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Determining toxic metal concentration changes in landscaping plants based on some factors

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Abstract

Toxic metals are one of the most culpable air pollutants. They do not dissolve naturally. Rather, they tend to be bioaccumulative, and some of them have toxic or carcinogenic effects even at low measures. Therefore, the ability to measure and monitor toxic metal concentrations in the air is vital in fighting pollution. To achieve this, bioindicators are widely used due to their efficiency and global availability. Bioindicators are plants that accumulate some of the toxic metals found in the soil or air. This study aims to determine the differences in toxic metal concentrations depending on plant species, plant organelles, and traffic density in certain landscaping plants grown in Kastamonu town center. The results showed that the elements subjected to the study varied significantly between the different species. The highest accumulation values of such metals were obtained in cherry plum (*Prunus cerasifera*), and the lowest values of all metals were found in the European ash (*Fraxinus excelsior*). Based on our observations in this study, we determined that the most suitable species used as biomonitor is the cherry plum (*Prunus cerasifera*). We noticed that the concentrations of the metals differed significantly according to the species. The biggest difference recorded was five times more in Ni metal concentration. The concentrations of the studied elements were also varied depending on organelles and on traffic density, which will be discussed in detail in this paper.

Keywords Air quality · Air pollution · Toxic metals · Elements · Biomonitor · Landscape plant · Traffic · Ni · Cd · Zn · Organelle

Introduction

The rapid economic development, urbanization, and industrialization processes occurring around the world within the last 30 to 40 years have increased the need for energy and raw materials, and thus the applications carried out for the production of such materials have significantly disrupted the composition and quality of the atmosphere by spreading various pollutants. Lately, air pollution has become a pressing issue in many countries, especially in industrialized countries, which has had harmful health effects on millions of people around the world. In fact, around 6.5 million people a year lose their lives due to reasons related to air pollution (Shahid et al. 2017; Saleh 2018; Erdem 2018: Cetin et al. 2019; Qarri et al. 2014; Abualqumboz et al. 2017).

Toxic metals such as As, Ni, Zn, Cr, Pb, Cd, and V are mostly industrial based and carcinogenic (Shahid et al. 2015). Elements such as Pb, Cr, As, Cd, and Hg are among the most toxic metals, especially in terms of their toxicity potential and impact on living organisms (Shahid et al. 2017; Qarri et al. 2014; Abualqumboz et al. 2017; Anttila et al. 2016; Gawrońska and Bakera 2015; Dimovska et al. 2014). Studies conducted show that almost all metals can have a toxic effect at certain measures. Even micronutrients such as Mn, Zn, Cr, Cu, Fe, and Ni, which are required for living organisms including plants, can also have harmful effects at high concentrations (Niazi et al. 2011; Harguinteguy et al. 2016; Erdem 2018; Anttila et al. 2016; Gawrońska and Bakera 2015; Dimovska et al. 2014). At high concentrations, the root and shoot growth of plants slows down, the roots become thinner, young leaves curl, chlorosis is observed, cell growth and elongation are inhibited, cell organelles are degraded and chlorophyll

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synthesis is reduced, and chromosomal abnormalities and mutations are seen in culture cells (Mossi 2018). Some metals such as Hg, Cd, As, and Pb cause severe toxicity in living organisms even at low concentrations (Shahid et al. 2015; Shahid et al. 2017; Saleh 2018). Hg, Cd, As, and Pb are the most toxic heavy metals. The presence of 0.5–1.0 mg/L in As drinking water causes poisoning in humans. Taking 70–180 mg of As has a lethal effect on living things. Hg can cause acute intoxications, neurological disorders, and kidney damage. Cd affects the kidneys the most and may cause deterioration in renal function and lung and prostate cancers. Pb may cause mental retardation, chronic anemia, nerve damage, brain damage, and death (Çağlarırmak and Hepçimen 2010). For this reason, determination of toxic metal concentration in the air and monitoring its change are of great importance in determining both the risky areas and the levels of risk (El-Hasan et al. 2002; Turkyilmaz et al. 2018b; Turkyilmaz et al. 2019; Cetin et al. 2019).

Plants used as bioindicators accumulate some of the toxic metals found in the soil or air by absorbing them into their bodies, and information on the toxic metal pollution of soil and air can be obtained by determining the level of this accumulation (Shahid et al. 2017; Turkyilmaz et al. 2018a). For this reason, the leaves (Gratani et al. 2008; Anicic et al. 2011; Ozel et al. 2015; Turkyilmaz et al. 2018a), bark (Fujiwara et al. 2011; Sawidis et al. 2011), woods (Gao et al. 2015; Turkyilmaz et al. 2018d), and fruits (Erdem 2018) of high-structured plants are used as biomonitors.

Material and method

Sampling

The study was conducted in the Kastamonu town center, Turkey. The Kastamonu town center was built in a valley area, and it is where the traffic is the densest. Within the scope of the study, the samples were collected from areas with high-density traffic, low-density traffic, areas with almost no traffic, and areas with no roadway within a radius of 50 m.

The high-density traffic area has a 4-lane highway with 2 lanes on each side. In this area, there is generally an intense traffic during the day. The areas with low-density traffic are en route to the main road but outside the town center. Taskopru and Inebolu routes are determined as areas with low-density traffic. There is a two-lane road in this area, the traffic is flowing and the traffic density is quite low compared with that in the town center. Kastamonu University campus area was selected as the area with no traffic, and the points, where there was no roadway found within 50-m vicinity, were selected from the campus area, and samples were collected from those locations (Fig. 1).

Samples were collected from cherry plum (*Prunus ceracifera*), horse chestnut (*Aesculus hippocastanum*), tilia *(Tilia tomentosa)*, European ash (*Fraxinus excelsior*), and Norway maple (*Acer platanoides*) plant species, which are often used in landscaping works. The samples were taken from last year's shoots, namely the one-year-old parts. Seeds of horse chestnut were used as seeds, whereas the seeds of Tilia, European ash, and Norway maple were used together with their coat and wings. However, the fruit flesh of cherry plum was used together with the peel. The samples were collected at the end of August, the end of vegetation season of 2017, and were brought to the lab after being packed and labeled.

Method

The samples in the lab were separated by being laid on the cardboards. The leaves, branches, and seeds were separated and grouped. Then the branches were broken to enable them to dry thoroughly, and the seeds were crushed using marble pieces; no metal tool was used during this process. The prepared samples were placed in glass plates and relabeled. The plum fruits were separated from the seed and were taken into glass settle plates and labeled. The samples prepared in this way were kept out for 15 days to ensure they are completely dried, and the laboratory was ventilated every day throughout this process. The air-dried samples were then dried further in a drying oven at 45 °C for a week.

Next, the plant samples were pulverized into powder with each weighing 0.5 g. Powdered samples were placed in tubes designed for a microwave. A volume of 10 mL of 65% HNO_3 was added onto the samples. Fume cupboard was used during this process. The prepared samples were then burned at 180 °C and under 280 PSI in the microwave device for a period of 20 min. The tubes were removed from the microwave after the process was completed and were left to cool down. The cooled samples were filled in until they reached 50 mL by adding deionized water. The prepared samples were read on the ICP-OES device at proper wavelengths after being filtered through the filter paper.

The data obtained were analyzed by using SPSS package program, and variance analysis was applied to the data. Homogeneous groups were obtained by applying Duncan's test to the values with differences at 95% of confidence level, statistically. The data obtained were interpreted after being simplified and tabulated. Whole processing of research methodology is shown in Fig. 2 with a flow chart.

Findings

Change of Ni concentration depending on traffic density

Change in Ni concentration was determined for each organelle separately in the areas with no traffic, with low-density traffic,

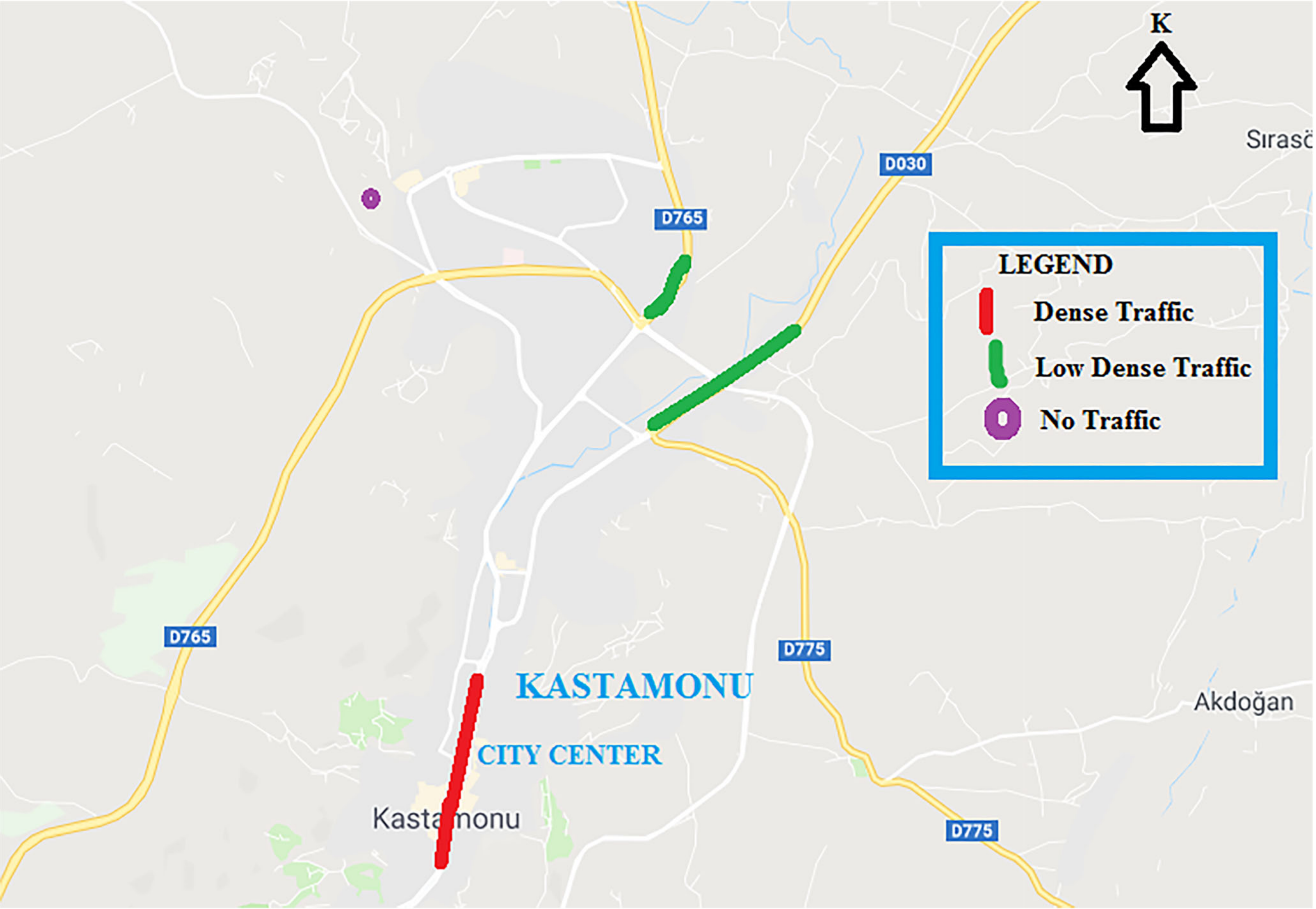

Fig. 1 The samples were collected in areas with no traffic, high-density traffic, and low-density traffic Figures 1 and 2 contains poor quality of text inside the artwork. Please do not re-use the file that we have rejected or attempt to increase its resolution and re-save. It is originally poor, therefore, increasing the resolution will not solve the quality problem. We suggest that you provide us the original format. We prefer replacement figures containing vector/editable objects rather than embedded images. Preferred file formats are eps, ai, tiff and pdf.Revised and uploaded Fig 1 and Fig 2 as you asked.

and with very dense traffic. Afterwards, the mean values, *F* value, and significance level were obtained as a result of the variance analysis and homogeneous groups formed as a result of Duncan's test are given in Table 1.

From our findings Table 1, it is observed that according to the results of the variance analysis, the change in Ni concentration in all organelles except the Tilia branches is statistically significant at minimum 95% confidence level. When the mean values and the groupings, which are formed as a result of the Duncan test, are examined in all organelles, it is determined that the data obtained in the areas with no traffic are in the first homogenous group, while the data obtained in the areas with dense traffic are in the last one. Therefore, it can be said that the Ni concentration correlatively increases with traffic density.

When the values were examined, significant differences were observed between the areas with no traffic and the areas with dense traffic in the same organelles as well as between both different organelles of the same species and the same organelles of different species. For example, while the Ni concentration in Norway maple seeds in the areas with no traffic is 370.3 ppb, it is seen that this concentration increases up to 20595 ppb in areas with dense traffic. Thus, the value obtained in areas with dense traffic is more than 55 times the value obtained in the areas with no traffic. Similarly, the value obtained in the leaves of the horse chestnut in the areas with dense traffic is about 107 times the value obtained in the seeds of the same species in the same region; and the value obtained in the seeds of the cherry plum in the areas with dense traffic is about 105 times the value obtained in the seeds of the horse chestnut in the areas with the dense traffic. These results show that the Ni concentration significantly changes in terms of traffic density, species, and organelle.

Change of Cd concentration depending on traffic density

Changes in the Cd concentration were determined for study samples in the areas with no traffic, with low-density traffic,

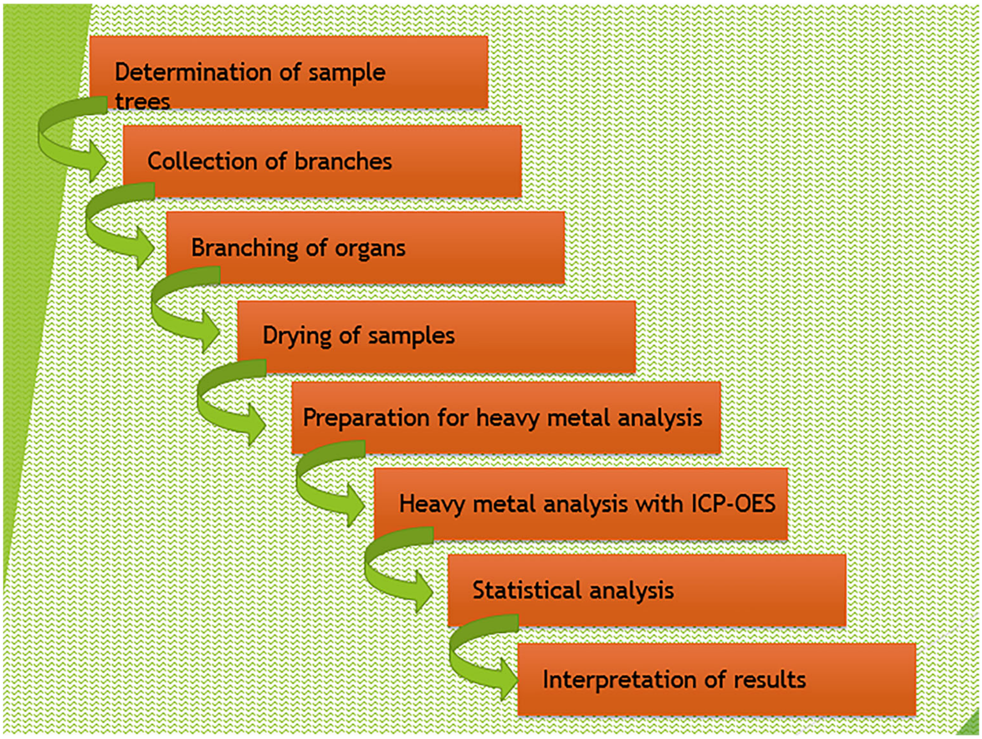

Fig. 2 Flowchart for showing the research methodology

and with very dense traffic. Afterwards, variance analysis and Duncan's test were applied to the data obtained. The mean values obtained, *F* value, and significance level obtained as a result of the variance analysis and the homogeneous groups formed as a result of Duncan's test are given in Table 2.

As a result of the variance analysis, it is determined that the change in Cd concentration depending on traffic density in all organelles is statistically significant at minimum 95% confidence level. When the mean values and Duncan test results are examined, it is seen that the values obtained in the areas with

Table 1 Concentrations of Ni (ppb) in plants and organelles in different vehicle flow paths

Species	Organelle	Traffic density			*F* value
		No traffic	Low-density traffic	Dense traffic	
Cherry plum	Leaves	1226.3^a	1837.2^b	2875.8^c	3813.411***
	Seed	4952.0^a	7284.6^a	36211.3^b	47.296***
	Branch	532.6^a	822.6^b	992.6^c	126.336***
Horse chestnut	Leaves	923.6^a	1656.3^b	36845.6^c	48,454.272***
	Seed	52.6^a	159.3^b	344.0^c	27.709**
	Branch	219.3^a	599.3^b	4211.3^c	2592.909***
Tilia	Leaves	407.0^a	875.3^b	1299.9^c	458.073***
	Seed	138.7^a	298.6^b	443.7^c	82.979***
	Branch	26.6	143.6	138.0	1.693 ns
European ash	Leaves	1504.8^a	2316.0^b	3519.2^c	4621.409***
	Seed	399.6^a	452.3^b	504.9^c	16.000**
	Branch	196.0^a	386.3^b	1670.0^c	323.996***
Norway maple	Leaves	93.6^a	193.0^b	1050.6^c	515.117***
	Seed	370.3^a	676.6^b	20595.0^c	624,168.577***
	Branch	760.0^a	811.0^a	10694.6^b	8546.413***

**significant at 0.01 level

***significant at 0.001 level

The letters a, b, and c mean according to Duncan's test results show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a numerical value grows

Table 2 Concentrations of Cd (ppb) in plants and organelles in different vehicle flow paths

Species	Organelle	Traffic density			*F* value
		No traffic	Low-density traffic	Dense traffic	
Cherry plum	Leaves	17.0^{a}	25.4^{b}	29.9^{c}	67.901***
	Seed	87.0^{a}	130.3^{ab}	168.6^{b}	10.279*
	Branch	45.6^{a}	53.6^{a}	328.0^{b}	4778.473***
Horse chestnut	Leaves	43.0^{a}	71.0^{b}	78.6^{c}	500.895***
	Seed	0.3^{a}	5.3^{b}	17.6^{c}	39.796***
	Branch	6.6^{a}	17.0^{b}	65.0^{c}	253.990***
Tilia	Leaves	34.4^{a}	37.6^{a}	82.3^{b}	274.467***
	Seed	70.0^{a}	76.6^{a}	167.5^{b}	122.466***
	Branch	44.0^{b}	56.0^{c}	23.6^{a}	98.808***
European ash	Leaves	23.3^{b}	19.9^{a}	52.1^{c}	583.003***
	Seed	7.4^{a}	10.9^{ab}	14.3^{b}	8.343*
	Branch	11.6^{a}	10.6^{a}	51.6^{b}	102.562***
Norway maple	Leaves	58.0^{a}	151.6^{b}	228.6^{c}	184.330***
	Seed	26.6^{a}	40.3^{b}	65.3^{c}	119.322***
	Branch	47.0^{a}	74.0^{b}	107.3^{c}	31.944**

*significant at 0.05 level

**significant at 0.01 level

***significant at 0.001 level

The letters a, b, and c means according to Duncan's test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a numerical value grows

no traffic in all organelles, except the Tilia seeds and European ash leaves, are in the first homogeneous group according to the Duncan test results. Whereas the values obtained in these organelles in the areas with dense traffic are included in the last homogenous groups according to the Duncan test results. After all, it can be said that Cd concentration also correlatively increases with traffic density.

When the changes of Cd concentration are examined, it is observed that it changes between 0.3 and 87 ppb in the areas with no traffic, between 5.3 and 151.6 ppb in the areas with low-density traffic, and between14.3 and 328 ppb in the areas with dense traffic. In general, the Cd concentration in areas with dense traffic is several times higher than the Cd concentration in areas with no traffic.

Change of Zn concentration depending on traffic density

Changes in Zn concentration were determined for study samples in the areas with no traffic, with low-density traffic, and with very dense traffic. Afterwards, variance analysis and Duncan's test were applied to the data obtained. The mean values obtained, *F* value, and significance level obtained as a result of variance analysis and the homogeneous groups formed as a result of Duncan test are given in Table 3.

According to the variance analysis results regarding the change of Zn concentration based on traffic density on the subject organelles, the change of Zn concentration in all organelles is statistically significant at 99.9% confidence level. According to the results of Duncan test, 3 homogeneous groups are formed in all of the 15 organelles, and while the areas with no traffic are in the first homogeneous group in 9 of the 15 organelles, the areas with dense traffic are in the last homogeneous group in 10 of the organelles.

While Zn concentration in areas with no traffic changes between 0.5 and 34.5 ppm, Zn concentration in areas with low traffic density changes between 2.0 and 44.2 ppm, and Zn concentration in areas with dense traffic changes between 0.6 and 131.6 ppm; the highest value is found as 50.0 ppm except the value of 131.6 ppm obtained from the cherry plum seeds in areas with dense traffic. According to these results, it can be said that the change of Zn concentration depending on traffic density is not as significant as other metals.

Result and discussion

The study results showed that the subject elements changed significantly on the basis of species. While the highest values in all the metals were obtained from the cherry plum, European ash was determined to be included in the first homogenous group regarding all metals. It was determined that the metal concentrations significantly differed based on the

Table 3 Concentrations of Zn (ppm) in plants and organelles in different vehicle flow paths

Species	Organelle	Traffic density			*F* value
		No traffic	Low-density traffic	Dense traffic	
Cherry plum	Leaves	9.9^{c}	2.0^{b}	0.6^{a}	22,629.000***
	Seed	9.3^{a}	15.6^{b}	131.6^{c}	1940.561***
	Branch	16.6^{a}	29.4^{b}	43.1^{c}	36,295.923***
Horse chestnut	Leaves	21.1^{b}	14.1^{a}	26.5^{c}	2610.325***
	Seed	0.5^{a}	4.8^{c}	3.4^{b}	1677.875***
	Branch	6.6^{a}	37.0^{b}	50.0^{c}	47,961.143***
Tilia	Leaves	4.9^{a}	18.8^{b}	31.4^{c}	118,609.750***
	Seed	6.3^{a}	24.4^{b}	40.7^{c}	44,329.056***
	Branch	34.5^{b}	44.2^{c}	16.5^{a}	44,451.750***
European ash	Leaves	10.7^{a}	13.3^{b}	31.4^{c}	42,707.625***
	Seed	8.8^{a}	14.0^{b}	19.1^{c}	10,098.143***
	Branch	16.7^{a}	27.2^{b}	43.1^{c}	79,501.500***
Norway maple	Leaves	19.2^{b}	7.7^{a}	27.3^{c}	18,655.929***
	Seed	24.6^{c}	17.9^{b}	17.0^{a}	4698.700***
	Branch	19.7^{b}	28.6^{c}	16.4^{a}	4689.696***

***significant at 0.001 level. The letters a, b, and c means according to Duncan's test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a numerical value grows

species, and this difference in Ni was found to be more than five times between the species.

In the studies conducted to date, the toxic metal concentrations changed significantly based on the species. In a study carried out by Mossi (2018), he states that the difference between species is approximately twice as much in Cd, which has toxic effects even at low doses, approximately 2.7 times in carcinogenic elements such as Ni and Cr, and more than 5 times in elements with toxic effects such as Cu. Saleh (2018) states that the difference between species is more than 5 times in Cu and even more than 24 times in Cd. In many studies conducted, it is found that toxic metal concentrations change significantly on the basis of species, which means that different toxic metals are retained by different plants more intensely (Turkyilmaz et al. 2018a, 2018c; Sevik et al. 2019; Cetin et al. 2019).

This situation is primarily associated with the anatomical structure of the plant (Mossi 2018; Saleh 2018). The toxic metal intake capability of the leaves varies depending on some factors such as the physical and chemical properties of the metals, their forms, morphology of the leaves, surface area, plant habitus next to the surface texture, toxic metals exposure time, environmental conditions, and gas exchange (Beckett et al. 2000; Shahid et al. 2017; Turkyilmaz et al. 2018a, 2018c; Sevik et al. 2019; Cetin et al. 2019; Mossi 2018).

We found that toxic metal concentrations could change significantly on organelle basis. However, one of the important results of the study was that the concentrations of toxic metals were different in organelles in terms of species. For example, while Ni concentration was obtained the highest in the seed of the cherry plum, it was obtained in the leaves of horse chestnut, Tilia, and European ash, and no statistically significant difference was found between the organelles in the Norway maple at minimum 95% confidence level.

The change of toxic metal concentrations based on organelles became the subject of many studies as well. Mossi (2018) found organelle differences between the leaf and branch organelles, while Turkyilmaz et al. (2018d) and Turkyilmaz et al. (2019) found it between bark and wood organelles; Erdem (2018) and Sevik et al. (2019) between leaf, seed, and branch organelles; and Elfantazi et al. (2018a, 2018b) between the leaf and branch organelles. In these studies, the toxic metal concentrations were found to be changing significantly on organelle basis.

As a result of the study, we deduced that there was a significant change in the concentration of the toxic metals according to the traffic density and on the basis of organelle; and in general, the concentration of Ni was determined to be increasing in all organelles of all species, while the concentrations of Cd and Zn were found to be increasing in most of the organelles depending on traffic density.

This result is also consistent with the literature in general. Industrial and traffic activities are considered to be the most important causes of toxic metal pollution

(Martley et al. 2004; Shahid et al. 2017; Erdem 2018). In many studies conducted, toxic metal concentrations in plant organelles are determined to be changing significantly depending on traffic density (Assirey et al. 2015; Galal and Shehata 2015; Saleh 2018; Turkyilmaz et al. 2018a, 2018b; Mossi 2018; Sevik et al. 2019; Cetin et al. 2019).

Accumulation of toxic metals within the body of plants is closely related to the environmental conditions. Toxic metals can be transported far from their sources with the help of the wind. Apart from this, environmental conditions directly affect the plant metabolism and the entry of toxic metals into the plant structure differentiates within this process. In addition, it is stated that there is a significant relationship between the entrance of toxic metals into the plant body and the air humidity and precipitation in particular (Uzu et al. 2009; Schreck et al. 2011; Shahid et al. 2017; Mossi 2018; Turkyilmaz et al. 2018c, 2018d: Turkyilmaz et al. 2019).

There are also some factors that are likely to affect the toxic metal concentrations. For instance, the changes of toxic metal concentrations depending on the plant species are presented in both this study and other studies (Sevik et al. 2019; Cetin et al. 2019; Saleh 2018; Erdem 2018). However, toxic metal concentrations may be expected to be at different levels in the sub-species, forms, varieties, and plant origins. Likewise, the studies conducted show that many phonological, morphological, and anatomical structures change in relation with these properties. In this case, it is inevitable for the plant metabolism to change and for this situation to affect toxic metal absorption (Speak et al. 2012; Cetin 2016a, 2016b, 2016c; Cetin and Sevik 2016a, 2016b; Cetin et al. 2017; Mossi 2018; Cetin 2017; Cetin et al. 2018).

The toxic metal absorption in plants is closely associated with plant metabolism (Speak et al. 2012; Shahid et al. 2017). Therefore, it is possible that many factors, which significantly affect the plant metabolism, such as the stress level of the plant (Sevik and Cetin 2015; Cetin and Sevik 2016a, 2016b; Cetin et al. 2017: Cetin et al. 2019), plant origin (Cetin et al. 2018), chlorophyll content (Cetin 2016a, 2016b, 2016c; Cetin 2017), and genetic structure (Yigit et al. 2016; Hrivnák et al. 2017) affect toxic metal absorption in plants and hence toxic metal concentration. As a result, the change of toxic metal concentration in plants is the result of a complex mechanism related to the interaction of many factors (Mossi 2018). However, the studies are not sufficiently conclusive yet to allow a complete understanding of this mechanism, and thus to clearly reveal the factors affecting the change of toxic metal concentration. For this reason, studies regarding this subject should be continued and diversified.

Recommendations

Air pollution is one of the most important problems of today's world. Air pollution has gained a particular importance with the increase in the consciousness level in this field along with the population density in city centers, and many studies have been carried out to solve this important problem. Increasing green spaces is considered one of the most effective methods among the solution proposals, for as much plants can reduce air pollution significantly.

However, the impacts of different species on different pollution factors are also at different levels. Although a large number of plant species have been the subject of studies to date, these studies are not at a sufficient level yet. There is no information on the toxic metal accumulation potentials of many plant species. In fact, great differences are determined between the toxic metal accumulation potentials of plant species in many other studies as well as this study. For this reason, it is necessary to use the species, which have not been subjected to any study, in similar studies and to identify the plants, which are to be more effective in both monitoring and reducing the toxic metal pollution. Therefore, we encourage the continuation the diversification of similar studies.

The research findings show that traffic density causes significant heavy metal pollution and also shows that *Prunus ceracifera* is the most suitable type for monitoring toxic metal concentrations. It also opens doors for future researches that might identify potential plants for different types of pollutions.

The ultimate aim of the research is to tackle pollution. We argue that the methods implemented in testing could lay the foundations for better measures in addressing pollution the right way and thus reducing its devastating effects as much as possible.

In the selection of landscaping plants used for city centers, their visual qualities are prioritized over their functional uses. However, in order for plants to be used in a functional manner, first of all, it is necessary to determine which plant is more effective in performing the desired function, and the selection of the species should be made accordingly. However, determination of plants, which are functional and have the visual quality, are of particular importance. For instance, in this study, the highest values of all the metals subjected to the study were obtained from cherry plum. Cherry plum is also one of the species that have visual quality and are mostly preferred in landscape activities. Thus, it is of great importance to carry out similar studies with the purpose of identifying the species, which are both functional and have high visual and esthetic quality and to determine the primary species.

References

Abualqumboz MS, Mohammed NI, Malakahmad A, Nazif AN (2017) Investigating indoor concentrations of PM 10 in an underground loading dock in Malaysia. Air Qual Atmos Health 10(2):147–159. https://doi.org/10.1007/s11869-016-0413-4

Anicic M, Spasic T, Tomasevic M, Rajsic S, Tasic M (2011) Trace elements accumulation and temporal trends in leaves of urban deciduous trees (Aesculus hippocastanum and Tilia ssp.). Ecol Indic 11(3): 824–830 https://www.sciencedirect.com/science/article/pii/S1470160X10001937

Anttila P, Stefanovska A, Nestorovska-Krsteska A, Grozdanovski L, Atanasov I, Golubov N, Ristevski P, Toceva M, Lappi S, Walden J (2016) Characterisation of extreme air pollution episodes in an urban valley in the Balkan Peninsula. Air Qual Atmos Health 9(2): 129–141. https://doi.org/10.1007/s11869-015-0326-7

Assire E, Al-Qodah Z, Al-Ahmadi M (2015) Impact of traffic density on roadside pollution by some heavy metal ions in Madinah city, Kingdom of Saudi Arabia. Asian J Chem 27(10):3770–3776 https://www.researchgate.net/publication/274193667_Impact_of_Traffic_Density_on_Roadside_pollution_by_Some_Heavy_metal_Ions_in_Madinah_City_KSA

Beckett KP, Freer-Smith PH, Taylor G (2000) The capture of particulate pollution by trees at five contrasting urban sites. Arboric J 24(2–3): 209–230. https://doi.org/10.1080/03071375.2000.9747273

Çağlarırmak N, Hepçimen A (2010) Effect of heavy metal soil pollution on food chain and human health. Akademik Gıda 8(2):31–35 http://www.academicfoodjournal.com/archive/2010/2/31-35.pdf

Cetin M (2016a) A change in the amount of CO_2 at the center of the examination halls: case study of Turkey. Studies on Ethno-Medicine 10(2):146–155. https://doi.org/10.1080/09735070.2016.11905483

Cetin M (2016b) Changes in the amount of chlorophyll in some plants of landscape studies. Kastamonu U J Forestry Fac16(1):239–245 https://www.researchgate.net/publication/319242469_Changes_in_the_Amount_of_Chlorophyll_in_Some_Plants_of_Landscape_Studies

Cetin M (2016c) Determination of bioclimatic comfort areas in landscape planning: a case study of Cide Coastline. Turkish J Agric Food Sci Technol 4(9):800–804 http://www.agrifoodscience.com/index.php/TURJAF/article/view/872/374

Cetin M (2017) Change in amount of chlorophyll in some interior ornamental plants. Kastamonu Univ J Eng Sci 3(1):11–19 https://dergipark.org.tr/download/issue-file/5600

Cetin M, Sevik H (2016a) Measuring the impact of selected plants on indoor CO_2 concentrations. Pol J Environ Stud 25(3):973–979 http://www.pjoes.com/Measuring-the-Impact-of-Selected-Plants-on-Indoor-CO2-Concentrations,61744,0,2.html

Cetin M, Sevik H (2016b) Change of air quality in Kastamonu city in terms of particulate matter and CO_2 amount. Oxid Commun 39(4-II):3394–3401

Cetin M, Sevik H, Saat A (2017) Indoor air quality: the samples of Safranbolu Bulak Mencilis cave. Fresenius Environ Bull 26(10): 5965–5970

Cetin M, Sevik H, Yigit N, Ozel HB, Aricak B, Varol T (2018) The variable of leaf micromorphogical characters on grown in distinct climate conditions in some landscape plants. Fresenius Environ Bull 27(5):3206–3211

Cetin M, Onac AK, Sevik H, Sen B (2019) Temporal and regional change of some air pollution parameters in Bursa. Air Qual Atmos Health 12(3):311–316. https://doi.org/10.1007/s11869-018-00657-6

Dimovska B, Šajn R, Stafilov T, Bačeva K, Tănăselia C (2014) Determination of atmospheric pollution around the thermoelectric power plant using a moss biomonitoring. Air Qual Atmos Health 7(4):541–557. https://doi.org/10.1007/s11869-014-0257-8

Elfantazi MFM, Aricak B, Baba FAM (2018a) Changes in concentration of some heavy metals in leaves and branches of Acer pseudoplatanus due to traffic density. Int J Trend Res Dev 5(2): 704–707

Elfantazi MFM, Aricak B, Ozer Genc C (2018b) Concentrations in Morus alba L. leaves and branches due to traffic density. Int J Curr Res 10(05):68904–68907

El-Hasan T, Al-Omari H, Jiries A, Al-Nasir F (2002) Cyprees tree (Cupressus semervirens L.) bark as an indicator for heavy metal pollution in the atmosphere of Amman City, Jordan. Environ Int 28(6):513–519 https://www.sciencedirect.com/science/article/pii/S016041200200079X?via%3Dihub

Erdem T (2018) Variation of heavy metal concentrations due to species, organelles and traffic density in some plants, Kastamonu University, Graduate School of Natural and Applied Sciences, Department of Forest Engineering, M.Sc. Thesis

Fujiwara FG, Gómez DR, Dawidowski L, Perelman P, Faggi A (2011) Metals associated with airborne particulate matter in road dust and tree bark collected in a megacity (Buenos Aires, Argentina). Ecol Indic 11(2):240–247 https://www.sciencedirect.com/science/article/pii/S1470160X10000774

Galal TM, Shehata HS (2015) Bioaccumulation and translocation of heavy metals by Plantago major L. grown in contaminated soils under the effect of traffic pollution. Ecol Indic 48:244–251 https://www.sciencedirect.com/science/article/pii/S1470160X14003689

Gao W, Jiang W, Xiong T, Sun S, Gao R (2015) The sources apportionment of heavy metal pollution base on tree ring in Jinan. In: Intelligent computation technology and automation (ICICTA), 2015 8th International Conference on pp. IEEE, pp 1040–1043

Gawrońska H, Bakera B (2015) Phytoremediation of particulate matter from indoor air by Chlorophytum comosum L. plants. Air Qual Atmos Health 8(3):265–272. https://doi.org/10.1007/s11869-014-0285-4

Gratani L, Crescente MF, Varone L (2008) Long-term monitoring of metal pollution by urban trees. Atmos Environ 42(35):8273–8277 https://www.sciencedirect.com/science/article/pii/S1352231008006791

Harguinteguy CA, Cofré MN, Fernández-Cirelli A, Pignata ML (2016) The macrophytes Potamogeton pusillus L. and Myriophyllum aquaticum Vell. Verdc. as potential bioindicators of a river contaminated by heavy metals. Microchem J 124:228–234 https://www.sciencedirect.com/science/article/pii/S0026265X15001861

Hrivnák M, Paule L, Krajmerová D, Kulac S, Sevik H, Turna I, Tvauri I, Gömöry D (2017) Genetic variation in tertiary relics: the case of eastern-Mediterranean Abies (Pinaceae). Ecol Evol 7(23):10018–10030 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5723589/

Martley E, Gulson BL, Pfeifer HR (2004) Metal concentrations in soils around the copper smelter and surrounding industrial complex of Port Kembla, NSW. Australia. Sci Total Environ 325(11):113–127 https://www.sciencedirect.com/science/article/pii/S004896970300665X?via%3Dihub

Mossi MMM (2018) Determination of heavy metal accumulation in some shrub formed landscape plants, Kastamonu University Institute of Science Department of Forest Engineering, PhD Thesis

Niazi NK, Bishop TF, Singh B (2011) Evaluation of spatial variability of soil arsenic adjacent to a disused cattle-dip site, using model-based geostatistics. Environ Sci Technol 45(24):10463–10470. https://doi.org/10.1021/es201726c

Ozel HB, Ozel HU, Varol T (2015) Using leaves of oriental plane (Platanus orientalis L.) to determine the effects of heavy metal pollution caused by vehicles. Pol J Environ Stud 24(6):2569–2575 http://www.pjoes.com/Using-Leaves-of-Oriental-Plane-Platanus-orientalis-L-to-Determine-the-Effects-of-Heavy-Metal-Pollution-Caused-by-Vehicles,59072,0,2.html

Qarri F, Lazo P, Stafilov T, Bekteshi L, Baceva K, Marka J (2014) Survey of atmospheric deposition of Al, Cr, Fe, Ni, V, and Zn in Albania by using moss biomonitoring and ICP-AES. Air Qual Atmos Health 7(3):297–307. https://doi.org/10.1007/s11869-014-0237-z

Saleh EAA (2018) Determination of heavy metal accumulation in some landscape plants, Kastamonu University, Institute of Science, Department of Forest Engineering, Ph.D. Thesis

Sawidis T, Breuste J, Mitrovic M, Pavlovic P, Tsigaridas K (2011) Trees as bioindicator of heavy metal pollution in three European cities. Environ Pollut 159(12):3560–3570 https://www.sciencedirect.com/science/article/pii/S0269749111004386

Schreck E, Foucault Y, Geret F, Pradere P, Dumat C (2011) Influence of soil ageing on bioavailability and ecotoxicity of lead carried by process waste metallic ultrafine particles. Chemosphere 85(10):1555–1562 https://www.sciencedirect.com/science/article/pii/S004565351100912X?via%3Dihub

Sevik H, Cetin M (2015) Effects of water stress on seed germination for select landscape plants. Pol J Environ Stud 24(2):689–693 http://www.pjoes.com/Effects-of-Water-Stress-on-Seed-Germination-for-Select-Landscape-Plants,50860,0,2.html

Sevik H, Ozel HB, Cetin M, Özel HU, Erdem T (2019) Determination of changes in heavy metal accumulation depending on plant species, plant organism, and traffic density in some landscape plants. Air Qual Atmos Health 12(2):189–195. https://doi.org/10.1007/s11869-018-0641-x

Shahid M, Khalid S, Abbas G, Shahid N, Nadeem M, Sabir M, Aslam M, Dumat C (2015) Heavy metal stress and crop productivity. In: Hakeem KR (ed) Crop production and global environmental issues SE − 1. Springer International Publishing, pp 1–25

Shahid M, Dumat C, Khalida S, Schreck E, Xiong T, Nabeel NK (2017) Foliar heavy metal uptake, toxicity and detoxification in plants: a comparison of foliar and root metal uptake. J Hazard Mater 325:36–58 https://www.sciencedirect.com/science/article/pii/S0304389416310937

Speak AF, Rothwell JJ, Lindley SJ, Smith CL (2012) Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atmos Environ 61(2012):283–293 https://www.sciencedirect.com/science/article/pii/S1352231012007157

Turkyilmaz A, Sevik H, Cetin M (2018a) The use of perennial needles as bio-monitors for recently accumulated heavy metals. Landsc Ecol Eng 14(1):115–120. https://doi.org/10.1007/s10661-018-6956-0

Turkyilmaz A, Cetin M, Sevik H, Isinkaralar K, Saleh EAA (2018b) Variation of heavy metal accumulation in certain landscaping plants due to traffic density. Environ Dev Sustain:1–14. https://doi.org/10.1007/s10668-018-0296-7

Turkyilmaz A, Sevik H, Cetin M, Ahmaida Saleh EA (2018c) Changes in heavy metal accumulation depending on traffic density in some landscape plants. Pol J Environ Stud 27(5):2277–2284 http://www.pjoes.com/Changes-in-Heavy-Metal-Accumulation-Depending-non-Traffic-Density-in-Some-Landscape,78620,0,2.html

Turkyilmaz A, Sevik H, Isinkaralar K, Cetin M (2018d) Using Acer platanoides annual rings to monitor the amount of heavy metals accumulated in air. Environ Monit Assess 190(10):578. 10.1007%2Fs10661-018-6956-0

Turkyilmaz A, Sevik H, Isinkaralar K, Cetin M (2019) Use of tree rings as a bioindicator to observe atmospheric heavy metal deposition. Environ Sci Pollut Res 26(5):5122–5130. https://doi.org/10.1007/s11356-018-3962-2

Uzu G, Sobanska S, Aliouane Y, Pradere P, Dumat C (2009) Study of lead phytoavailability for atmospheric industrial micronic and sub-micronic particles in relation with lead speciation. Environ Pollut 157(4):1178–1185 https://www.sciencedirect.com/science/article/pii/S0269749108004995?via%3Dihub

Yigit N, Sevik H, Cetin M, Gul L (2016) Clonal variation in chemical wood characteristics in Hanönü (Kastamonu) Günlüburun black pine (Pinus nigra Arnold. subsp. pallasiana (Lamb.) Holmboe) seed orchard. J Sustain Forest 35(7):515–526. https://doi.org/10.1080/10549811.2016.1225512