World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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THE USE OF TREE GROWTH RINGS TO DETERMINE CHANGES IN ATMOSPHERIC PB, CR, AND MN CONCENTRATIONS

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World Journal of Advanced Research and Reviews, 2026, 31(03), 615–622

Publication history: Received on 02 August 2026; revised on 09 September 2026; accepted on 11 September 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.31.3.2345

ABSTRACT

Air pollution is one of the most significant problems facing the world today. Among the components of air pollution, Pb, Cr, and Mn—which primarily originate from traffic and anthropogenic sources—are extremely harmful, toxic, and carcinogenic elements for human and environmental health. For this reason, monitoring changes in the concentrations of these elements in the air is of great importance. Within the scope of this study, changes in the atmospheric concentrations of Pb, Cr, and Mn in Düzce Province over the past 60 years were determined. The study was conducted by using the annual rings of the *Tilia platyphyllos* tree as a biomonitor. The study determined how the concentrations of Pb, Cr, and Mn in the air in Düzce have changed over the past 60 years and to what extent these elements have been transferred into the wood. The results of the study indicate that the accumulation of Pb, Cr, and Mn in the tree under study is largely related to traffic, and that Pb and Cr, in particular, can be redistributed within the wood. Based on these results, it can be concluded that the *Tilia platyphyllos* species is not a suitable biomonitor for tracking changes in Pb, Cr, and Mn pollution.

Keywords: Air Pollution, Biomonitor, Tree Ring

1 INTRODUCTION

Today, air pollution has become one of the most significant problems on a global scale (Özel et al., 2025). In fact, it is reported that air pollution causes the deaths of 9–12 million people worldwide each year, and approximately 12.5% of global mortality rates are attributed to air pollution (Kulac et al., 2025). It is noted that air pollution ranks second among the risks leading to death globally, and it is reported that approximately one-third of deaths from stroke, lung cancer, heart attack, and COPD are attributable to air pollution (Brauer et al., 2021). The World Health Organization (WHO) states that nearly the entire world population (99%) breathes air that exceeds WHO air quality limits and poses a threat to their health (Kulac et al., 2025). Pollution affects not only humans but all living beings. In fact, it has been noted that certain pollutants, such as nanoparticles, may soon affect even the most remote ecosystems (Özel et al., 2024). Similarly, heavy metals can be hazardous, harmful, and toxic to humans even at very low concentrations. Furthermore, the release of heavy metals into the environment is steadily increasing (Sevik et al., 2019a; Ozturk Pulatoglu et al., 2025).

In addition to this, air pollution, coupled with unplanned urbanization, has become one of the major environmental issues threatening ecosystems (Isinkaralar et al., 2024a, b). Particularly for individuals with various health conditions, exposure to air pollution—which intensifies in urban areas—can lead to serious adverse health effects. Air quality can be significantly degraded due to anthropogenic factors, primarily industry, traffic, and heating (Sevik et al., 2025; Demirci et al., 2026).

Although air pollution consists of many components, heavy metals hold particular significance among them because they do not easily degrade or disappear in nature, tend to bioaccumulate in living organisms, are often toxic, carcinogenic, and poisonous, and can be lethal to human health even at low concentrations (Sevik et al., 2020). In particular, Pb, Cr, As, Cd, and Hg are considered among the most toxic heavy metals in terms of their potential toxicity and effects on living organisms. Industrial activities and traffic are identified as the most significant sources of heavy metals. For this reason, monitoring changes in heavy metal pollution in areas with high levels of industrial activity and traffic is of great importance (Isinkaralar et al., 2025a, b). Monitoring of heavy metal pollution in the atmosphere can be conducted directly or indirectly. However, direct measurement of pollution is not widely preferred due to its high cost and the inability to determine the direct impact of atmospheric pollution on ecosystems. The most effective method used to monitor the indirect effects of heavy metal pollution is biomonitors. In particular, plants used as biomonitors accumulate heavy metals in various parts of their bodies, and determining the concentration of heavy metals in these parts provides important information about the concentration of heavy metals in the air (Sevik et al., 2019a, b; Ozturk Pulatoglu et al., 2025).

By evaluating studies on the use of plants as biomonitors, gaps in the literature were identified, and this study was planned. Within the scope of this study, the temporal and directional variations in the concentrations of Pb, Cr, and Mn—heavy metals most closely associated with traffic density—in the annual rings of a Tilia platyphyllos tree growing in Düzce were determined. As part of the study, heavy metal concentrations in the topsoil and subsoil were also determined.

2 MATERIAL AND METHODS

The study was conducted on a *Tilia platyphyllos* tree growing in the city center of Düzce. The log and soil samples used in the study were collected in February 2022 during a felling operation at the Düzce City Cemetery; the north side of the log was marked and its coordinates were recorded. Age analyses performed on the collected log samples determined that the tree was approximately 60 years old. Subsequently, the upper surface of the log was sanded smooth in the laboratory to make the annual rings more clearly visible. For the purposes of this study, the log was divided into 12 groups, each representing a 5-year interval, from the outer to the inner layers, based on annual ring widths. After the wood surface was divided into groups and the age ranges were determined, samples were taken from the wood in each age range using a steel-tipped drill and placed in glass Petri dishes. The collected wood samples were broken down into sawdust. Care was taken during these procedures to avoid using tools made of the metals under study.

Soil samples were collected from three different soil layers—representing depth ranges of 0–5 cm, 5–15 cm, and 15–50 cm—after the surface litter had been removed. The collected soil samples were left to air-dry under laboratory conditions for two weeks, labeled, and stored. After the soil samples reached room-dry condition, they were sieved and transferred to glass Petri dishes. The samples in the glass dishes were left open in the laboratory until they reached room-dry condition, and the room-dry samples were then placed in an oven and dried at 45 °C for two weeks. A 0.5-gram sample was taken from the dried specimens; 6 mL of 65% HNO_3 and 2 mL of 30% H_2O_2 were added, and the mixture was placed in a microwave oven. The microwave program was set to heat up to 200 °C in 15 minutes and maintain that temperature for 15 minutes. After the samples were digested in the microwave oven, the resulting solutions were transferred to graduated flasks and diluted to 50 mL with ultrapure water, and heavy metal analyses were performed using an ICP-OES instrument. Since 0.5 g of each sample was taken and diluted with water to 50 g, the analysis results were multiplied by 100. For analysis results that fell outside the calibration curve, separate calibration curves were created at the ppm or ppb level, and the readings were repeated. This method is frequently used in studies conducted on similar topics in recent years (Gültekin et al., 2025; Ismail et al., 2026). Analysis of variance (ANOVA) was applied to the obtained data using the SPSS 21.0 software package, and the results were tabulated and interpreted.

3 FINDINGS

The results of the analysis of variance regarding the directional variation of the elements under study are presented in Table 1

Table 1: Variation of the elements under study by direction

Direction	Cr (ppb)	Mn (ppb)	Pb (ppb)
South	349.8 a	4472.1	1651.3 a
West	431.7 a	4849.5	1226.0 a
North	835.0 b	4536.0	3733.8 b
East	1358.2 c	3113.2	6106.5 c
F Value	27.295***	0.413 ns	54.146***

According to the results of the analysis of variance, the variation of Mn—one of the elements under study—by direction is not statistically significant. Therefore, Mn concentrations were not evaluated. The variation of Cr and Pb by direction, however, is statistically significant at a 99.9% confidence level. The lowest Cr concentrations by direction were obtained in the south and west, while the highest Cr concentrations were obtained in the east. The lowest Pb concentrations by direction were obtained in the south and west, while the highest Pb concentrations were obtained in the east. The results of the analysis of variance regarding the variation of the elements under study by age range are presented in Table 2.

Table 2: Variation of the elements under study by age range

Age Range	Cr (ppb)	Mn (ppb)	Pb (ppb)
1983-1987	492.1	1679.1 ab	2307.4
1988-1992	591.6	1220.3 a	3157.3
1993-1997	604.0	2189.4 b	3050.2
1998-2002	593.5	1924.0 b	3115.1
2003-2007	466.7	2265.2 b	2490.3
2008-2012	673.9	1716.5 ab	2580.0
2013-2017	512.2	1986.1 b	2321.0
2018-2022	433.5	1887.8 b	1858.3
F Value	0.480 ns	2.448*	0.688ns

According to the results of the analysis of variance, the variation in Cr and Pb concentrations—the elements under study—by age range is not statistically significant. However, the variation in Mn concentration by age range is statistically significant at the 95% confidence level. The lowest Mn concentration by age group was observed in 1988–1992, while the highest Mn concentration was observed in 2003–2007. The results of the analysis of variance regarding the variation of the elements under study by organ are presented in Table 3.

Table 3: Variation of the elements under study by organ

Organ	Cr (ppb)	Mn (ppb)	Pb (ppb)
Wood	545.9 a	1858.5 a	2610.0 a
Inner Bark	1463.1 b	5080.8 b	5770.0 b
Outer Bark	1606.3 b	22477.9 c	5144.2 b
F Value	40.345***	519.288***	15.036***

According to the results of the analysis of variance, the variation in all elements under study by organ is statistically significant at a 99.9% confidence level. The lowest Cr concentration by organ was obtained in wood, while the concentrations obtained in the bark were classified in the same group according to the Duncan test. The lowest Mn concentration by organ was found in the wood, while the highest Mn concentration was found in the outer bark. The lowest Pb concentration by organ was found in the wood, while the concentrations obtained from the bark were grouped together based on the Duncan test results. Based on these results, it can generally be stated that the lowest values were obtained in the wood and the highest values in the bark. The results of the analysis of variance regarding the variation of the elements under study in soils based on depth are presented in Table 4.

Table 4: Variation of the elements under study in soils based on soil depth.

Soil Depths	Cr (ppb)	Mn (ppb)	Pb (ppb)
Lower (0-5 cm)	316.0 b	18.9 a	18.9 b
Middle (5-15 cm)	271.1 a	24.9 b	32.1 c
Upper (15-50 cm)	323.2 b	23.9 b	13.4 a
F Value	101.392***	97.138***	1399.136***

According to the results of the analysis of variance, the variation in all elements studied based on soil depth is statistically significant at a 99.9% confidence level. The Duncan test revealed that the lowest Cr concentration was found in the middle-depth soils, while the Cr concentrations in the upper and lower soils were classified in the same group based on the Duncan test. The lowest Mn concentration was found in the lower soil layers, while the Mn concentrations in the upper and middle soil layers were classified in the same group according to the Duncan test. According to the Duncan test, the lowest Pb concentration was found in the upper soil layers, while the highest Pb concentrations were found in the middle soil layers.

4 RESULT AND DISCUSSION

The results of the study indicate that the highest concentrations of the elements under investigation were generally found in the eastern part of the study area. It is believed that the highway located in the eastern part of the study area is responsible for this situation. This is because Pb is one of the heavy metals most closely associated with traffic density. In their study, Sevik et al. (2020) determined that the Pb concentration in trees on the roadside was 2,160.9 ppb, whereas the average Pb concentration in trees on the opposite side was 980.1 ppb. Sevik et al. (2019b) found that Pb concentrations in Ailanthus altissima leaves, which were 321 ppb in areas without traffic, rose to 8,181 ppb in areas with heavy traffic. Similarly, numerous studies have demonstrated that heavy metal concentrations in plants increase due to traffic (Koç et al., 2026a, b; Sevik et al., 2026; Ozturk Pulatoglu et al., 2026).

The study concluded that variations in heavy metal concentrations by plant organ were also significant, and the highest values were generally observed in the outer bark. This is largely related to particulate matter contaminated with heavy metals. Studies have shown that heavy metals in the air adhere to particulate matter, contaminating it with heavy metals, and that as this particulate matter settles on plant organs, heavy metal concentrations in those organs increase (Key et al., 2023; Erdem et al., 2024; Sevik et al., 2024). The rough surface structure of the outer bark facilitates the adhesion of particulate matter; the high concentrations of heavy metals observed on bark facing the direction of heavy traffic are explained by the contamination of particulate matter in that direction with traffic-derived heavy metals (Koc et al., 2025a, b; Sevik et al., 2025).

Knowledge regarding the speciation of heavy metals within plants and their transfer between organs, starting from their entry into the plant, is quite limited. Some studies on this topic have shown that the transfer of certain elements within wood can vary from species to species. For example, it has been determined that Pb and Zn can be transferred within the wood of *Cedrus deodora*; As, Sr, Pd, V, Ag, Se, Sb, and Tl within the wood of *Pinus nigra*; Co within the wood of *Cedrus atlantica*; and Bi, Li, and Cr within the wood of *Cupressus arizonica*. In contrast, it has been noted that the transfer of Cu in *Cedrus deodora,* Tl in *Picea orientalis*, Ni, Cr, and Mn in *Cedrus atlantica*, Cd, Ni, Cr, Tl, Fe, and Zn in *Cupressus arizonica*, and Cd, Ni, Zn, Co, Pb, Cr, Mn, and Zn in *Corylus colurna* is more limited (Key et al., 2023; Koç, 2025; Şevik et al., 2024). In this study, however, the values obtained for Pb and Cr in wood from different years were not statistically significant. This result can be interpreted to mean that these elements are transferred within the wood of the species under study.

Heavy metals can enter a plant’s system directly from the soil via roots, or from the air through leaves or stem sections (Key et al., 2023). However, when evaluating heavy metals in the soil in this study, it can be stated that their uptake into stem sections is not related to the heavy metals in the soil.

Heavy metal accumulation can vary significantly depending on plant species and organs within the same species (Dışbudak et al., 2026; Erdem et al., 2026). This is because many factors play a simultaneous role in the uptake and accumulation of heavy metals in plants. The uptake and movement of heavy metals within plants are influenced by various factors, including plant species, organ structure, surface area, interactions between heavy metals and plants, and weather conditions (Yaşar İsmail et al., 2024; Canturk et al., 2024). Furthermore, plant habitus and development also significantly influence heavy metal uptake and accumulation (Erdem et al., 2023). Consequently, all factors affecting plant habitus also influence the uptake and accumulation of heavy metals in these plants. Plant habitus, genetic structure (Sevik et al., 2012; Kurz et al., 2023; Onat et al., 2026), edaphic factors (Yucedag et al., 2019; Kravkaz Kuşçu et al., 2018), and climatic factors (Yigit et al., 2019; Gür et al., 2024; Aricak et al., 2024; Ertürk et al., 2024; Cantürk et al., 2025), as well as stress factors (Sevik and Topacoglu, 2015), maintenance, pruning, and hormone applications (Guney et al., 2016; Özel et al., 2022; Kalayci et al., 2025), among many others. Consequently, many of these factors directly and indirectly influence one another and, consequently, the plants' potential for heavy metal accumulation; however, our understanding of this complex mechanism has not yet reached a sufficient level (Kravkaz Kuşçu, 2025).

5 CONCLUSION

The study results revealed that heavy metal concentrations in linden bark are higher than those in wood. However, it was determined that heavy metal concentrations in wood generally vary within a narrow range. The fact that the range of variation in the wood is so limited has been interpreted to mean that the heavy metals under study can be transferred between wood tissues. This indicates that the species studied is not a suitable biomonitor for tracking changes in Pb, Cr, and Mn contamination.

The results of the study showed that the highest values for Cr and Pb were obtained in the eastern direction. There is a heavily trafficked highway to the east of the study area. This suggests that traffic is the primary source of Pb and Cr pollution. It is recommended that research on this topic be diversified and expanded, that other heavy metals be included in future studies, and that necessary measures be taken to reduce pollution.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

This study is supported by the Kastamonu University Scientific Research Project Coordination Unit (Project Number is KÜBAP-01/2022-11). We sincerely thank to Kastamonu University Scientific Research Project Coordination Unit.

Funding Source

This study is supported by the Kastamonu University Scientific Research Project Coordination Unit (Project Number is KÜBAP-01/2022-11).

Disclosure of conflict of interest

The authors declare that they no conflict of interest.

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