



# Do Annual Rings Really Reveal Cd, Ni, and Zn Pollution in the Air Related to Traffic Density? An Example of the Cedar Tree

Hatice Cobanoglu · Hakan Sevik · İsmail Koç

Received: 19 October 2022 / Accepted: 10 January 2023 / Published online: 18 January 2023  
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2023

**Abstract** Heavy metals (HMs) in air pollution seriously threaten the environment. Although plant species are known as good biomonitors, it has not been determined which HM is absorbed by which plant and organs and how much traffic is caused. The objectives are to determine (a) if the HMs examined here are transferred between the annual tree rings and (b) originate from the traffic, and (c) the variation of these HMs' concentrations by wood, outer bark, and inner bark within these organs and density of the traffic. In this study, annual growth rings of *Cedrus* sp. tree located in Kastamonu city center, Türkiye, were used to determine the variation of cadmium (Cd), nickel (Ni), and zinc (Zn) by organ and traffic density through the last 39 years. As a result, Cd, Ni, and Zn concentrations in outer bark on the roadside were approx. 22.3, 9.6, and 2.5 folds of the concentration in the outer bark on the opposite side. Compared to

the values obtained from wood, the concentrations obtained from outer bark were approx. 16.5 folds for Cd, 3.2 folds for Ni, and 5.1 folds for Zn. The results reveal that Cd, Ni, and Zn elements can diffuse into the air due to traffic, their accumulation potential in the cedar tree's woods is relatively high, and their transfer in the wood is limited. In conclusion, the usage potential of this species is high to monitor and reduce the change of Cd, Ni, and Zn in the air from the past to the present.

**Keywords** Air pollution · Biomonitor · Cadmium · Heavy metal · Nickel · Zinc

## 1 Introduction

Throughout the world in this century, climate change has become an environmental problem, the effects of which started to be strongly felt and a concern for the entire world (Koç et al., 2022; Koç, 2022a, b, c). Besides it, pollution has become a serious threat to the environment worldwide. The environmental pollution arising from plant cover damaged, fossil fuels consumed, and industrial zones established so as to meet the growing energy demand depending on the increasing human population density is the main factor (Isinkaralar et al., 2022; Koç, 2021) influencing climate change (Canturk & Kulaç, 2021; Varol et al., 2021). Heavy metal (HM) contamination plays a vital role in the resultant environmental pollution.

---

H. Cobanoglu (✉)  
Institute of Science, Düzce University, 81620 Düzce,  
Turkey  
e-mail: hatice96073@ogr.duzce.edu.tr

H. Sevik  
Faculty of Engineering and Architecture, Kastamonu  
University, 37210 Kastamonu, Turkey  
e-mail: hsevik@kastamonu.edu.tr

İ. Koç  
Forestry Vocational School, Düzce University,  
81620 Düzce, Turkey  
e-mail: ismailkoc@duzce.edu.tr

The non-biodegradable HMs in nature originate from various anthropogenic activities and directly threaten human and environmental health (Turkyilmaz et al., 2018).

HMs naturally exist in nature, but they are released into nature due to the effects of fossil fuels, minerals, packages, papers, cosmetics, textiles, food industry, natural gas, galvanic, metal treatment, and waste incineration facilities (Cimboláková et al., 2019). These industrial advancements result in the accumulation of HMs in nature. Hence, climate change and air pollution caused by the HMs accumulating in nature are significant sources of concern (Shahid et al., 2017). Annually, approx. 7 million individuals (gradually increasing) die because of medical problems, including cardiac diseases, lung cancer, acute respiration, chronic obstructive pulmonary disease, and acute respiratory tract diseases (Elsunousi et al., 2021; WHO, 2021). According to the data provided by European Environment Agency (EEA), air pollution is considered the only and most crucial environmental concern in Europe. The latest estimations emphasized that pollutants having fine particle structures caused more than 400 thousand preventable deaths in Europe in 2018 (EEA, 2020).

Plants are frequently used in reducing the effects of air pollution and estimating the dimensions of pollution (Sevik et al., 2019a, 2019b; Turkyilmaz et al., 2020). Since plants act as a sink, they accumulate particles and harmful gasses in the atmosphere within their organisms. Making use of this characteristic of plants, they recently started being used as biomonitors (Alaouri et al., 2020; Koç, 2021; Turkyilmaz et al., 2019). Information about the HM contamination in the atmosphere can be gathered by taking samples from the organs of plants being used as biomonitors, such as fruit (Sevik et al., 2020), bark (Isinkaralar et al., 2022; Sawidis et al., 2011), branch (Karacocuk et al., 2022), leaf (Aricak et al., 2020; Isinkaralar et al., 2022), and wood (Isinkaralar et al., 2022; Key & Kulaç, 2022; Key et al., 2022; Savas et al., 2021).

Historically, the dendrochemical studies started in the late 1960s according to the theory of the chemical structure of annual rings (Lepp, 1975), which exhibits the chemical composition of its environment (Watmough, 1997). Several projects approved the usability of tree rings in tracing the chemical contamination and the correlation between a dirty

environment and element concentration (Lageard et al., 2008; Lee et al., 2015). However, some scientists claimed that dendrochemistry could not unveil the chemical and elemental differences in the ecosystems (Pearson et al., 2006; Watmough & Hutchinson, 2003). Furthermore, the former studies indicated that diverse plant species have diverse abilities for accumulating specific HMs in distinct organs (Sevik et al., 2020). Consequently, dendrochemistry is a robust tool for watching air pollution on the circumstance that a proper and suitable testing procedure should be selected and a suitable plant species should be assigned (Liu et al., 2018).

Monitoring the air HM pollution in the air is very pricy and challenging expensive from several aspects. Therefore, commonly, biomonitors are used to watch the HM contamination in the air. However, it was stated that among the biomonitors presently used, the most suitable one is woody plants' annual rings because annual rings can provide substantial proof of HM change in overtime (Mulenga et al., 2022; Savas et al., 2021). Moreover, since the study is conducted on a single tree, it prevents divergences from the genetic structure. Plant growth and development are shaped by the interaction between genetic arrangements and environmental factors (Koç, 2019, 2022a; Koç et al., 2022). Thus, different plants with diverse genetic structures may have various physiological and phenotypic characteristics even under similar environmental situations (Ghoma et al., 2022; Varol et al., 2022). It can also affect the HM accumulation potential of the plants (Karacocuk et al., 2022). Therefore, the studies on the same single tree excluded the differences resulting from the genetic structure. However, it advises that the species have different levels of HM accumulation potential (Cesur et al., 2021).

In previous studies, Ram et al. (2014) investigated *Ficus benghalensis* and *Polyalthia longifolia* plants in terms of dust particles accumulation on the leaf adaxial and rachis surface, while Mu'taz and Mandiwana (2007) HM accumulation in the *Pinus halepensis* L. needle leaves. In addition, *Pinus sylvestris* branch and needle leaf samples (Aricak et al., 2019), mosses of *Octoblepharum* and *Isopterygium* species (Saat et al., 2016), leaves of *Eucalyptus citriodora* and *Melia azedarach* (Khatkhat & Jabeen, 2012), leaves of *Quercus ilex* (Granati et al., 2008), root, bark, leaf samples of *Salix fragilis* L. (Yavuzer & Etem, 2018), the outer bark

of *Azadirachta indica* (Sulayman et al., 2021), leaves of *Populus nigra*, and needles of *Cedrus libani* (Çiftçi et al., 2021) in terms of HM accumulation were investigated. However, HM accumulation in wood and bark (inner and outer) samples of trees was not studied. In this study, the particulate matter on the outer surface of the cedar tree and the amount of HM accumulation in the wood part of the plant were determined. In addition, in previous studies, 1-year or maximum of 5-year organs of plants were taken into account, and data were obtained about the recent past or today. This study aimed to shed light on the HM accumulation and sources in the air for the past 39 years. Hence, it is essential to define annual rings of which tree species can be used as biomonitors of which metals.

The level of pollution that plants, which begin and stop their annual development within the vegetation period, were exposed to during the vegetation season can be determined by taking samples from their organs, such as branches, fruit, and bark (Karcocuk et al., 2022; Koç, 2021). In recent years, information about the pollution that plant species, which have annual rings, have been exposed to in the past can be obtained by taking samples from the wood parts. For this reason, many studies have been conducted on the usability of annual rings in monitoring HM pollution in the air from the past to the present. However, HM pollution in the annual rings of trees grown in any region was evaluated in studies and interpreted considering the polluting sources in the region (Turkyilmaz et al., 2019; Yayla et al., 2022). However, there still needs to be more information on the way metals enter the tree and their transfer between the organs from their entry into the tree. In addition, there needs to be more information about which metal traffic creates HM pollution.

The current study aimed to gather information about the 39-year accumulation of Cd, Zn, and Ni in the cross-sectional sample taken from a cedar (*Cedrus* sp.) tree in Kastamonu province of Türkiye as well as the relationship of this accumulation with traffic. The study aimed to reach information about how much the HMs Cd, Zn, and Ni, which are the most dangerous for the environment and human health, increase depending on the traffic source and the level of transition between the organs of the cedar tree.

## 2 Material and Method

This current study was carried out in Kastamonu province, Türkiye. A lateral cross-sectional sample was taken from the trunk of 39-year-old cedar tree (45.7 cm d.b.h.) cut from a public garden (5 m away from the main road in the city center—heavy traffic all day long), which includes a playground in it, at the city center of Kastamonu province in late 2019. The sample was taken from approx. 80 cm above the ground level, but the roadside was marked on the sample prior.

After smoothing out the upper surface of the trunk, annual rings were counted, and it was determined that it was 39 year-old. Considering the widths of annual rings, they were gathered in 3-year groups and labeled from 1 to 13 in the outside-in direction. In previous studies, annual rings are grouped as 10 (Key & Kulaç, 2022; Key et al., 2022), 5 (Yigit, 2019), 3 (Koç, 2021), and 2 years (Turkyilmaz et al., 2019) based on annual rings widths. The samples from the inner bark, outer bark, and wood parts using steel drill equipment were taken into glass petri dishes. The samples were air-dried for 2 weeks. Then, the air-dried samples were moved into an oven (45 °C) and dried for about 1 week. The dried samples were ground, divided into 0.5 g portions, and then put into a glass flask designed for microwaving. Then, they were assed with 10 ml 65% HNO<sub>3</sub> on a fume cupboard. The arranged samples were combusted in the microwave (at 180 °C temperature and under 280 PSI pressure) for about 20 min. Then, the cooling solutions were completed to 50 ml by adding distilled water. The samples filtered through filter paper were scanned at proper wavelengths using inductively coupled plasma-optic emission spectrometer (ICP-OES) (GBC Scientific Equipment Pty Ltd., Melbourne, Australia).

For the samples' analysis, the ICP-OES device's plasma was burned, and ultrapure water was passed through the system for 15 min to reach equilibrium. A calibration chart was created by preparing standard solutions according to the elements to be analyzed. After the calibration chart was created, the samples were given to the system, and the reading process was performed. According to the analysis results that did not fall into the calibration graph, different calibration graphs were created at ppm or ppb level, and re-reading was performed. Cd, Ni, and Zn concentrations

were calculated by multiplying the obtained results by the dilution factor of 100. This method is one of the most frequently used methods in recent years for the determination of HM analyses in both wood and plant parts such as leaves, roots, bark, and fruit (Cetin et al., 2022; Kravkaz Kuscü et al., 2022; Sulhan et al., 2022).

The data obtained were subjected to variance analysis (ANOVA) using SPSS package software. Duncan's test was conducted for the values, which were found to have a statistically significant difference (95% confidence level) in ANOVA. The homogeneous groups obtained from the Duncan test were then tabularized and interpreted.

### 3 Results

The element concentration (mean) levels in various organs (on the roadside and opposite sides) are given in Table 1. According to the ANOVA, the changes in Cd concentrations by organ were not significant ( $P > 0.05$ ) only for the opposite direction. However, the changes in other elements' concentrations by organ were significant ( $P < 0.05$ ). The concentration of Cd in outer bark on the roadside was approx. 22.3 folds of the concentration in outer bark on the opposite side. Similar results were also achieved for the other elements. Compared to the outer bark facing the opposite side, the values from the outer bark facing the roadside were around 9.6 folds for Ni and 2.5 folds for Zn. Accordingly, it can be concluded that the accumulation of all three elements increased with traffic.

Besides that, examining the changes by organs, the highest and lowest values on the roadside were found

in wood, followed by inner bark and outer bark, and the concentrations found in the outer bark were much higher. Compared to the values obtained from wood, the concentrations obtained from outer bark were approx. 16.5 folds for Cd, 3.2 folds for Ni, and 5.1 folds for Zn. The analysis results of the variation in annual rings' concentrations by years are presented in Table 2.

Examining the changes by year ranges, it can be seen that mean Cd concentration increased in the 1–3-year age group; on the opposite side, decreases were observed until the age group of 7–9 years, and twofold increase was observed after the age group of 10–12 years. In the age group of 10–12 years, Cd concentrations in the opposite direction increased to 182.8 ppb, decreasing to 152.9 ppb on the roadside. Even though Cd concentrations slightly decreased until the age group of 28–39 years on both roadside and opposite side, it increased to 220.0 ppb on the roadside and 212.6 ppb on the opposite side in the age group of 31–33 years. Cd concentration, which decreased by approx. 100.0 ppb in the age groups between 24 and 36 years, increased to 200.0 ppb in the age group of 37–39 years.

Given the ANOVA results of the change of Ni concentrations by year, it was determined that the roadside and opposite side values were significant ( $P < 0.05$ ), but there was no detectable difference between the mean values. In general, Ni concentration remained below 500.0 ppb in roadside, opposite side, and mean values. However, it increased up to 743.8 ppb on the opposite side in the age group of 25–27 years. After these years, the values found on the opposite side decreased and reached the minimum of 322.7 ppb in the age group of 37–39 years. From a general perspective, it can be stated that

**Table 1** Changes in Cd, Ni, and Zn element concentrations by organs

Organs	Elements								
	Cd (ppb)			Ni (ppb)			Zn (ppm)		
	Opposite side	Roadside	Aver	Opposite side	Roadside	Aver	Opposite side	Roadside	Aver
Outer bark	116.6	2601.2 <sup>b</sup>	1358.9 <sup>b</sup>	94.7 <sup>a</sup>	1735.6 <sup>c</sup>	915.1 <sup>b</sup>	10.4 <sup>b</sup>	25.7 <sup>c</sup>	18.0 <sup>c</sup>
Inner bark	166.5	176.8 <sup>a</sup>	171.6 <sup>a</sup>	1942.0 <sup>c</sup>	1196.6 <sup>b</sup>	1569.3 <sup>c</sup>	9.5 <sup>b</sup>	8.4 <sup>b</sup>	9.0 <sup>b</sup>
Wood	139.7	156.9 <sup>a</sup>	201.2 <sup>a</sup>	365.3 <sup>b</sup>	533.4 <sup>a</sup>	449.4 <sup>a</sup>	3.4 <sup>a</sup>	5.0 <sup>a</sup>	4.2 <sup>a</sup>
<i>F</i> values	1.735	61.62	22.074	137.077	722.595	50.849	56.325	133.461	73.966
<i>P</i> values	0.189	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

According to Duncan's test results, the letters a, b, etc., represent the statistical differences between organs

**Table 2** The variations of element concentrations in annual rings by year ranges

Year ranges	Cd (ppb)			Ni (ppb)			Zn (ppm)		
	Opposite side	Roadside	Average	Opposite side	Roadside	Average	Opposite side	Roadside	Average
1–3	168.2 <sup>g</sup>	137.4 <sup>bc</sup>	152.8 <sup>bcde</sup>	481.4 <sup>h</sup>	499.7 <sup>cde</sup>	490.6	6.7 <sup>e</sup>	3.6 <sup>b</sup>	5.1 <sup>bc</sup>
4–6	129.9 <sup>d</sup>	156.4 <sup>cde</sup>	143.1 <sup>bcde</sup>	412.4 <sup>fg</sup>	532.0 <sup>fg</sup>	472.2	1.8 <sup>a</sup>	4.4 <sup>c</sup>	3.1 <sup>a</sup>
7–9	74.3 <sup>a</sup>	173.9 <sup>ef</sup>	124.1 <sup>ab</sup>	409.6 <sup>fg</sup>	459.3 <sup>a</sup>	434.4	2.0 <sup>a</sup>	5.7 <sup>d</sup>	3.9 <sup>ab</sup>
10–12	182.8 <sup>h</sup>	152.9 <sup>de</sup>	167.9 <sup>de</sup>	436.4 <sup>g</sup>	643.5 <sup>i</sup>	539.9	6.2 <sup>e</sup>	10.3 <sup>f</sup>	8.3 <sup>d</sup>
13–15	148.4 <sup>ef</sup>	179.0 <sup>fg</sup>	163.7 <sup>cde</sup>	337.8 <sup>d</sup>	636.8 <sup>hi</sup>	487.3	3.3 <sup>c</sup>	5.4 <sup>d</sup>	4.4 <sup>abc</sup>
16–18	117.1 <sup>c</sup>	163.0 <sup>def</sup>	140.1 <sup>bcd</sup>	388.6 <sup>ef</sup>	525.0 <sup>ef</sup>	456.8	2.7 <sup>b</sup>	4.6 <sup>c</sup>	3.6 <sup>ab</sup>
19–21	153.1 <sup>f</sup>	124.4 <sup>ab</sup>	138.8 <sup>bcd</sup>	436.9 <sup>g</sup>	508.0 <sup>cdef</sup>	472.5	3.5 <sup>d</sup>	4.5 <sup>c</sup>	4.0 <sup>ab</sup>
22–24	110.1 <sup>b</sup>	144.8 <sup>bcd</sup>	127.4 <sup>ab</sup>	360.9 <sup>de</sup>	472.5 <sup>ab</sup>	416.7	3.5 <sup>d</sup>	1.2 <sup>a</sup>	2.3 <sup>a</sup>
25–27	132.8 <sup>d</sup>	140.0 <sup>bc</sup>	136.4 <sup>abc</sup>	743.8 <sup>i</sup>	484.4 <sup>abc</sup>	614.1	3.5 <sup>d</sup>	4.5 <sup>c</sup>	4.0 <sup>ab</sup>
28–30	133.7 <sup>d</sup>	143.7 <sup>bc</sup>	138.7 <sup>bcd</sup>	179.2 <sup>c</sup>	513.2 <sup>def</sup>	346.2	2.0 <sup>a</sup>	3.7 <sup>b</sup>	2.8 <sup>a</sup>
31–33	212.6 <sup>i</sup>	220.0 <sup>h</sup>	216.3 <sup>f</sup>	144.5 <sup>b</sup>	552.2 <sup>g</sup>	348.3	2.8 <sup>bc</sup>	5.5 <sup>d</sup>	4.1 <sup>abc</sup>
34–36	109.6 <sup>b</sup>	109.1 <sup>a</sup>	109.3 <sup>a</sup>	389.9 <sup>ef</sup>	490.6 <sup>bcd</sup>	440.2	2.6 <sup>b</sup>	3.2 <sup>b</sup>	2.9 <sup>a</sup>
37–39	143.2 <sup>e</sup>	195.6 <sup>g</sup>	169.4 <sup>e</sup>	28.1 <sup>a</sup>	617.4 <sup>h</sup>	322.7	3.7 <sup>d</sup>	8.3 <sup>e</sup>	6.0 <sup>c</sup>
<i>F</i> values	245.6	6.1	5.58	279.3	54.1	1.8	65.8	218.8	6.5
<i>P</i> values	0.000	0.000	0.000	0.000	0.000	0.054	0.000	0.000	0.000

According to Duncan's test results, the letters a, b, etc., represent the statistical differences between each column

Ni concentrations followed a horizontal course and showed a slight increase trend after the age of 24 years on the roadside. However, on the opposite side, it decreased especially after the age group of 25–27 years, and the mean values remained much lower after the 28th year of age compared to the other age groups.

Zn concentration ranged between 1.8 and 6.7 ppm on the opposite side. The highest Zn concentration was observed in the age groups of 1–3 years (6.7 ppm) and 10–12 years (6.2 ppm), while the lowest Zn amount was in the age of 4–6 years (1.8 ppm). On the roadside, it was generally in an increasing trend until the age group of 10–12 years and increased to 10.3 ppm at a point. It was found that Zn concentration started decreasing and reached the minimum level in the age group of 22–24 years (1.2 ppm). After that, it started increasing, reaching 8.3 in the age group of 37–39 years.

#### 4 Discussion

The current study aimed to determine the variation of Ni, Cd, and Zn concentrations in the examples taken from the trunk of a cedar tree. When examining the results achieved here, it was aimed to determine if the

HMs were transferred between the annual rings. As a result, it was found that there were remarkable differences in Cd, Zn, and Ni concentrations between the annual rings, which have formed in the same period, in both the same direction and opposite directions on both roadside and opposite side. For instance, Cd concentration on the roadside in the age group of 31–33 years was 220.0 ppm, but it was found to be 109.1 ppm in the age group of 34–36 years. Similarly, while the Ni concentration was found to be 617.4 ppm in the age group of 37–39 years on the roadside, it was found to be only 28.1 ppm on the opposite side. This finding suggests that the transfer of all three elements within the annual rings of cedar trees was limited; thus, this species is a good biomonitor to track the HM concentration in the air.

A single tree was usually considered adequate in studies on annual tree rings. The annual rings of 180-year-old *Corylus colurna* (Key & Kulaç, 2022; Key et al., 2022), 55-year-old *Malus floribunda* (Yigit, 2019), and 33-year-old *Cedrus atlantica* (Koç, 2021) were grouped as 10, 5, and 3 years, respectively, and the mean values of each HM were used in those studies. A single tree was used to compare the effect of traffic on HM accumulation on the *Cedrus* tree (Cesur et al., 2021; Koç, 2021). Annual rings of a single tree (grouped as 3 years) were also used to see

the differences in traffic density based on directions of HM concentration (Isinkaralar, 2022a; Koç, 2021; Savas et al., 2021). The grouping of annual rings is done due to their widths of them. When the tree has narrow annual rings, obtaining samples is challenging due to the possibility of mixing the wood chips of annual rings close to each other. So, the grouping of annual rings is done based on the study purpose and annual ring width (Isinkaralar, 2022a, b; Savas et al., 2021).

Previous studies stated that a solitary plant is adequate to determine the variation in the level of HMs. One of the significant obstacles in using trees as biomonitors is the effect of genetic structure on the ability of HM accumulation. As it is known, genetic structure and environmental situation interactions have shaped the plants' phenotypic features (Koç, 2019) and HM accumulation (Karacocuk et al., 2022). Differences in genetic structure affect the emergence of distinctive phenotypic characteristics and the accumulation potential of HMs in other individuals and individuals of the same species (Ghoma et al., 2022). So, the same tree is used because it reveals the effect of environmental situations more clearly and excludes the changes result from genetic structure (Isinkaralar, 2022a, b).

Previous studies on the biomonitors reported that the most critical information deficiency is about the transfer of elements between and within the organs (Shahid et al., 2017). However, it was stated that the movement of Cd element in annual tree rings of *Pinus halepensis* was from wood to bark (Martin et al., 2018). In contrast, it was stated that there was almost no transfer in annual tree rings of *Corylus colurna* (Key et al., 2022). Another study on 14 plant species reported that the Cd element in wood was often below the detectable limits or at the lowest (Isinkaralar et al., 2022). Cd can be easily absorbed and accumulated in the systems of plants due to being water-soluble (Seven et al., 2018). Ni and Co elements transfer in *Cedrus atlantica* woods was limited (Koç, 2021), while Pb and Zn elements were transferred in the annual rings to a specific level, but Cu was not at all (Zhang, 2019). However, Ni and Cd elements transfer in the woods of *Cupressus arizonica* was limited, but the bismuth element was transferred at a much higher level (Cesur et al., 2021). Hence, it can be stated that the results achieved here were generally in parallel with the literature.

Within the scope of the current study, it was also intended to determine if the HMs examined here originated from the traffic. As a result, compared to the opposite side, the values found on the roadside were 22.3 folds for Cd, 9.6 folds for Ni, and 2.5 folds for Zn, and this finding suggests that all three elements might have traffic origin. However, examining the values, it can be thought that traffic is an important source of Cd and Zn pollution. In previous studies carried out on this subject, it was stated that the concentrations of these elements in various organs of plants increased in relationship with the traffic. For instance, Cd concentration was 172.4 ppm in the barks of *Pinus sylvestris* near the road (Arıcak et al., 2019), but it decreased to 46.9 ppm 100 m away from the road. Sevik et al. (2019a) reported that Ni concentration in branches of *Aesculus hippocastanum* was 219.3 ppb in no-traffic areas but 4211.3 ppb in high-traffic areas. In contrast, Cd concentration was 6.6 ppm in no-traffic areas, which increased to 65.0 ppm, and Zn concentration was 6.6 ppm in no-traffic regions, increased to 50.0 ppm in the high-traffic region. Analyzing the leaves of *Salix babylonica*, Turkyilmaz et al. (2020) reported the Cd concentration to be 29.3 ppb in no-traffic regions and 123.3 ppb in high-traffic zones, Ni concentration to be 8.3 ppb in no-traffic regions and 17.6 ppb in the high-traffic region, and Zn concentration to be 5.9 ppm in no-traffic areas and 19.2 ppm in high-traffic areas.

Cesur et al. (2021) studied *Cupressus arizonica* and reported that Cd concentration in outer bark was 16 folds higher than in the wood and 14 times higher than in the inner bark. Koç (2021) determined that Ni concentration in the outer bark of *Cedrus atlantica* on the roadside was 18 folds higher than on the opposite side. It was also emphasized in other studies that the concentrations of these elements increased in relationship with the traffic (Sevik et al., 2019a, b).

However, HMs' much higher concentration in the outer bark on the roadside than on the opposite side is mainly related to particle matters. Several studies claimed that HM concentrations, especially in the high-pollution areas, were related to particle matters. Particles act as a sink for the HMs in the air, and the particle matters contaminated by these HMs adhere to the organs of plants and can significantly increase the HM levels in these organs (Karacocuk et al., 2022). Moreover, the porous structure of bark provides a

better place for the HM-contaminated particles to adhere (Koç, 2021).

Another objective of the current study was to determine the variation in concentrations of these HMs by the organ in the inner bark, outer bark, and wood. The results showed that, for the roadside, the lowest concentrations were found in wood, followed by inner bark and outer bark. However, this ranking, which was found to be related to traffic, differs on the opposite side. There is a difference, which is not related to traffic, between the concentrations in barks and woods only in Zn. In previous studies carried out on the accumulation of HMs in the plant organs, it was reported that the most critical factor influencing this accumulation was the plant species and organs. Many studies were carried out on the differences between HM accumulations in different organs of the same plant (Cetin et al., 2020).

The results achieved suggest that the change in the HM concentrations in annual rings was not linear. Nechita et al. (2021) explained that this is because the metal concentrations (Cu, Ni, Pb, Zn, Cd, and Mn) in the annual ring are related to climatic factors. They have a positive correlation with temperature and a negative correlation with water content in the soil during the periods in which they were dormant during the vegetation period. Yiğit (2019) stated that the increase in HM concentration in trees could be high in several periods and low in others without a linear increase because of the morphological structure and ecological effects of trees. All the phenotypic characteristics of plant species are shaped by the interaction between environmental circumstances and the plant's genetic structure (Ghoma et al., 2022; Varol et al., 2022). It also applies to the HM concentration in plants (Ghoma et al., 2022).

Many of the HMs, including Ni, Cd, and Zn, which are the subject of the study, are essential macro or micronutrients for plant growth and development (Erdem et al., 2023; Riaz et al., 2021). However, the presence of these elements at high concentrations, especially in the soil, causes plant stress and slows plant growth (Kuzmina et al., 2023; Wani et al., 2018). HMs can accumulate in the plant body by being absorbed by the root, through the air, through the leaves, and directly entering the stem parts (Chen et al., 2021). Depending on the type of ions absorbed, HM ions enter the plant via either the symplast or the apoplast. The plant can restrict HM uptake by

precipitating metals or forming complexes in the rhizospheric region (Wani et al., 2018).

The transport of elements within the wood part of plants is related mainly to the cell structure, especially the cell wall. The cell wall–plasma membrane (CWPM) interface represents an apoplastic mechanical barrier and a flexible structure involved in stress sensing, perception, and signaling for the metal/metalloid stress. The CWPs, engaged in response to various abiotic stresses, have been extensively recognized and characterized among different crop plants. Under various stress conditions, the main (CWPM) include phospholipases, the salt overly sensitive kinases (SOS), transcription factors, C-repeat binding factor, dehydration-sensitive element-binding proteins, mitogen-activated protein kinases and phosphatases, and abscisic acid-responsive-binding factors. The cell wall–plasma membrane interface is believed to be the potential site of HM tolerance as it accumulates large fractions of HMs (Wani et al., 2018).

HM concentration in plants results from a complicated mechanism originating from the mutual interaction between numerous factors influencing each other, and this mechanism has not been completely revealed yet (Shahid et al., 2017). The lack of most important information on this subject is about the transfer of HMs entering the wood among the organs (Shahid et al., 2017). The study results show that the transfers of Cd, Ni, and Zn elements in the cedar tree subject to the study are limited. However, the transfer of HMs in the organ may vary from species to species. For example, Zn and Pb concentrations shifted slightly, while the Cu concentration did not change in *Cedrus deodara* annual rings (Zhang, 2019). It was pointed out that the transfer of Ni, Co, and Mn in *Corylus colurna* woods is quite limited (Key et al., 2022). It was also reported that the transfer of Fe, Cd, and Ni was limited in *Cupressus arizonica* woods, but Bi, Li, and Cr transfer was higher (Cesur et al., 2021, 2022). Therefore, suitable tree species should be determined separately for each HM pollution determination.

## 5 Conclusion

In conclusion, it has been determined that the Cd, Ni, and Zn elements have a very high accumulation potential in the annual rings of the cedar tree; these elements increase due to traffic, and their transfer in

the wood is limited. According to these results, the subject species can be used to monitor the change of Cd, Ni, and Zn pollution from the past to the present. In addition, this species can be used effectively in reducing HM pollution in the air because, unlike many species, the potential to accumulate these elements in their wood is very high, and the woody part is the part of a plant with the most mass. Therefore, HM pollution in the air can be reduced by trapping the HMs in this section.

However, this does not apply to every tree species. Studies reveal that the transitions of different HMs between organs in different tree species are at different levels. Therefore, the tree species suitable for determining each HM pollution should be determined separately. The studies to be carried out for this purpose are extremely expensive, and difficult to find suitable materials because the trees to be used in the study must be in a suitable and old location. For this reason, it would be appropriate to evaluate many elements simultaneously in areas where suitable materials can be found.

By using the annual rings of much older trees, this method can provide sufficient information about how the air metal contamination has changed from past to current, as well as the extent of the effects of changes beginning from a long time ago and occurring in a long period such as urbanization and Industrial Revolution on the HM contamination in the air. However, there is a lack of knowledge about the transfer of elements within and between the organs, and further research on this theme should be expanded and carried out in controlled environments.

**Acknowledgements** This study is produced from the MSc thesis titled as “Determination of Heavy Metal Accumulation in Atmosphere by Being Aid of Annual Rings” conducted at Kastamonu University, Institute of Science, Department of Sustainable Agriculture and Natural Plant.

**Author Contribution** HC: design, raw material collection, performed the analysis, writing. HS: design, raw material collection, performed the analysis, and reviewing. İK: data analysis, writing, reviewing and editing. All authors read and approved the final manuscript.

**Data Availability** Not applicable.

**Declarations**

**Ethics Approval and Consent to Participate** Not applicable.

**Consent for Publication** Not applicable.

**Competing Interests** The authors declare no competing interests.

## References

- Alağouri, H. A. A., Genc, C. O., Arıcak, B., Kuzmina, N., Menshikov, S., & Cetin, M. (2020). The possibility of using scots pine needles as biomonitor in determination of heavy metal accumulation. *Environmental Science and Pollution Research*, 27(16), 20273–20280.
- Arıcak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2019). The change of some heavy metal concentrations in scotch pine (*Pinus sylvestris*) depending on traffic density, organelle and washing. *Applied Ecology and Environmental Research*, 17(3), 6723–6734.
- Arıcak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2020). The usability of scotch pine (*Pinus sylvestris*) as a biomonitor for traffic-originated heavy metal concentrations in Turkey. *Polish Journal of Environmental Studies*, 29(2), 1051–1057.
- Canturk, U., & Kulaç, Ş. (2021). The effects of climate change scenarios on *Tilia* ssp Turkey. *Environmental Monitoring and Assessment*, 193(12), 1–15.
- Cesur, A., Cetin, I. Z., Aisha, A. E. S. A., Alrabiti, O. B. M., Aljama, M. O., Jawed, A. A., Cetin, M., Sevik, H., & Ozel, H. B. (2021). The usability of *Cupressus arizonica* annual rings in monitoring the changes in heavy metal concentration in air. *Environmental Science and Pollution Research*, 28(27), 35642–35648.
- Cesur, A., Zeren Cetin, I., Cetin, M., Sevik, H., & Ozel, H. B. (2022). The use of *Cupressus arizonica* as a biomonitor of Li, Fe, and Cr pollution in Kastamonu. *Water, Air, & Soil Pollution*, 233(6), 1–9.
- Cetin, M., Aljama, A. M. O., Alrabiti, O. B. M., Adiguzel, F., Sevik, H., & Zeren Cetin, I. (2022). Using topsoil analysis to determine and map changes in Ni, Co pollution. *Water, Air, & Soil Pollution*, 233(8), 1–11.
- Çetin, M., Dönmez, A. H., & Türkkkan, F. (2020). An investigation on employees’ methods of coping with stress in the COVID-19 outbreak process. *Turkish Studies (Electronic)*, 15(6).
- Chen, S., Yao, Q., Chen, X., Liu, J., Chen, D., Ou, T., Liu, J., Dong, Z., Zheng, Z., & Fang, K. (2021). Tree-ring recorded variations of 10 heavy metal elements over the past 168 years in southeastern China. *Elementa: Science of the Anthropocene*, 9(1), 00075.
- Çiftci, H., Caliskan, C. E., Aslanhan, E., & Aktoklu, E. (2021). Monitoring of heavy metal pollution by using *Populus nigra* and *Cedrus libani*. *Sigma Journal of Engineering and Natural Sciences*, 39(4), 367–373.
- Cimboláková, I., Uher, I., Laktičová, K. V., Vargová, M., Kimáková, T., & Papajová, I. (2019). Heavy metals and the environment. In Ivan, U. (Ed.), *Environmental factors affecting human health*. (pp 1–31). Intechopen.
- EEA (European Environment Agency) (2020). *Health and environment, including air and noise pollution*

- *Putting EEA's work in the spotlight*. Retrieved August 21, 2021, from <https://www.eea.europa.eu/articles/health-and-environment-including-air>
- Elsunousi, A. A. M., Sevik, H., Cetin, M., Ozel, H. B., & Ucu Ozal, H. (2021). Periodical and regional change of particulate matter and CO<sub>2</sub> concentration in misurata. *Environmental Monitoring and Assessment*, 193(11), 1–15.
- Erdem, R., Cetin, M., Aricak, B., & Sevik, H. (2023). The change of the concentrations of B and Na in some forest soils depending on plant species. *Forestist* (In press). <https://doi.org/10.5152/forestist.2022.22061>
- Ghoma, W. E. O., Sevik, H., & Isinkaralar, K. (2022). Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke. *Air Quality, Atmosphere and Health*, 15, 415–424.
- Gratani, L., Crescente, M. F., & Varone, L. (2008). Long-term monitoring of metal pollution by urban trees. *Atmospheric Environment*, 42(35), 8273–8277.
- Isinkaralar, K. (2022a). Atmospheric deposition of Pb and Cd in the *Cedrus atlantica* for environmental biomonitoring. *Landscape Ecological Engineering*, 18, 341–350.
- Isinkaralar, K. (2022b). Some atmospheric trace metals deposition in selected trees as a possible biomonitor. *Romanian Biotechnological Letters*, 27(1), 3227–3236.
- Isinkaralar, K., Koc, I., Erdem, R., & Sevik, H. (2022). Atmospheric Cd, Cr, and Zn deposition in several landscape plants in Mersin, Türkiye. *Water, Air and Soil Pollution*, 233(4), 1–10.
- Karacocuk, T., Sevik, H., Isinkaralar, K., Turkyilmaz, A., & Cetin, M. (2022). The change of Cr and Mn concentrations in selected plants in Samsun city center depending on traffic density. *Landscape and Ecological Engineering*, 18, 75–83.
- Key, K., Kulaç, Ş., Koç, İ., & Sevik, H. (2022). Determining the 180-year change of Cd, Fe, and Al concentrations in the air by using annual rings of *Corylus colurna* L. *Water, Air and Soil Pollution*, 233(7), 1–13. <https://doi.org/10.1007/s11270-022-05741-3>
- Key, K., & Kulaç, Ş. (2022). Proof of concept to characterize historical heavy metal concentrations from annual rings of *Corylus colurna*: Determining the changes of Pb, Cr, and Zn concentrations in atmosphere in 180 years in North Turkey. *Air Quality, Atmosphere and Health*, 15, 1623–1633.
- Khattak, M. I., & Jabeen, R. (2012). Detection of heavy metals in leaves of *Melia azedarach* and *Eucalyptus citriodora* as biomonitoring tools in the region of Quetta valley. *Pakistan Journal of Botany*, 44(2), 675–681.
- Koç, İ. (2021). Using *Cedrus atlantica*'s annual rings as a biomonitor in observing the changes of Ni and Co concentrations in the atmosphere. *Environmental Science and Pollution Research*, 28(27), 35880–35886.
- Koç, İ. (2022a). Do various conifers respond differently to water stress? A comparative study of white pine, concolor and balsam fir. *Kastamonu University Journal of Forestry Faculty*, 22(1), 1–16.
- Koç, İ. (2022b). Determination of the near-future biocomfort zones in Samsun province by global climate change scenarios. *Kastamonu University Journal of Forestry Faculty*, 22(2), 181–192.
- Koç, İ. (2022c). Comparison of gas exchange parameters of two maple species (*Acer negundo* and *Acer pseudoplatanus*) seedlings under drought stress. *Journal of Bartın Faculty of Forestry*, 24(1), 65–76.
- Koç, İ., Nzokou, P., & Cregg, B. (2022). Biomass allocation and nutrient use efficiency in response to water stress: Insight from experimental manipulation of balsam fir, concolor fir and white pine transplants. *New Forests*, 53(5), 915–933.
- Koç, İ. (2019). Conifers response to water stress: Physiological responses and effects on nutrient use physiology. Dissertation, Michigan State University, USA
- Kravkaz Kusu, İ.S., Kılıç Bayraktar, M., & Tunçer, B. (2022). Determination of heavy metal (Cr Co, and Ni) accumulation in selected vegetables depending on traffic density. *Water, Air, & Soil Pollution*, 233(6), 1–10.
- Kuzmina, N., Menshchikov, S., Mohnachev, P., Zavyalov, K., Petrova, I., Ozel, H. B., Aricak, B., Onat, S. M., & Sevik, H. (2023). Change of aluminum concentrations in specific plants by species, organ, washing, and traffic density. *BioResources*, 18(1), 792–803.
- Lageard, J. G. A., Howell, J. A., Rothwell, J. J., & Drew, I. B. (2008). The utility of *Pinus sylvestris* L. in dendrochemical investigations: Pollution impact of lead mining and smelting in Darley Dale, Derbyshire UK. *Environmental Pollution*, 153(2), 284–294.
- Lee, K. H., Luong, T. H., Jang, K. S., Choi, W. J., Park, G. S., Ohga, S., & Oga, S. (2015). Analysis of tree-ring chemistry to interpret variations in tree-ring growth of *Larix leptolepis* and *Cryptomeria japonica* in relation to atmospheric environmental changes in Southern Korea. *Journal of the Faculty of Agriculture, Kyushu University*, 60, 33–42.
- Lepp, N. W. (1975). The potential of tree-ring analysis for monitoring heavy metal pollution patterns. *Environmental Pollution*, 9(1), 49–61.
- Liu, Y., Ta, W., Cherubini, P., Liu, R., Wang, Y., & Sun, C. (2018). Elements content in tree rings from Xi'an, China and environmental variations in the past 30 years. *Science of the Total Environment*, 619, 120–126.
- Martin, J. A. R., Gutiérrez, C., Torrijos, M., & Nanos, N. (2018). Wood and bark of *Pinus halepensis* as archives of heavy metal pollution in the Mediterranean Region. *Environmental Pollution*, 239, 438–447.
- Mu'taz, M., & Mandiwana, K. L. (2007). The use of Aleppo pine needles as a bio-monitor of heavy metals in the atmosphere. *Journal of Hazardous Materials*, 148(1–2), 43–46.
- Mulenga, C., Clarke, C., & Meincken, M. (2022). Bioaccumulation of Cu, Fe, Mn and Zn in native *Brachystegia longifolia* naturally growing in a copper mining environment of Mufulira, Zambia. *Environmental Monitoring and Assessment*, 194(1), 1–13.
- Nechita, C., Iordache, A. M., Lemr, K., Levanič, T., & Pluhacek, T. (2021). Evidence of declining trees resilience under long term heavy metal stress combined with climate change heating. *Journal of Cleaner Production*, 317, 128428.
- Pearson, C. L., Manning, S. W., Coleman, M., & Jarvis, K. (2006). A dendrochemical study of *Pinus sylvestris* from Siljansfors experimental forest, central Sweden. *Journal of Applied Geochemistry*, 21(10), 1681–1691.

- Ram, S. S., Majumder, S., Chaudhuri, P., Chanda, S., Santra, S. C., Maiti, P. K., Sudarshan, M., & Chakraborty, A. (2014). Plant canopies: Bio-monitor and trap for re-suspended dust particulates contaminated with heavy metals. *Mitigation and Adaptation Strategies for Global Change*, 19(5), 499–508.
- Riaz, M., Kamran, M., Fang, Y., Wang, Q., Cao, H., Yang, G., Deng, L., Wang, Y., Zhou, Y., Anastopoulos, I., & Wang, X. (2021). Arbuscular mycorrhizal fungi-induced mitigation of heavy metal phytotoxicity in metal contaminated soils: A critical review. *Journal of Hazardous Materials*, 402, 123919.
- Saat, A., Mohamed, N. A., Hamzah, Z., & Hamzah, S. (2016). Application of moss as bio-monitor for heavy metals deposition in Port Dickson, Malaysia. *Jurnal Teknologi*, 78(6–6), 41–46.
- Savas, D. S., Sevik, H., Isinkaralar, K., Turkyilmaz, A., & Cetin, M. (2021). The potential of using *Cedrus atlantica* as a biomonitor in the concentrations of Cr and Mn. *Environmental Science and Pollution Research*, 28, 55446–55453.
- Sawidis, T., Breuste, J., Mitrovic, M., Pavlovic, P., & Tsigaridas, K. (2011). Trees as bioindicator of heavy metal pollution in three European cities. *Environmental Pollution*, 159(12), 3560–3570.
- Seven, T., Darende, B. N., & Ocak, S. (2018). Hava ve toprakta ağır metal kirliliği. *National Journal of Environment and Scientific Research*, 1(2), 91–103.
- Sevik, H., Cetin, M., Ozel, H. B., & Pinar, B. (2019a). Determining toxic metal concentration changes in landscaping plants based on some factors. *Air Quality, Atmosphere and Health*, 12(8), 983–991.
- Sevik, H., Ozel, H. B., Cetin, M., Özel, H. U., & Erdem, T. (2019b). Determination of changes in heavy metal accumulation depending on plant species, plant organism, and traffic density in some landscape plants. *Air Quality, Atmosphere and Health*, 12(2), 189–195.
- Sevik, H., Cetin, M., Ozel, H. U., Ozel, H. B., Mossi, M. M., & Cetin, I. Z. (2020). Determination of Pb and Mg accumulation in some of the landscape plants in shrub forms. *Environmental Science and Pollution Research*, 27(2), 2423–2431.
- Shahid, M., Dumat, C., Khalid, S., Schreck, E., Xiong, T., & Niazi, N. K. (2017). Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake. *Journal of Hazardous Materials*, 325, 36–58.
- Sulayman, A. F., Abdu, H., Saidu, A. A., Ahmad, F., Suleiman, J. Z., & Saleh, I. (2021). Bark of neem tree (*Azadirachta indica*) as bioindicator for deposition of heavy metals around Katsina Steel Rolling Company in Katsina Township. *Current Approaches in Science and Technology Research*, 3, 9–18.
- Sulhan, O. F., Sevik, H., & Isinkaralar, K. (2022). Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye. *Environment, Development and Sustainability*, 1–20. <https://doi.org/10.1007/s10668-022-02647-2>
- Turkyilmaz, A., Sevik, H., Isinkaralar, K., & Cetin, M. (2018). Using *Acer platanoides* annual rings to monitor the amount of heavy metals accumulated in air. *Environmental Monitoring and Assessment*, 190(10), 1–11.
- Turkyilmaz, A., Sevik, H., Isinkaralar, K., & Cetin, M. (2019). Use of tree rings as a bioindicator to observe atmospheric heavy metal deposition. *Environmental Science and Pollution Research*, 26(5), 5122–5130.
- Turkyilmaz, A., Cetin, M., Sevik, H., Isinkaralar, K., & Saleh, E. A. A. (2020). Variation of heavy metal accumulation in certain landscaping plants due to traffic density. *Environment, Development and Sustainability*, 22(3), 2385–2398.
- Varol, T., Canturk, U., Cetin, M., Ozel, H. B., & Sevik, H. (2021). Impacts of climate change scenarios on European ash tree (*Fraxinus excelsior* L.) in Turkey. *Forest Ecology and Management*, 491, 119199.
- Varol, T., Cetin, M., Ozel, H. B., Sevik, H., & Zeren Cetin, I. (2022). The effects of climate change scenarios on *Carpinus betulus* and *Carpinus orientalis* in Europe. *Water, Air, and Soil Pollution*, 233, 45.
- Wani, W., Masoodi, K. Z., Zaid, A., Wani, S. H., Shah, F., Meena, V. S., Wani, S. A., & Mosa, K. A. (2018). Engineering plants for heavy metal stress tolerance. *Rendiconti Lincei. Scienze Fisiche e Naturali*, 29(3), 709–723.
- Watmough, S. A. (1997). An evaluation of the use of dendrochemical analysis on environmental monitoring. *Environmental Reviews*, 5(3–4), 181–201.
- Watmough, S. A., & Hutchinson, T. C. (2003). A comparison of temporal patterns in trace metal concentration in tree rings of four common European tree species adjacent to a Cu-Cd refinery. *Water, Air, and Soil Pollution*, 146(1), 225–241.
- WHO (2021). *Air pollution*. Retrieved August 21, 2021. [https://www.who.int/health-topics/air-pollution#tab=tab\\_1](https://www.who.int/health-topics/air-pollution#tab=tab_1).
- Yavuzer, H., & Etem, O. (2018). Salix fragilis L. (Gevrek Söğüt)'in ağır metal kirlenmesinde biomonitör olarak değerlendirilmesi. *Anadolu University Journal of Science and Technology C-Life Sciences and Biotechnology*, 7(2), 122–129.
- Yayla, E. E., Sevik, H., & Isinkaralar, K. (2022). Detection of landscape species as a low-cost biomonitoring study: Cr, Mn, and Zn pollution in an urban air quality. *Environmental Monitoring and Assessment*, 194(10), 1–10.
- Yigit, N. (2019). Determination of heavy metal accumulation in air through annual rings: The case of *Malus floribunda* species. *Applied Ecology and Environmental Research*, 17(2), 2755–2764.
- Zhang, X. (2019). The history of pollution elements in Zhengzhou, China recorded by tree rings. *Dendrochronologia*, 54, 71–77.

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.