap water, and the jars were shaken vigorously and washed. The water was changed, and the same process was continued until the water remained clear. Finally, the samples were thoroughly rinsed with distilled water. Each washing step was repeated at least 5 times. Then, the organs were separated without using any metal instrument. All the samples were marked with "+" (washed) and "-" (unwashed). In the further steps, the organs were labelled according to the status of washing as follows: washed leaves as "L+", unwashed leaves as "L-", washed barks as "B+", unwashed barks as "B-", and wood samples as "W". Tools containing the metals subject to the study were not used during the samples' fragmentation, separation, and grinding.

After the pre-treatment, the marked samples were kept under room conditions (25°C) for 2 weeks without direct sunlight until air-dried. Then, samples were dried in an oven at 45°C for 2 days to constant weight. Dried plant samples were ground, and 0.5 g sub-samples were put into tubes intended to be exposed in microwave oven. 10 mL 65% HNO_3 (nitric acid) was added to the tubes. Then the preparations were burnt in a microwave oven under a pressure of 280 PSI and at a temperature of 180°C for 20 minutes. After completing the procedure, the tubes were taken out of the oven and left to cool at room temperature. The cooled samples were added with deionized water to 50 mL volume. The preparations were filtered through filter paper and analysed in an ICP-OES device (GBC Scientific Equipment Pty Ltd. Melbourne, Australia) at proper wavelengths. The obtained results were multiplied with the dilution factor to obtain actual Pb and Zn concentrations.

Statistical analysis

Obtained data were analysed applying SPSS 21.0 software package (IBM 2012). We used analysis of variance (ANOVA), and to get homogeneous groups, Duncan's multiple range test was performed. A level of significance of $\alpha = 0.05$ was used for inferring any statistical significance. In addition, a principal component analysis (PCA) was also applied to find the Pb and Zn variations between organs depending on traffic density using PC ORD software package (Wild Blueberry Media 2011).

Results

Variation of Pb and Zn concentrations (ppb) in dry mass by the plant species and traffic density

The Pb concentration differences in low/no-traffic (LT), moderate traffic (MT), and heavy traffic (HT) areas were separately determined regardless of organ type and washing status. All samples, washed and unwashed, from all organs (leaf, bark, and wood) were pooled and average values were calculated. The average values and *F*-values received from ANOVA, significance level and the results from Duncan's test were used to determine homogeneous groups, which are presented in Table 1.

The Pb concentration change with regard to traffic density was statistically meaningful ($p < 0.05$) only for *A. hippocastanum* (Table 1). The Pb concentration change with regard to traffic density in other species and the variation in values for different traffic intensities by the species were not significant ($p > 0.05$) (Table 1).

Table 1. Variation of Pb concentration (ppb) by plant species and traffic density

Species	LT	MT	HT	*F*-value
AA	727.68	1952.19	1683.22	2.343 ns
AH	1415.99 B	622.77 A	1455.86 B	4.461 *
AN	1220.23	1916.67	2761.79	1.246 ns
TT	1403.34	2868.78	2143.14	1.012 ns
EJ	1162.10	2399.06	2175.11	0.815 ns
F-value	0.864 ns	1.136 ns	0.722 ns	

Note: According to Duncan's test results, *A* and *B* stand for the statistical differences between traffic densities in each plant species; * = significant at 0.05 level; ns = not significant.

The mean Zn concentration variation with regard to the plant species and traffic density is shown in Table 2. Zn concentration changes with regard to traffic density in *T. tomentosa* and *E. japonica*, and the species-specific changes in Zn concentration in heavy-traffic areas were non-significant ($p > 0.05$) (Table 2). Zn concentrations were found to increase with traffic density in *A. altissima, A. hippocastnum*, and *E. japonica*. The lowest values in the LT areas were obtained only in *A. hippocastnum*.

Table 2. Variation of Zn concentration (ppb) with regards to plant species and traffic density

Species	LT	MT	HT	*F*-value
AA	17959.72 *abA*	24359.53 *bB*	24408.38 *B*	3.461 *
AH	11686.99 *aA*	12049.38 *aA*	24482.59 *B*	9.309 ***
AN	24228.33 *b*	23866.45 *b*	27973.87	0.418 ns
TT	21933.77 *b*	21930.70 *b*	28839.59	1.281 ns
EJ	14580.25 *aA*	25396.16 *bB*	28575.00 *B*	5.710 **
F-value	4.869 **	2.778 *	0.483 ns	

Note: According to Duncan's test results, *A* and *B* stand for the statistical differences between traffic densities in each plant species. In contrast, *a* and *b* stand for the statistical differences between plant species within each traffic density.

Variations of Pb and Zn concentrations (ppb) in dry mass by traffic density, plant species and organ

The differences in Pb concentration in the LT, MT, and HT areas were determined separately for each species and organ. The average values and *F*-values received from ANOVA, level of significance, and the results from Duncan's test were used to determine homogeneous groups (Table 3).

Given the data for the changes in Pb concentration, it can be pointed out that the traffic density-related changes in all organs of all species and the organ-related changes at all traffic density levels were significant ($p < 0.05$). The highest concentrations of Pb were obtained from unwashed leaves of *T. tomentosa* (11,794.53 ppb) and *E. japonica* (10,639.06 ppb) in the LT areas, followed by the values obtained from unwashed leaves of *A. negundo* in the HT area (Table 3). It can be noted that the maximum concentration values were found in leaves.

The Pb concentration was found to be irregular in many species and organs with regard to traffic, and there is a general increasing trend in unwashed leaves of *A. altissima* and *A. negundo* in parallel with traffic (Table 3). Taking into account both exchange status and concentration, it can be concluded that leaves of *A. negundo* are a valuable useful biomonitor for tracking Pb levels.

The differences in Zn concentrations in the LT, MT and HT areas were separately determined for each species and organ, and the results are presented in Table 4. The traffic density-related changes in Zn concentration were significant in the organs of all studied species ($p < 0.05$). However, it was also found that the shift in Zn concentration statistically did not differ with regard to the organs ($p > 0.05$).

Table 3. Variations of Pb concentration (ppb) by plant species, organ, and traffic density

Note: Lowercase letters stand for the statistical differences (the combination of plant species x organ x traffic density) in the vertical direction, whereas uppercase letters stand for the horizontal direction; *** = significant at 0.001 level; ** = significant at 0.01 level. ns = not significant.

Species	Organ	LT	MT	HT	*F*-value
AA	L+	97.86 abA	1093.86 fC	594.80 bcdeB	140.153 ***
	L-	142.63 abA	1757.20 hB	4994.30 lC	3292.903 ***
	B+	303.83 cdA	1280.30 gC	736.66 deB	364.499 ***
	B-	3017.86 mB	5298.46 lC	1938.93 hA	5254.399 ***
	W	76.20 dA	331.13 bcC	151.43 aB	90.216 ***
AH	L+	387.73 deB	57.80 aA	1014.80 fgC	790.063 ***
	L-	1834.03 B	146.86 abA	1882.00 hB	787.062 ***
	B+	1071.33 hB	204.80 abA	2423.93 iC	1028.464 ***
	B-	537.73 fA	2151.86 iC	839.36 efB	1159.243 ***
	W	3249.13 nC	552.53 deA	1119.23 gB	572.865 ***
AN	L+	773.33 gA	2540.00 jB	2536.76 iB	471.710 ***
	L-	144.53 abA	4582.53 B	10302.00 nC	2719.089 ***
	B+	468.63 efB	265.56 bcA	340.03 abA	17.931 **
	B-	4338.80 oA	206.20 abB	129.00 aC	33681.352 ***
	W	375.86 deA	1989.06 iC	501.16 bcdB	733.072 ***
TT	L+	214.00 bcA	1054.06 fC	532.93 bcdB	50.923 ***
	L-	1542.53 iA	11794.53 nC	4006.53 B	627.064 ***
	B+	526.73 fA	445.03 cdA	2042.00 hB	283.023 ***
	B-	1678.9 jB	468.66 cdeA	2307.46 iC	87.616 ***
	W	3054.53 mC	581.60 deA	1826.80 hB	736.324 ***
EJ	L+	1467.16 iC	650.06 eB	469.20 bcdA	163.913 ***
	L-	1526.26 iA	10639.06 mC	6156.13 mB	2583.936 ***
	B+	1964.66 lC	138.83 abA	694.93 cdeB	326.672 ***
	B-	700.53 gB	297.93 bcA	456.83 bcA	14.731 **
	W	151.90 abA	269.40 bcA	3098.46 jB	1237.176 ***
F-value		4.161 **	11.367 ***	23.436 ***	

Table 4. Changes of Zn concentration (ppb) with regard to the plant species, organs, and traffic densities

Note: Lowercase letters stand for the statistical differences (the combination of plant species x organ x traffic density) in the vertical direction, whereas uppercase letters stand for the horizontal direction; *** = significant at 0.001 level; ** = significant at 0.01 level; ns = not significant.

Species	Organ	LT	MT	HT	*F*-value
AA	L+	21669.86 iA	27135.33 lB	21350.53 eA	149.996 ***
	L-	15056.50 eA	32442.40 nC	30209.66 iB	2123.490 ***
	B+	14688.13 eA	15381.53 fA	23916.10 fB	362.270 ***
	B-	31641.73 sA	32195.00 mnB	31419.33 kA	7.863 *
	W	6742.40 bA	14643.40 efB	15146.26 bC	2209.652 ***
AH	L+	4373.80 aA	16899.36 gB	43827.60 nC	2020.606 ***
	L-	22821.40 jB	2644.86 aA	33175.86 kC	59943.522 ***
	B+	8526.93 cA	8557.60 cA	13944.80 aB	153.440 ***
	B-	6147.63 bA	20494.10 jC	16002.66 bB	2211.257 ***
	W	16565.20 fC	9639.20 cA	15462.03 bB	527.717***
AN	L+	38062.26 rC	31487.06 mnB	29005.63 hA	169.531 ***
	L-	18129.33 hA	30972.53 mB	63974.00 pC	20041.695 ***
	B+	11501.46 dA	11686.76 dA	13960.40 aB	58.259 ***
	B-	35746.26 pC	20494.10 iB	15454.96 bA	1085.383 ***
	W	17702.33 ghA	24691.80 B	17474.36 cA	385.237 ***
TT	L+	9148.53 cA	6927.76 bA	25375.20 gB	109.518 ***
	L-	23400.53 jkA	55420.53 oC	45166.40 oB	305.976 ***
	B+	34034.66 oC	26803.10 lB	20872.26 eA	63.196 ***
	B-	17009.96 fgB	11404.90 dA	37264.80 lC	692.764 ***
	W	26074.80 mC	9097.23 cA	15519.30 bB	1191.053 ***
EJ	L+	4913.33 aS	13448.10 eB	32150.13 jkC	11216.526 ***
	L-	4472.93 aA	56777.86 pC	41756.93 mB	57957.440 ***
	B+	24684.43 lB	20416.40 iA	20508.93 dA	78.938 ***
	B-	24163.06 klC	18581.86 hA	19604.26 dB	8045.290 ***
	W	14667.50 eA	17756.60 ghB	28854.73 hC	4477.034 ***
F-value		1.345 ns	7.496 ***	22.480 ***	

The highest concentrations were observed in unwashed leaves of *A. negundo* (63,974.00 ppb) in the HT area, followed by the values of unwashed leaves of *E. japonica* (56,777.86 ppb) and *T. tomentosa* (55,420.53 ppb) in the LT area (Table 4). As in Pb concentrations, the highest Zn concentrations were found in unwashed leaves. Zn concentration is irregular in many species and organs in parallel with the traffic density (Table 4). Additionally, given the changing conditions and concentration level, as with Pb concentration, *A. negundo* can be a useful biomonitor for monitoring Zn concentration.

Principal component analysis of Pb and Zn based on plant organs and traffic density

As a result of the PCA analysis, the variance explanation rates (%) of the axes are given. The total variance explanation rate of Axis 1, and Axis 2 is 63.691% for Pb (Figure 2) and 60.036% for Zn (Figure 3), and graphical interpretation was performed on Axis 1 and Axis 2. When the graphs are obtained from PCA analysis for Pb (Figure 2), there is a negative relationship between the value for unwashed bark and the values for washed and unwashed leaves. There is a positive correlation between the values for unwashed and washed leaves. A weak negative relationship exists between the values from wood and unwashed bark.

Depending on the traffic level, the Pb values measured in the unwashed bark were the highest in a2 and following c1 and the lowest in c3 and c2. In addition, the Pb values measured on the washed leaves were the highest in c3 and then in c2, while the lowest in b2 and a1. Also, the Pb values measured in unwashed bark were the highest in a2 and c1 while the lowest in c3 and c2. Moreover, the Pb values measured in the washed bark were the highest in b3 and d3 while the lowest in c3 and c2. Furthermore, the Pb values measured in wood were the highest in b1 and e3 and the lowest in a1 and a2.

When the graphs were obtained from the PCA analysis for Zn (Figure 3), it was determined that values for unwashed bark B- had a positive correlation with washed

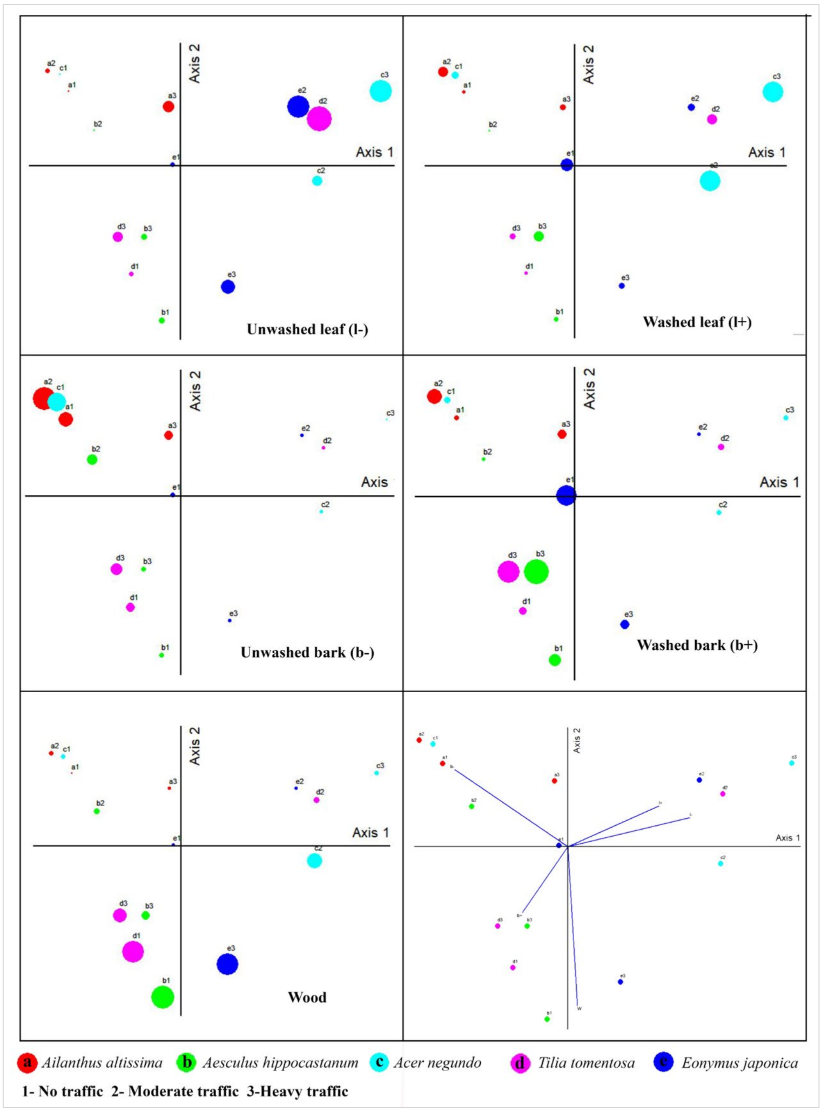

Figure 2. The correlation of Pb content between organs based on traffic density

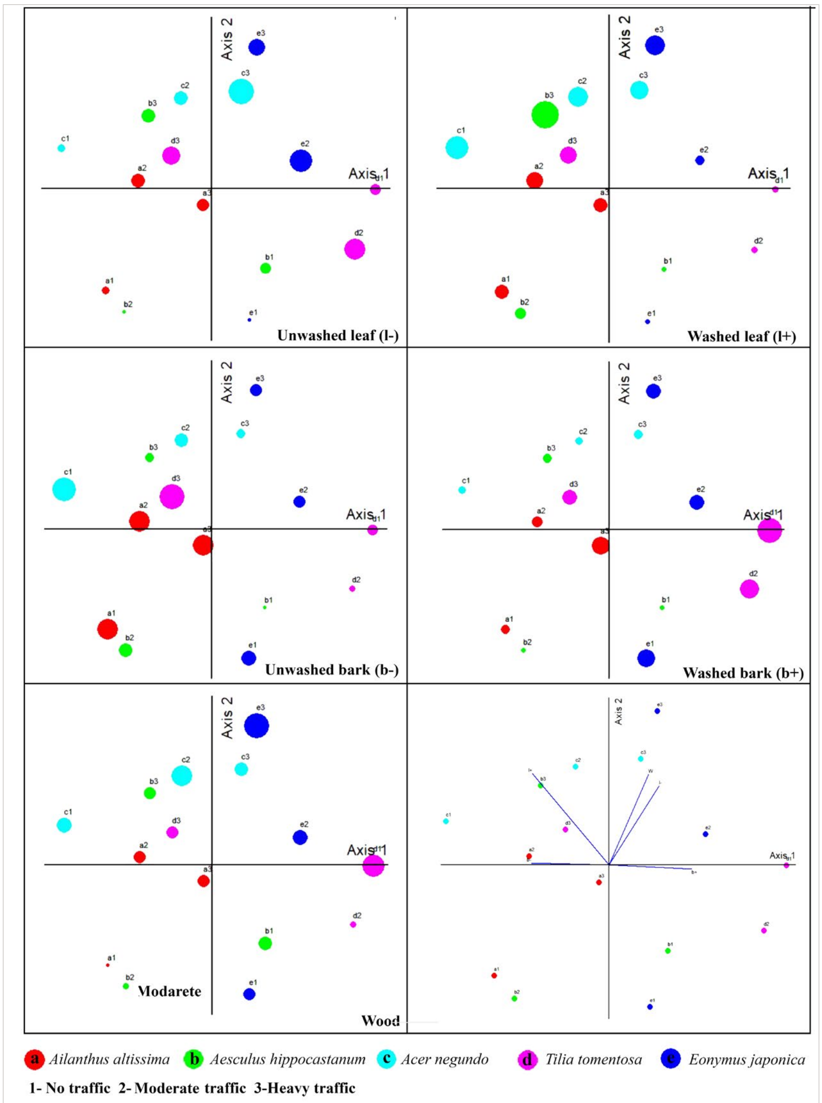

Figure 3. The correlation of Zn content between plant organs based on traffic densities

leaves, while it had a robust negative relationship with the value for washed bark and a weak negative relationship with the value for unwashed leaves. The value for wood has a positive correlation with the values for unwashed and washed leaves.

Based on the traffic density, the Zn values measured in unwashed leaves were the highest in c3 and then in e2 and the lowest in e1 and b2. In addition, the Zn values measured in washed leaves were the highest in b3 and then in c1, while the lowest in e1 and b1. Also, the Zn values measured in unwashed bark were the highest in d3 and a3 while the lowest in b1 and d2. Moreover, the Zn values measured in washed bark were the highest in d1 and d2 while the lowest in b1 and b2. Furthermore, the Zn values measured in the collected wood samples were the highest in e3 and c2 and the lowest in a1 and b2.

Discussion

The current study aimed to reveal Pb and Zn concentration changes (in dry mass of leaf, bark, and wood) in several species and organs with regard to traffic density. In this study it was shown that the concentration of Pb reached 11,794.53 ppb in unwashed leaves of *T. tomentosa*. The lead level may exceed normal levels, especially in the herbal and animal food products grown in industrial areas and regions near the city centres (França et al. 2017). Besides that, lead-containing petrol is the primary source of lead. Thus, some studies documented the correlation between Pb concentration and traffic density (Begum et al. 2017, Shahid et al. 2017). In some studies, Pb concentrations were reported to be 11,934.00 ppb in unwashed leaves of *Buxus sempervirens* (Mossi 2018), 17,900.00 ppb in leaves of *Aesculus hippocastanum* (Turkyilmaz et al. 2020), and 5,077.00 ppb in unwashed branches of *Ligustrum vulgare* (Sevik et al. 2020c). It was pointed out that Pb concentration in plants increased significantly with the traffic density (Uka et al. 2021). For instance, the Pb concentration is higher in the samples collected from polluted areas than in the control samples. Pb concentrations were 1,780, 1,750, and 1,280 ppb in the control samples of *Terminalia catappa*, *Mangifera indica*, and *Polyalthia longfolia* species, respectively, while in the samples taken from the polluted areas they reached 3,210, 3,410, 4,680 ppb, respectively (Uka et al. 2021). While the background values of Pb content in *Platanus orientalis*, *Robinia pseudoacacia* and *Ulmus minor* leaves amounted 2,700 ppb, it was determined that Pb content increased to 15,700 ppb in areas with heavy traffic and up to 18,800 ppb at Gisha bridge (Abbasi et al. 2017). Another study pointed out that the Pb concentration in the leaves of *Ficus religiosa* increased up to 14,100 ppb, and the correlation analysis pursued by the authors revealed a robust correlation between traffic density and Pb accumulation in plants (Agrahari et al. 2018). In many studies it has been confirmed that Pb concentration increases depending on traffic density (Al-Shidi et al. 2020, Juwah and Tachere 2021, Soba et al. 2021).

Although Zn investigated within the scope of the current research is an element that is necessary for living organisms, it is harmful for them at high concentrations, and its change should be monitored (Mossi, 2018). In the present study it has been shown that Zn concentration reached 63,974.00 ppb in the unwashed leaves of *Acer negundo*. In previous studies, the level of Zn was reported to reach 17,119.00 ppb in the unwashed leaves of *Ligustrum vulgare* (Mossi 2018), 31,400.00 ppb in the leaves of *Tilia tomentosa*, 50,000.00 ppb in the branches of *Aesculus hippocastanum* (Sevik et al. 2019), and 14,084.00 ppb in the leaves of *Salix babylonica* (Turkyilmaz et al. 2020). Numerous studies have also pointed out that Zn content increases in relation to traffic density. It has been stated that the Zn content in the leaves of *Araucaria heterophylla* reached 18.34 ppb in the areas with no traffic, 28.52 ppb in the places with low traffic, 42.58 ppb in the places with moderate traffic, and 60.43 ppb in heavy traffic areas (Alexandrino et al. 2020). While the Zn content of *Eucalyptus globulus* was determined as 2110, 5180, and 9,220 ppb in control, lightly polluted, and heavily polluted areas, respectively, these rates were 2,090, 9,230 and 12,210 ppb in *Ficus nitida* in the same environments (Youssef 2020). It has been determined that Zn concentration in *Nerium oleander* leaves in different seasons varies between 33– 47 million ppb in the control environment, while it varies between 55–75 million ppb in areas with traffic (Santos et al. 2019). Similarly, it has been reported in different studies that Zn concentration increases with traffic density (Uka et al. 2021). Compared with similar studies, our results show that Pb and Zn concentrations are relatively lower than in polluted areas in other regions but higher than in clean places. These results can be interpreted as the study area being less contaminated than other cities with high traffic density but still polluted.

Although trace metal elements can be emitted from diverse sources, they can penetrate plant stems from the soil or air. They can enter the plant body through the stomata on leaves, through roots or stem parts from soil (Kuzmina et al. 2023). It has been reported that the primary source of trace metals in the air is mostly caused by industrial activities and traffic (Aricak et al. 2020, Cetin et al. 2020, Koç 2021, Key and Kulac 2022). The primary sources of Pb and Zn in the study area are thought to be traffic. The studies conducted in the region emphasized that Pb and Zn concentrations in the plants were mainly caused by traffic (Sevik et al. 2020c, Cobanoglu et al. 2023).

Various studies show that trace metal concentrations in soils are high in areas with heavy traffic. For example, a study conducted in China determined that Pb concentration was 26,900 ppb in areas far from the road, 66,300 ppb in roadside soils, and 142,900 ppb in road dust. In the same region, Zn concentration was determined to be 159,000 ppb in areas far from the road, 158,600 ppb in roadside soils, and 415,700 ppb in road dust (He et al. 2023). Another study determined that while Pb concentration increased to 11,850 ppb on a highway without heavy traffic, these values could rise to 17,990 ppb on a road with heavy traffic (She et al. 2022). In another study, it was determined that Pb concentration, which was 18,600 ppb in the forest area, reached 39,500 ppb at the roadside, at the same time Zn concentration, which was 30,400 ppb in the forest area, reached 190,400 ppb at the roadside (Istanbullu et al. 2023). Similarly, it has been determined that many other trace metals are in high concentrations in soils under the influence of traffic (Akinsete and Olatimehin 2023; Bampoe et al. 2023).

One of the most critical ways trace metals enter the plant body is through roots from the soil (Kuzmina et al. 2023). However, trace metals entering the plant through its roots mostly accumulate in them and the organs of the plant located close to them, while trace metals accumulated in the end branches and leaves enter via air through stomata or direct contact (Karacocuk et al. 2022). Therefore, trace metal concentrations in soil were not evaluated in this study, considering that the effect of trace metals coming from the soil on the trace metal accumulation in the materials used in the study is quite limited. However, this has been demonstrated in various studies. For example, Butkus and Baltrénaité (2007) added industrial sewage sludge, which was determined to contain 597,000–1,421,000 ppb Pb and 383,000–538,000 ppb Zn in the soils with a concentration of 13,700 ppb Pb and 19,300 ppb Zn in the control group of soils. The concentrations of Pb and Zn in the leaves of trees grown in these soils were investigated. As a result, measured Pb concentrations in the needles of *Pinus sylvestris* and leaves of *Betula pendula*, and *Alnus glutinosa* were 2,300, 1,680, and 2,730 ppb, respectively, in the control group soils, while the Pb concentrations in the leaves of the same trees in the soils with industrial sewage sludge were 330, 650, and 970 ppb, respectively. In the needles of

Pinus sylvestris and leaves of *Betula pendula*, Zn concentrations were measured as 27,000 ppb and 214,000 ppb, respectively. In comparison, the Zn concentrations in the needles and leaves of the same trees were determined as 304,000 ppb and 101,000 ppb in the soils with industrial sewage sludge added (Butkus and Baltrénaité 2007).

In another study, Lorenc-Plucińska et al. (2013) evaluated Pb and Zn concentrations in the organs of *Alnus incana* and *Alnus glutinosa* grown in control soils with an average Pb content of 38,100 ppb and Zn content of 25,000 ppb and in soils with 490,000 ppb of Pb and 72,000 ppb of Zn. It was found that Pb concentration in the roots of *Alnus incana* individuals from different origins was between 1,470–2,190 ppb in the control soil, and 173,000–245,000 ppb in the polluted soils, while Zn concentration was between 25,400–31,000 ppb in the control soil and 57,000–69,700 ppb in the polluted soils. In *Alnus glutinosa*, Pb concentration in the roots was between 1,930–3,510 ppb in the control soils and 198,000–215,000 ppb in the polluted soils, while Zn concentration was between 31,600–34,500 ppb in the control soils, and 57,300–76,600 ppb in the polluted soils. In *Alnus incana*, Pb concentration in leaves was between 279–430 ppb in the control soils and 490–640 ppb in the polluted soils, and Zn concentration was between 21,000–3,000 ppb in the control soils, and 39,000–61,000 ppb in the polluted soils. On the other hand, in *Alnus glutinosa*, Pb concentration in leaves was between 630–920 ppb in the control soils and 790–1,230 ppb in the polluted soils, and Zn concentration was between 19,200–27,000 ppb in the control soils, 39,200–48,000 ppb in the polluted soils. Similar results were obtained for different trace metals in numerous other studies (Yanqun et al. 2004; Shin et al. 2012; Molnárová et al. 2018).

As can be seen, the trace metal concentrations in soils exert a significant influence on the trace metal concentrations in roots, while the influence of trace metal concentrations in soils on the trace metal accumulation in leaves and other organs located far from the soil is insignificant. In fact, in many studies, trace metal concentrations in various organs, especially leaves, of plants grown in areas with high soil pollution are lower than those in plants grown in unpolluted areas (Butkus and Baltrénaité 2007, Lorenc-Plucińska et al. 2013, Erdem et al. 2023). This situation is related to the chemical speciation and transfer of trace metals after they are taken into the plant body. The transfer mechanism of each trace metal within the plant may differ in different plant species (Key et al. 2022, Cobanoglu et al. 2023). In addition, the different amounts of trace metals in the environment can cause plant stress, and all stress factors, such as drought, frost, and biotic damage disrupt plant growth (Tekin et al. 2022, Tandogan et al. 2023). Since the ability of plants to absorb trace metals in the environment is related to plant metabolism, an increase in trace metal concentration in the environment may cause stress, and stress may cause a decrease in plant metabolism and even dormancy. As a result, trace metal accumulation in plants results from a complex mechanism, and studies on the accumulation, chemical speciation, and transfer of trace metals in plants, especially after trace metal entry into the plant body, are not yet sufficient (Koç 2021, Key et al. 2022, Kuzmina et al. 2023).

Conclusion and suggestion

Air pollution as one of the crucial problems nowadays is gaining more importance due to the increase in the urban population and the higher level of environmental awareness amongst people. In recent years many scientific studies have been carried out to resolve the increasing air pollution problems. One of the most essential suggestions for such solutions is to increase the number of green areas with amenities that significantly reduce air pollution. Different plant species absorb and intake air pollutants at different rates. Although many studies have been conducted on many plant species to this day, such studies are still insufficient. It can be claimed that the potential of trace metal accumulation in plants from air is not studied sufficiently. However, previous studies together with the present study showed that plant species demonstrate significant differences in trace metal accumulation. It all adds up to that the plant species which have not been examined so far should be subjected to similar studies. Moreover, the plant species that can be more efficient in trapping and, in this way, diminishing trace metals pollution of surface air should be determined. Thus, further studies are needed.

Regarding the use in urban green spaces, ornamental value of plants are generally given the primary priority in the species selection, and their functional use is of secondary importance. The selection of urban species should consider whether the plants fulfil the expected functions or not. In addition to high functional as well as ornamental values, it is also critical to identify their physiological features. For instance, the highest values of trace metals revealed in the present study were detected in *Acer negundo*, which is one of the most preferred species in landscaping and greening. As in the present study, the studies on determining the primary species with ornamental value and functionality for urban areas are vital.

In studies pursued until today, trace metal pollution levels in different organs of plants have been tried to be determined. However, as seen in the literature, it is obvious that the amount of information on this subject is quite limited, especially on the source of trace metals, which are accumulated in the plant (whether they enter the plant body from the air, soil, or another source), their migration between the organs and tissues since their entry into the plant organism. It is suggested that studies should be performed in a controlled environment to eliminate the lack of knowledge on this subject.

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