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Using *Acer platanoides* annual rings to monitor the amount of heavy metals accumulated in air

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Abstract Annual rings are good indicators for determining the increase in the amount of heavy metals in the atmosphere from past to the present. Air pollution has rapidly increased in Ankara over the past 20 years. In particular, there is a serious increase in the concentration of heavy metals that adversely affect human health. In this study, the accumulation of Al, Zn, Cu, Co, Fe, Mn, Cr, Cd, Na, Ca, Ba, P, Mg, As, and B on *Acer platanoides* rings has been determined using the GBC Integra XL-SDS-270 ICP-OES instrument. Based on our experimental findings, we determined that the concentration of heavy metals accumulated on the rings over the past 20 years varied and that there was a significant correlation between heavy metal concentration in air and heavy metal accumulation on trees. The main reasons for this increase were an increase in the amount of exhaust emission gases and most importantly the transport of heavy metals by the prevailing winds from heavy industrial plants established after 1990 in Ankara. As a result, when the values were examined, we found that except for Na, all the elements, which showed differences at statistically significant levels, were in considerably high quantities in the bark. On average, the values obtained for bark were 6 times higher than those obtained for wood. In terms of elements that showed statistically significant level of differences, this difference was the lowest in P (1.61 times higher), Mg (2.52 times higher), and B (3.94 times higher) and the highest in Mn (23.87 times higher), Al (22.0 times higher), and Fe (14.27 times higher). In the case of Na, we found that the value obtained for wood was 1.64 times higher than that obtained for bark.

Keywords Air pollution · Annual rings · Heavy metal · Bioindicator

Introduction

Today's rapidly increasing usage of natural resources and the release of the waste generated by humans into the atmosphere and the environment has caused adverse effects on the environment and human health. In particular, pollution sources, e.g., industrial activities, fossil fuels used for heating purposes, and exhaust emission gases from vehicle traffic, are the most important pollutants of air, soil, and water that are necessary for the survival of the living beings. The emission of toxic substances into the environment is spreading, particularly from industrialized countries. Heavy metals are released into the atmosphere because of the presence of large number of industrial facilities and heavy traffic (Onder and Dursun 2006). These pollution sources have also increased rapidly over the past two decades in parallel with population increase in cities. Therefore,

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since the 2000s, a rapid increase has been observed in important illnesses, e.g., pulmonary diseases and heart diseases. Also, recycled plastic composes no hurtful emissions while it is being manufactured or while it is being used by the consumer. Plastic spills no toxic chemicals into the water or soil and recycling diminishes pollution. While recycling plastic, it helps to create eco-friendly products and prevents from putting tons of waste into our landfills. Since the use of plastics is increasing, the new method is considering a solution like recycling. One of methods is that some of the plastics get mixed in the other materials for recycling; the recycled plastic then becomes valuable. Whole plastic material can be used as a binder in the recycling of permeable pavements, which has also been an improvement. Along with that, the pollution of materials are effective in the plants during urban cities (Brooks and Cetin 2012; Cetin 2013a, b, 2015a, b).

Trace elements, particularly heavy metals, cause genotoxic effects, cancer, and damage to immune system and neurological system (Moreira et al. 2016). The most important reason for the increase in the occurrence of these diseases is the increase in heavy metal pollution in the atmosphere. The history of the past 200 years of pollution in Beijing, China, has been determined from the tree rings, and the diversity of elements in the tree rings has been found to be closely related to the industrial development in Shenyang. In particular, in Jinan, coal, iron, steel melting, and exhaust emission gases are major factors causing heavy metal pollution (Liu et al. 2018). Industrial plants and monitoring of air pollution in cities are considerably important for determining the effect of pollution on the past environmental systems. However, air pollution monitoring stations were established in the 1980s. Hence, historical pollution can only be determined for a considerably short period of the past (Perone et al. 2018). The most reliable source for determining the increase in heavy metal air pollution is tree rings from past to the present.

Tree rings can be used as indicators of pollution events that affect the environment in which trees grow. At the same, these indicators provide information about chronology and element composition of pollution (Beramendi-Orosco et al. 2013). Since the 1960s, due to the fact that the increase in the number of layers in many tree species is stable, many researchers have used annual rings for the analysis of heavy metal composites (Medeiros et al. 2008). Low concentrations of heavy metals are necessary for the continuation of life. However, concentrations of heavy metals present in the waste generated by humans are increasing in air, soil, and water. Therefore, the level of intake of heavy metals by humans and plants exceeds the required amount for the continuation of life and leads to health problems. Low concentrations of copper, iron, manganese, and zinc are necessary for the physiological activities of plants. However, the effects of arsenic, cadmium, and lead on the development of plants are unknown. Heavy metal accumulation in plants varies according to plant species and element types (Arévalo-Gardini et al. 2017).

Heavy metals provide important information about the concentration of air pollution by accumulating in different organelles of plants. Therefore, in the process of indirectly determining heavy metal pollution caused because of the waste generated by humans over time, trees show the course of heavy metal concentration increase in air, especially in areas with heavy traffic, by accumulating heavy metals generated as a result of exhaust emission gases on their trunks, roots, fruits, barks, and leaves.

Besides mines and smelting areas, it has been observed that the concentration of heavy metals on the leaves of plants growing in urban areas is also increasing. Therefore, research on the biomonitoring of heavy metal pollution in the atmosphere and plants around the industrial facilities or roadsides are of great importance (Shahid et al. 2017). Heavy metal accumulation occurs first in soil. Then, plants absorb these heavy metals from the soil through their roots. The second way for the heavy metals to enter the structure of plants is through the parts above the ground, e.g., leaves and barks. Hence, tree leaves, barks, and rings are used as good indicators for the biomonitoring method to observe the level of heavy metal pollution in air in the past.

Dendrochemical techniques are widely used for determining the level of heavy metal pollution in urban and industrial areas (Anderson et al. 2000; Bellis et al. 2002; Watmough and Hutchinson 1996). The organelles that are used the most for determining the level of heavy metal concentration are leaves. The main reasons for this are (a) the accumulation of heavy metals in leaves during photosynthesis through stomates, (b) the fact that gathering leaves does not cause permanent damage to trees, and (c) since the age of leaves is known, it is possible to determine how long the accumulation of heavy metals took. In fact, trees are not a better indicator than mushrooms, algae, and mosses; however, the presence of trees all over the cities and their longer life span compared to those of other indicator plants provide more information to scientists in their search concerning the increase of heavy metal pollution in air from past to the present (Sawidis et al. 2011; Shahid et al. 2017; Turkyilmaz et al. 2018).

The objective of this study is to determine the amount of heavy metal pollution between 1989 and 2016 in the tree rings of the *Acer platanoides* species in the Ulus region, which is one of the most densely populated areas of the Ankara Province. Thus, we aimed to determine the change in the heavy metal concentration in air, which cannot be measured directly, over the past 27 years. Additionally, the usage potential of this species for determining heavy metal concentration for the near past was aimed to be assessed within the context of this study.

Materials and methods

Site description

The study area is in Ulus-Ankara. Ulus region, which is one of the most densely populated areas in the Ankara Province (39° 56′ 18.7″N, 32° 51′ 01.0″E), as shown in the topographic map, blow from the direction of the organized industrial zone Sincan and from the direction of Çubuk region, where an airport is located. Therefore, the Ulus district, the area from which the samples of this study were taken, is also located in this valley. Two major organized industrial zones of Ankara were established in 1990, and they have been operational since then. When the wind conditions of the central stations were examined in general, it was obvious that the prevailing winds changed based on the topographic structure. In Fig. 1, we can observe that the prevailing wind directions are from the west of Ulus district and from the northeast in Esenboğa, Çubuk, Ayaş, and Yenimahalle; from the west in Haymana (İkizce), Sincan, Dikmen, and Nallıhan; from the southeast in Kızılcahamam; and from the north-northeast in Beypazarı. The months of strong winds in Ankara are March and April. The highest wind speed detected in Ankara is 29.2 m/s (Governorship of Ankara 2016).

Sampling

The study was conducted with materials obtained from *A. platanoides* tree found in the Ulus region. Samples were cut in December 2016 following the end of vegetation and brought to the laboratory. They were then cut into disks (thickness 1 cm) in the laboratory, after which the disks were sanded to achieve smooth surfaces to make the annual tree rings clearly visible. After counting, it was determined that the tree was 27 years old. Further, it was decided that the annual rings should be grouped into three ages at a time considering their widths. The annual rings were divided into 3-year sections, and the samples taken from two opposite sides of the tree were classified. In total, 10 samples consisting of nine 3-year tree rings and a bark sample were obtained.

The study was carried out on *A. platanoides* tree rings. Until this day, many studies have investigated the availability of leaves of different species as biomonitor. *A. platanoides* leaves were also used for monitoring heavy metal pollution in different studies (Kosiorek et al. 2016; Kowalski and Frankowski 2016). Acer species are plants used extensively in landscape studies in many countries of the world. *A. platanoides* is also preferred in this study because it is used extensively in landscape studies especially outside the natural spreading area (Sevik et al. 2012).

The gathered wood samples were chopped and turned into shavings. During these procedures, care was taken to avoid the use of tools made from the metals that are the subject matter of this study. The samples were allowed to stand for 30 days until they became room dry, after which they were dried in oven at 50 °C for 1 week. In total, 0.5 g of the dried samples was taken and 6 ml of 65% HNO_3 and 2 ml of 30% H_2O_2 were applied to their surfaces, after which the samples were placed in a microwave oven. The microwave oven was set to reach 200 °C in 15 min and remain at the same temperature for the same duration. After the samples were fired in a Milestone brand Ethos One model microwave oven, the samples, which have become a solution, were placed into balloons and were completed with 50 ml of ultrapure water to prepare them for Fe, Co, Ni, Zn, Cd, Hg, and Pb analyses using a GBC Integra XL-SDS-270 ICP-OES instrument. Then, the plasma of the ICP instrument was fired for the analysis of the samples and ultrapure water was passed through the system for 15 min for the instrument to reach balance. Standard solutions were prepared based on the elements to be analyzed, and a calibration chart was created. After creating the calibration graph, the samples were run through the system and the reading process was performed. Since the samples were taken in amounts of 0.5 g and filled with water to reach 50 g, the results of

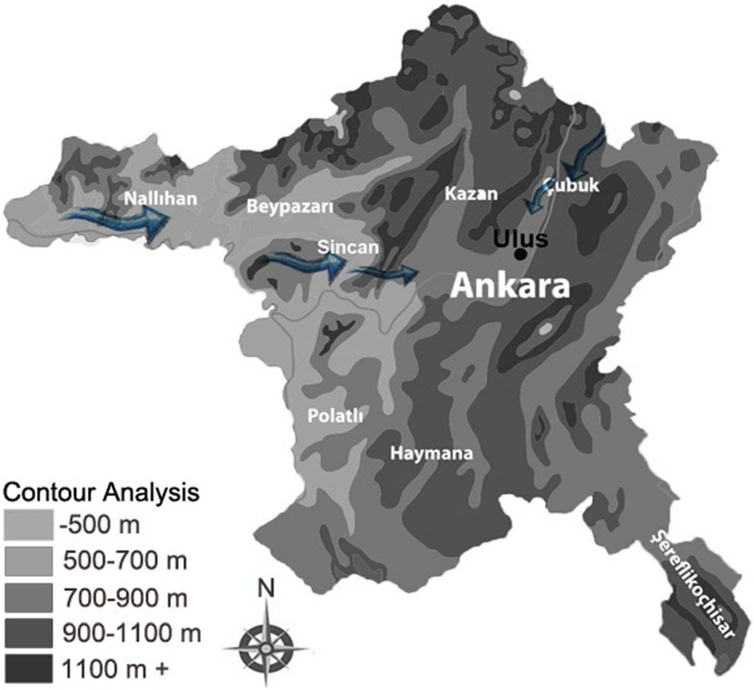


Fig. 1 A topographic map of Ankara and prevailing wind directions

the analyses were multiplied by 100. Different calibration graphs were created at ppm or ppb levels for those analytical results that did not fall within the calibration graph, and the reading process was repeated. The detection limits of the GBC Integra X-SDS-270 ICP-OES instrument are as follows: Pb ➔ 0.377 ppb, Cu ➔ 0.639 ppb, Ca ➔ 0.00208 ppm, Mg ➔ 0.00758 ppm, Cd ➔ 0.063 ppb, Cr ➔ 0.311 ppb, Ni ➔ 0.171 ppb, Fe ➔ 0.00068 ppm, Mn ➔ 0.00015 ppm, and Zn ➔ 0.00634 ppm. In the study, all the measurements were repeated three times. Then, the data were evaluated with the help of SPSS software package (Table 1).

Results

In total, 17 elements were considered herein. Variance analysis and Duncan test were applied to the obtained results in terms of the elements studied. The mean values obtained for wood and bark and the *F* values calculated as a result of variance analysis are listed in Table 2.

From the results summarized in Table 2, we found that there is no statistically significant difference of at least 95% confidence level only between Ni, Ca, and As in bark and wood. The values for Cd and Pb measured with regard to wood are below the detection levels. For the rest of the elements, there are statistically significant differences between wood and bark. According to the calculated *F* values, the values obtained for bark and wood are significantly different at 95% confidence level for Na and at 99.9% confidence level for all other elements (Table 3).

Herein, correlation analysis was performed to determine the relationships of the elements with each other, the results of which are presented in Table 4.

Discussion

A 27-year-old tree was used herein, and its annual rings were grouped into 3-year groups from which samples were obtained. Table 2 contains the following: (a) the average values obtained as a result of the evaluation based on the ages of wood and (b) *F* values calculated as a result of variance analysis, and Table 3 contains homogenous groups that occurred as a result of the Duncan test.

When the values were examined, we found that except for Na, which showed differences at statistically significant level, all other elements were present in higher quantities in the bark. The average values obtained for the bark were 6 times higher than those obtained for wood. In terms of the elements that showed statistically significant level of differences, this difference was

Table 1 Usage rates of agricultural land used for other purposes in other areas (Sezgin and Varol 2012)

Usage type		1985		1997		2007	
		Area (ha)	%	Area (ha)	%	Area (ha)	%
Industrial	Sincan OIZ	0	0.0	575	4.0	575	2.7
	Western corridor (Old İstanbul Road)	0	0.0	50	0.4	365	1.7
	İvedik + Ostim OIZ	350	9.29	800	5.6	800	3.8
	Northwest Cordial (Çubuk Road)	0	0.0	260	1.8	400	1.9
Housing		1,317	34.96	10,457	73.4	17,023	80.0
Other		2,100	55.75	2,100	14.8	2,100	9.9
Total		3,767	100.0	14,242	100.0	21,263	100.0

the lowest in P (1.61 times higher), Mg (2.52 times higher), and B (3.94 times higher) and the highest in Mn (23.87 times higher), Al (22.0 times higher), and Fe (14.27 times higher). For Na, we found that the value obtained for wood was 1.64 times higher than that obtained for bark.

For Co and Cr, two elements evaluated herein, the quantities of the elements were found below the detection levels in the annual rings of 2002 and later. Additionally, as a result of the Duncan test, in woods of different ages, all quantities of elements, except for As, have been found to have differences at statistically significant levels; this difference was statistically significant at 99% confidence level for Cr and at 99.9% confidence level for the rest of the elements. According to the results summarized in Table 3, most groupings occurred in Al, Zn, Cu, Mn, Fe, and Mg. We observed that the nine age groups that were evaluated in these elements were gathered in eight homogenous groups. The graphics, which were prepared to make the changes associated with heavy metals according to the ages more clearly understandable, are presented in Fig. 2.

Table 2 Average values and variance analysis results for wood and bark

Elements	Bark	Wood	*F*
Al (ppb)	157.24	7.15	4,316.17
Zn (ppb)	14.79	3.59	215.91
Cu (ppb)	43,229.00	1.59	91.58
Ni (ppb)	0.723	0.739	0.005 ns
Co (ppb)	0.312	0.067	412.25
Fe (ppb)	134.87	9.45	1,149.09
Mn (ppb)	49.23	2.06	150,697.19
Cr (ppb)	0.817	0.087	7,341.83
Cd (ppb)	62.47		
Pb (ppb)	1.48		
Na (ppb)	191.33	313.64	6.707*
Ca (ppb)	3,211.43	2,842.70	0.988 ns
Ba (ppb)	43,159.00	3.87	1,441.63
P (ppb)	764.17	474.78	0.819 ns
Mg (ppb)	1,755.6	697.02	267.35
As (ppb)	1.43	1.36	2.207 ns
B (ppb)	21.67	5.50	245.72

ns not significant

*significant at 0.05 level

On analyzing Table 3, we found that the elements were generally in a strong and positive directional relationship with the statistically significant levels. However, some results were particularly striking. For example, Ni is in a relationship at a statistically significant level with only Na and P. This is a negative directional relationship. Additionally, P, excluding Ni, is in a relationship at a statistically significant level with only Co. This is a considerably strong (0.983) and positive directional relationship. Another striking point is that Na is in a negative directional relationship with nearly all elements. Correlation analysis is a statistical analysis that reveals the magnitude, direction, and significance of the relationship between two variables. The relationship measured in correlation analysis is related to the linear part of the relationship between the variables. The correlation coefficient calculated via correlation analysis is denoted by r and can take values between -1 and $+1$. A coefficient close to $+1$ represents a good relationship between two variables and that close to -1 also represents a good relationship but in the opposite direction; i.e., one of the variables increases while the other decreases (Sevik et al. 2017). When the results are examined in this regard, the level of relation between some

Table 3 Average values and variance analysis results based on age in wood samples

Ages										
Elements	1990–1992	1993–1995	1996–1998	1999–2001	2002–2004	2005–2007	2008–2010	2011–2013	2014–2016	*F*
Al	9.833 g	8.819 f	15.114 h	9.913 g	2.592 a	4.942 d	5.086 e	3.435 b	4.586 c	11,858.427
Zn	2.726 c	6.454 h	2.385 a	4.802 g	2.542 b	4.036 f	2.406 a	3.370 d	3.591 e	5,895.313
Cu	4.585 h	2.795 g	1.663 e	0.810 d	0.570 c	0.154 a	0.758 d	0.411 b	2.565 f	887.872
Ni	0.190 a	1.378 f	0.947 e	0.806 d	0.816 d	0.734 c	0.957 e	0.595 b	0.223 a	863
Co	0.089 c	0.077 c	0.040 a	0.062 b	–	–	–	–	–	29.375
Fe	9.239 e	23.673 h	6.380 d	3.690 b	2.698 a	12.416 f	6.428 d	6.088 c	14.445 g	10,307.351
Mn	2.226 g	2.146 e	1.789 b	1.757 a	1.841 c	2.184 f	2.143 e	2.107 d	2.358 h	471.241
Cr	0.101 b	0.094 b	0.072 a	0.076 a	–	–	–	–	–	13.756**
Na	358.1 e	320.4 c	356.0 e	377.2 g	356.5 e	351.0 d	364.0 f	193.6 b	145.9 a	2,585.934
Ca	1,806.9 b	1,686.2 a	2,671.7 c	3,216.3 f	3,332.3 g	3,336.9 g	3,359.0 g	2,993.1 d	3,181.7 e	5,483.679
Ba	3.10 b	3.90 d	4.10 e	4.30 f	3.43 c	3.53 c	2.90 a	3.00 ab	6.60 g	612.632
P	86.1 b	65.1 a	71.2 a	113.5 c	95.3 b	287.1 d	858.9 e	1,109.4 f	1,586.3 g	19,693.26
Mg	804.3 g	635.2 d	523.1 a	569.8 b	606.4 c	800.3 g	789.8 f	723.1 e	821.1 h	1,183.7
As	1.27 a	1.33 a	1.37 a	1.40 a	1.33 a	1.40 a	1.47 a	1.33 a	1.37 a	1.981 ns
B	7.60 e	9.36 f	5.56 d	4.56 c	5.40 d	4.00 a	4.56 c	4.33 bc	4.13 ab	309.529

The letters a, b, c, etc. means according to Duncan 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

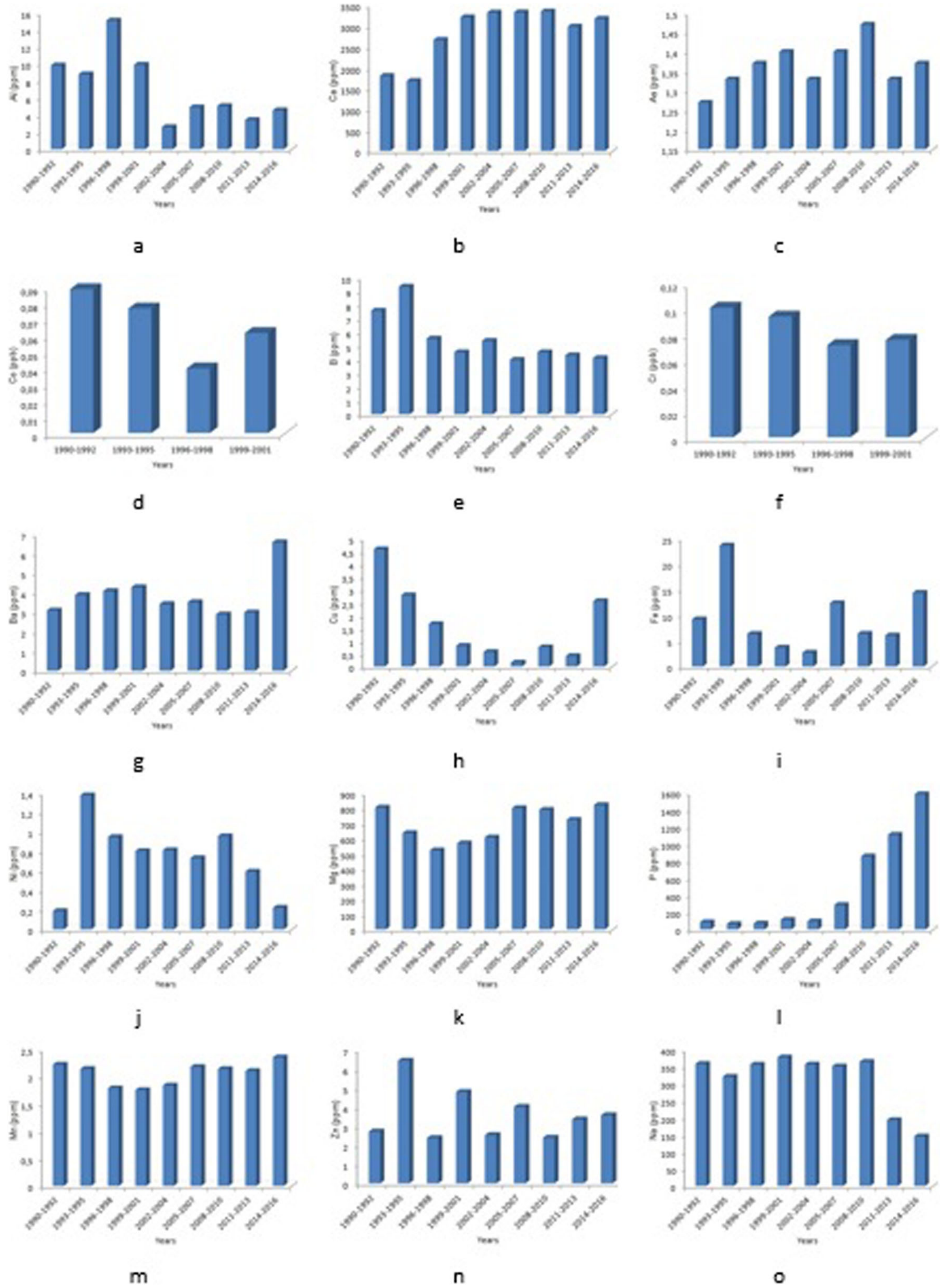
ns not significant

**significant at 0.01 level

Table 4 Correlation analysis results

	Zn	Cu	Ni	Co	Fe	Mn	Cr	Cd	Pb	Na	Ca	Ba	P	Mg	As	B
Al	0.940**	0.889**	0.003	0.978**	0.986**	0.996**	0.997**	−0.41	−0.755	−0.408*	0.144	0.988**	0.126	0.935**	0.263	0.955**
Zn		0.839**	0.141	0.948**	0.967**	0.941**	0.948**	0.954	0.736	−0.432*	0.048	0.942**	0.101	0.879**	0.242	0.940**
Cu			−0.178	0.949**	0.898**	0.878**	0.930**	−0.94	−0.711	−0.414*	−0.23	0.881**	0.095	0.865**	0.039	0.936**
Ni				−0.17	0.025	−0.02	−0.13	−0.98	−0.795	0.407*	−0.12	−0.055	−0.451*	−0.192	0.228	0.101
Co					0.985**	0.986**	0.989**	0.139	0.545	−0.958**	0.42	0.979**	0.983**	0.994**	0.39	0.978**
Fe						0.989**	0.993**	0.561	0.158	−0.471**	0.094	0.985**	0.176	0.952**	0.249	0.965**
Mn							0.999**	0.16	−0.273	−0.446*	0.182	0.991**	0.176	0.955**	0.269	0.948**
Cr								0.766	0.422	−0.966**	0.562*	0.997**	0.997**	0.984**	0.466	0.973**
Cd									0.906	−0.999*	0.82	0.934	−0.37	0.964	−0.934	0.934
Pb										−0.892	0.501	0.694	−0.73	0.762	−0.694	0.694
Na											−0.18	−0.505**	−0.834**	−0.527**	−0.014	−0.34
Ca												0.201	0.421*	0.197	0.479**	−0.116
Ba													0.23	0.944**	0.271	0.930**
P														0.338	0.203	−0.007
Mg															0.261	0.882**
As																0.148

*significant at 0.05 level; **significant at 0.01 level


Al (ppm)
Ca (ppm)
As (ppm)
Cd (ppb)
B (ppm)
Cr (ppb)
Ba (ppm)
Cu (ppm)
Fe (ppm)
Ni (ppm)
Mg (ppm)
P (ppm)
Mn (ppm)
Zn (ppm)
Na (ppm)
Years
1990-1992
1993-1995
1996-1998
1999-2001
2002-2004
2005-2007
2008-2010
2011-2013
2014-2016
a
b
c
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◀ **Fig. 2** Annual changes in heavy metal concentrations over years (**a** changes in Al concentrations, **b** changes in Ca concentrations, **c** changes in As concentrations, **d** changes in Co concentrations, **e** changes in B concentrations, **f** changes in Cr concentrations, **g** changes in Ba concentrations, **h** changes in Cu concentrations, **i** changes in Fe concentrations, **j** changes in Ni concentrations, **k** changes in Mg concentrations, **l** changes in P concentrations, **m** changes in Mn concentrations, **n** changes in Zn concentrations, **o** changes in Na concentrations

elements is considerably high. For example, the correlation coefficients between Cr and Mn (0.999), Cr and Al (0.997), Cr and Ba (0.997), and Cr and P (0.997) are considerably high. Similarly, the correlation coefficient calculated between Na and Cd (− 0.999) is negative but considerably strong. Additionally, considerably strong relations are observed among many elements.

Although some elements (CI, K, Mg, P, and S) can be transported more actively in the metabolic activities of the plant, the transport of some elements (B, Ba, Ca, Cu, Fe, Li, Mn, Mo, and Zn) in the phloem is more limited (Perone et al. 2018). The nature and density of the element concentration in the environment has increased in the recent decades due to human activities, e.g., melting, artificial fertilization, and vehicle traffic. Some data show that the climate change is affected not only by pollution tracks but also by plant metabolism and the distribution of elements in plants. This is why the transport of an element within the plant's organs also changes (Cui et al. 2013). Figure 3 shows that concentrations of Ba, Ca, Mg, Mn, and Na almost same remain in the annual rings. Hence, the origin of these metals is unknown.

The accumulation of the metals solely in the plane tree rings appears to accurately reflect the amount of metals accumulated in the atmosphere; however, it is unclear whether the increase in metal concentration in xylem comes directly from the metals accumulated in the atmosphere, soil, or both (Watmough and Hutchinson 1996).

The areas allocated for industry in Ankara are listed in Table 1. It is evident from Fig. 1 that the prevailing winds of Ankara, as shown in the topographic map, blow from the direction of the organized industrial zone Sincan and from the direction of Çubuk region, where an airport is located. Therefore, the Ulus district, the area from which the samples of this study were taken, is also located in this valley. Two major organized industrial zones of Ankara were established in 1990, and they have been operational since then. When the wind conditions of the central stations were examined in general, it was obvious that the prevailing winds changed based on the topographic structure. In Fig. 1, we can observe that the prevailing wind directions are from the west of Ulus district and from the northeast in Esenboğa, Çubuk, Ayaş, and Yenimahalle; from the west in Haymana (İkizce), Sincan, Dikmen, and Nallıhan; from the southeast in Kızılcahamam; and from the north-northeast in Beypazarı. The months of strong winds in Ankara are March and April. The highest wind speed detected in Ankara is 29.2 m/s (Governorship of Ankara 2016). Therefore, when heavy metal/year change graphs (Fig. 2) were examined, we observed that heavy metals, such as Ni, Zn, Al, As, Co, and Cr, which occur as a result of industrial activities in the Sincan and Ostim organized industry zones, have been transported to the city center by the prevailing winds and that the accumulation of heavy metals in the tree rings increased since 1993. The slow winds caused because of the topography of the region and unplanned urbanization are the main causes of heavy air pollution in the past (Yatin et al. 2000). It has been shown that in the case high concentration of heavy metals in the atmosphere, these pollutants can be

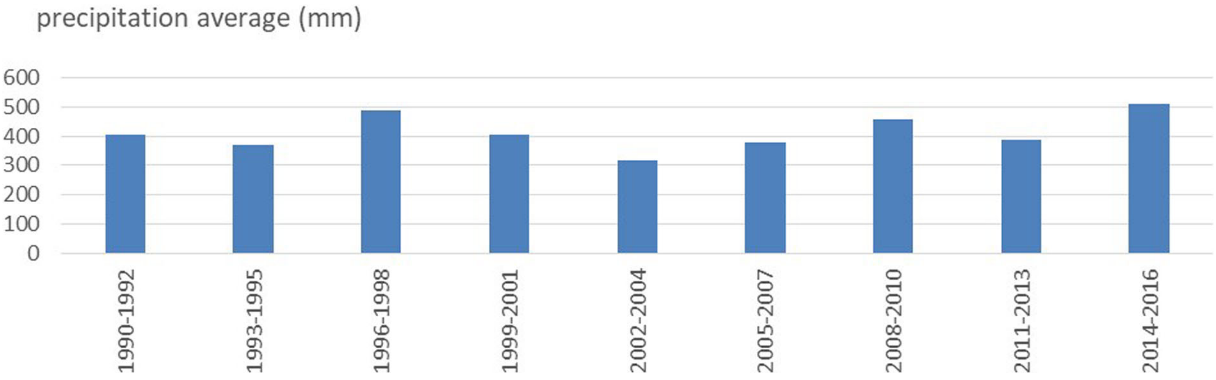

Fig. 3 A precipitation graph of the period between 1990 and 2016 for the study area

transported kilometers away depending on the wind regime (Shahid et al. 2017).

Previous studies reported have that the accumulation of heavy metals in plants is also related to precipitation. Therefore, the data obtained in this study were interpreted by correlating with the amount of precipitation. The precipitation graph of the period between 1990 and 2016 for the study area is shown in Fig. 3.

Conclusions

In total, 17 elements were analysis in our study; when the amount of precipitation/annual change graph was examined, we found that the low average amount of rainfall between 1990 and 1992 and the increase in the amount of heavy metals in the atmosphere supported the increase in the amount of heavy metals in tree rings. Therefore, trees used in landscapes in areas with heavy traffic and industries are good bioindicators of heavy metal concentrations in the atmosphere. Hence, our findings reveal that the concentration of all heavy metals adversely affecting human health increases with age. However, this increase is not linear. The fact that the increase in the amount of heavy metals in tree rings is high in some years and low in some years is due to the morphological structure of the tree. Similar results have been obtained in studies conducted on different species (Beramendi-Orosco et al. 2013). Beramendi-Orosco et al. reported that in their study on *Prosopis julifora* annual rings, 1.09 ppm of Cu in the 1988–1992 period was 1.27 ppm in the 2003–2007 period and 0.35 ppm of Pb amount in the 1993–1997 period was 0.46 ppm in the 1998–2002 period. Similar results were obtained in studies in which the changes were determined based on months (Norouzi et al. 2015).

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