



Assessing the possibility of airborne bismuth accumulation and spatial distribution in an urban area by tree bark: A case study in Düzce, Türkiye

Kaan Isinkaralar¹ · Oznur Isinkaralar² · İsmail Koç³ · Halil Barış Özel⁴ · Hakan Şevik¹

Received: 2 March 2023 / Revised: 24 May 2023 / Accepted: 25 May 2023 / Published online: 30 May 2023
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2023

Abstract

Heavy metal accumulation has been a hot topic of many studies in recent years, as they are toxic elements that can be highly harmful to human health and the environment. The metal concentrations of some trees used for monitoring air quality give information about the pollutant sources in the ambient atmosphere. In this study, *P. pinaster*, *C. arizonica*, *P. orientalis*, *C. atlantica*, and *P. menziesii* were determined to investigate their use as biomonitors for air quality. Metallic bismuth and bismuth compounds, which have been widely used in several industries, have low toxicity to humans, although bismuth toxicity can show over-dosage depending on its application. The variability of bismuth levels in the organs of the species was investigated to explain atmospheric deposition over the years. The bismuth accumulation of *C. arizonica* and *P. pinaster* increases depending on time interval. The ascending-descending trend in other species could not be obtained clearly via dry and wet deposition of atmospheric metals. Our analysis reveals that the total deposit (barks and wood) of *P. pinaster*, *C. arizonica*, *P. orientalis*, *C. atlantica*, and *P. menziesii* were 134, 115, 94, 131, and 148 mg/kg, respectively, and they have been quite clearly reflected atmospheric bismuth deposition. The bismuth concentration has significantly increased since the 1983 sampling; *P. menziesii* can be valuable bioindicators for highlighting polluted areas. Compared with the traditional air samplers, the proposed *P. menziesii* bioindicator is proven to be more effective, low cost, and sustainable and thus has broad application prospects in bismuth concentration.

Keywords Atmospheric deposition, Metal · Urban area · Spatio-temporal analyzes

1 Introduction

The population concentrated in urban neighborhoods needs land use changes for many urban services with the complex dynamics and dissolution of rural areas [1–3]. Anthropogenic activities such as the concentration of

buildings, transportation infrastructure, and production systems raise many environmental issues and climatic risks, deforestation, land degradation, and ecosystem losses [4, 5]. In addition to the well-known ecological costs of these changes, the need for a comprehensive assessment of their irreversible impact on public health is increasing daily. Human health in cities has risen enormously depending on pollution types arising from the wrong positioning of commercial, industry, school, parks, and industrial and commercial zones [6, 7]. Heavy metals constitute environmental pollution that extends to various regions simply as a function of air flows and atmospheric deposition [8, 9]. Moreover, interrupting the urban ventilation in cities and the fact that structures and capacity built against prevailing winds do not allow the distribution and diluting pollutants increase the presence of air pollutants, and over 90% of the urban population is exposed to atmospheric pollution in Europe region [10, 11]. In addition, the innovative and exciting process proposed in this

✉ Kaan Isinkaralar
kisinkaralar@kastamonu.edu.tr

¹ Department of Environmental Engineering, Faculty of Engineering and Architecture, Kastamonu University, 37150 Kastamonu, Türkiye
² Department of City and Regional Planning, Faculty of Engineering and Architecture, Kastamonu University, 37150 Kastamonu, Türkiye
³ Forestry Vocational School, Düzce University, Düzce, Türkiye
⁴ Faculty of Forestry, Department of Forestry, Bartın University, Bartın, Türkiye

paper thoroughly absorbed bismuth (Bi) metal in the tree residues for extraction, which significantly improved the source in urban to recover from the bark in future studies.

Currently, air pollutant concentrations occur in a dense smog layer like pollution cover in that region because resolution gases released cannot be dispersed in the high-pressure air environment [12]. Moreover, many toxic metals do not spread easily, especially heavy metals can remain in the region for quite a long time and threaten all age group's respiratory and immune systems [13]. Previous reports stated that toxic metals could adversely affect human health and, unfortunately, cause more negative effects in children than in adults [14, 15]. Since the daily intake of toxic substances in children is less than in adults [16, 17]. Therefore, it is necessary to continuously monitor environmental pollutants and determine the measures to be taken if their concentrations increase to protect the environment and public health. However, since it is tough to monitor pollutants continuously, methods have been used for air quality in urban [18]. At the beginning of the species used in biomonitors studies, tree and landscape species had high absorption capacity in the region. The usability of trees used in many studies in monitoring heavy metals and toxic substances in urban areas has been tested, and positive results have been obtained [19–21]. Anthropogenic pollutants from the atmosphere trees may absorb onto foliage and bark, which can be successive uptake by roots over time. The potential of tree bark has been substantially exercised as an extraordinary natural biosorbent material of atmospheric organic pollutants, including wet and dry deposition (gas and particle phases) by researchers [22–24]. In particular, these species placed in regions to keep the emissions from traffic, industry, and businesses in cities have been determined to be relatively high compared to the other areas [25–27]. However, deposition of all types was not positively correlated with heavy metal releases for all species. Both semivolatile and particles can be absorbed by the bark from the urban air [28, 29]. The accumulation of air pollutants depends on organ, perennial, defoliation-evergreen, and resistance to toxic substances in this species. The assembly of several metal elements in a tree's organ is mainly controlled as the passive atmospheric sampler. In contrast, organ trace metals are attributed to dry and wet atmospheric deposition [30–33]. The application of tree bark (inner and outer) and wood in monitoring toxic metal can obtain depending year. This method is more economically practical than active air samplers. It can be extensively and routinely used for many tree species' pollutants in atmospheric deposition conditions. Based on the above information, we hypothesize that tree bark in directions can perform as a possible passive sampler to evaluate the concentration of Bi.

To the best of our knowledge, this investigation is the first work on the biomonitoring capacities of the selected

species in the Bi minerals weakly accumulation correlates for a wide range of deposit types by possibly including the dense residential and traffic areas in the province of Düzce. Bi is diamagnetic and a group V element, known as a harmful by-product and a critical mineral by the European Commission in 2017. However, the chemical industry has been widely used as an essential metal for its economic importance in pharmaceutical, paint, and solvent areas. The accumulation in the organs of the *P. pinaster*, *C. arizonica*, *P. orientalis*, *C. atlantica*, and *P. menziesii* was obtained at the urban scale and had the same characteristics as the literature data. In line with the findings, it is aimed at a passive atmospheric sampler to estimate primary Bi-level and to spread the species that can be used as biomonitors, to minimize the impact of the pollutants in the cities on public health. We also anticipate that considering arousing curiosity, can we make the semiconductor or conductors that accumulate ready for reuse? It provides new insight into the atmospheric metal deposition on biomonitoring species, which will assist in a future strategy for green metal recovery from nature.

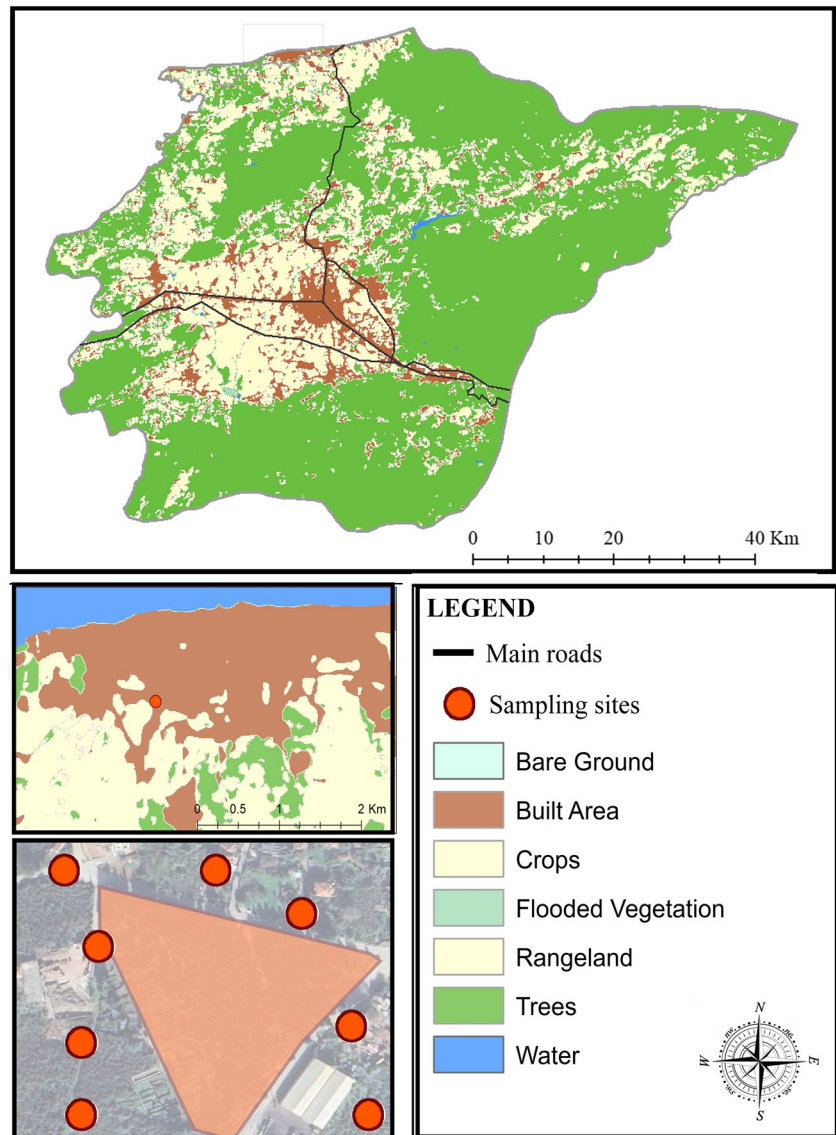
2 Materials and methods

2.1 Study area and preparation sampling

Figure 1 shows that the study includes species collected from the rural region of Düzce in Türkiye and counts more than 400,976. Their common feature is that they are widely found and have the same age. At each site, a total of 135 samples were prepared for collecting trees to coincide from May to June without rainy conditions in 8 sampling locations. To separately evaluate the inner bark, outer bark, and wood parts of *Pinus pinaster*, *Cupressus arizonica*, *Picea orientalis*, *Cedrus atlantica*, and *Pseudotsuga menziesii* were detailed described in our previous study [34]. Trees precisely measured tree-ring series width, preferentially chosen 40 years for each annual tree ring and a trunk diameter of 20–30 cm due to frequent planting throughout Düzce City. The 2–3 mm outer bark from each direction of the trunk was removed at 1.5 m from the topsoil, and the 2–3 cm thick inner bark samples were taken with a homogenization by stainless-steel twist drill. Also, the bark samples from 3 to 4 individual trees with the same species were separately prepared for the calculation content of Bi. The samples were taken to the polyethylene bags and kept at $-18\text{ }^{\circ}\text{C}$ before analysis.

Briefly, the samples were taken care of and without being exposed to any contamination, individually packaged from every position (west, east, south, and north), and brought to the laboratory, respectively; (i) it was put in an oven at $55\text{ }^{\circ}\text{C}$ for 2 weeks for drying, (ii) cut

Fig. 1 Overview of the study site showing the sampling plots



into small pieces after making sure that the moisture was removed, (iii) 10 mL of 65% HNO_3 (Merck) was added to the samples for acid digestion performed assisting within a microwave treatment at 280 PSI and 180 °C during 20 min. Samples were prepared for microwave-assisted digestion after the tubes cooled down following their removal from the microwave (Ethos One, Milestone GmbH, Germany); distilled water was added to fill up to 50 mL according to US EPA 3052 Method [35], (iv) the element concentrations in the samples filtered through the filter paper were read at the appropriate wavelengths in the inductively coupled plasma optical emission spectrometry (ICP-OES, SpectroBlue, Spectro, Analytical Instruments GmbH, Germany) using Method 6020B [36]. Method detection limits (MDL: 1.8 $\mu\text{g}/\text{kg}$) were appointed from method blanks with

every 10 for Bi according to US EPA 200.7 Method [37] and presented calibration correlation coefficients ranges of 0.989–0.995.

2.2 Statistically data use and visualization

Applying variance analysis of one-way ANOVA and Duncan's was involved through the SPSS version 22.0 used for the data attained as a result of laboratory analysis of the samples. The data was followed by a test for Bi elements with statistically significant differences at the 95% confidence level, and results were interpreted via the ANOVA and Duncan's test. Values were periodically assessed with every eight samples for blanks and matrix spikes during the statistical analysis. The limits of detection (LODs) and

quantitation (LOQs) were determined as the concentration yielding a signal-to-noise ratio of 2–11, and the values of Bi were changed from 0.025 to 0.177 $\mu\text{g}/\text{kg}$. The distribution of excessive amounts of Bi concentrations was plotted based on the average in ArcMap 10.7 via spatial analysis tool.

3 Results

The total accumulation of Bi concentrations in the progressively collected samples' outer, inner bark, and wood vary according to year and directions. It has been demonstrated that biomonitoring approaches can be obtained through tree bark uptake with airborne Bi in five ornamental species. Bi's maximum and minimum values were obtained to evaluate the location, yearly variations, and directions. The measured concentrations of Bi varied and spatiotemporal trends and atmospheric conditions directly affected the absorption capacity.

3.1 Effect of directions on the spatial distribution

The ANOVA and Duncan's test results determined the variation of Bi concentration based on species in all directions in Table 1. The highest Bi concentrations are obtained in *C. arizonica* and *C. atlantica* in all directions, especially in the north, which is higher than others. The Bi concentration is statistically significant, and the highest values were obtained in *P. orientalis* and *C. atlantica* in all directions. To examine the directional variation, we summarized published data on Bi accumulation and compared

Table 1 Directional variation of Bi concentration (mg/kg)

Species	North	East	South	West
<i>P. pinaster</i>	43 a	74 c	17 a	10 a
<i>C. arizonica</i>	63 b	76 c	37 c	11 a
<i>P. orientalis</i>	37 a	58 b	30 bc	7 a
<i>C. atlantica</i>	64 b	44 a	26 b	63 b
<i>P. menziesii</i>	47 a	54 ab	38 c	61 b
F value	12.1***	9.9***	7.3***	54.8***

*** indicate $p < 0.001$, and Duncan's test results show that the group is located as a, b, c, etc.

Table 2 The mean of the Bi accumulation (mg/kg) concentration in bark and wood

Organ	<i>P. pinaster</i>	<i>C. arizonica</i>	<i>P. orientalis</i>	<i>C. atlantica</i>	<i>P. menziesii</i>	F value
Outer bark	49 ab	26 a	28 a	32 ab	57 b	2.4 ns
Inner bark	52 b	37 ab	27 a	53 b	45 ab	2.3 ns
Wood	33 a	53 c	41 ab	47 bc	49 bc	7.8***

Ns, not significant, and *** indicate $p < 0.001$, and Duncan's test results show that the group is located as a, b, c, etc.

each other. Among the five species analyzed, East and North were the two major interaction contributors to the total Bi, with mean concentrations of 61 and 51 (mg/kg).

The changes in the concentration of other metals, except for Bi, have been examined in all species in Table 2. They are statistically significant at the 95% confidence level that the Bi concentration is analyzed for statistically significant (at least $p < 0.05$). Duncan's test results showed that all species were in the first group, while the highest values were attained in the outer bark. The variation of Bi concentration in the outer bark based on species is not statistically significant. However, the highest concentrations were obtained in the outer bark; although the most elevated amounts were gained in *C. arizonica* and *C. atlantica* in wood, the lowest values were procured in *P. orientalis* and *P. menziesii*. The variation of Bi concentration by species is statistically significant in all directions. When examining the values, it is noteworthy that the highest values were obtained in *P. orientalis* and *C. atlantica* species.

Based on the data obtained, the Bi distributions in the immediate vicinity of the area are spatially presented in Fig. 2. It is reflected by spatial analysis that the values are lower in the south directions. It has been determined that the Bi concentration is effective in the east and north directions.

The average Bi content of the area according to the measurements made from different directions is shown in Fig. 3. Measurements of *P. pinaster*, *C. arizonica*, and *P. orientalis* plants show similar behavior. In these measurements, the values are higher east and north directions than in the others. *C. atlantica* and *P. menziesii* gave similar results. The measurements in the north and west directions are higher than in other directions. What all the measures have in common is that there is a northward accumulation. Bi content is the highest in the southeast direction, reaching 62.2 mg/kg according to its mean values.

The accumulation levels among the species were compared in terms of outer bark, inner bark, and wood. Based on Bi accumulation levels in outer bark, inner bark, and wood, they were determined as follows: 32, 53, and 47 mg/kg in *C. atlantica*; 26, 37, and 53 mg/kg in *C. arizonica*; 57, 45, and 49 mg/kg in *P. menziesii*; 28, 27, and 41 mg/kg in *P. orientalis*; 49, 52, and 33 mg/kg in *P. pinaster*. It shows that the interorgan transmission in Bi accumulation is from outside to inside, except for *C. atlantica*, is

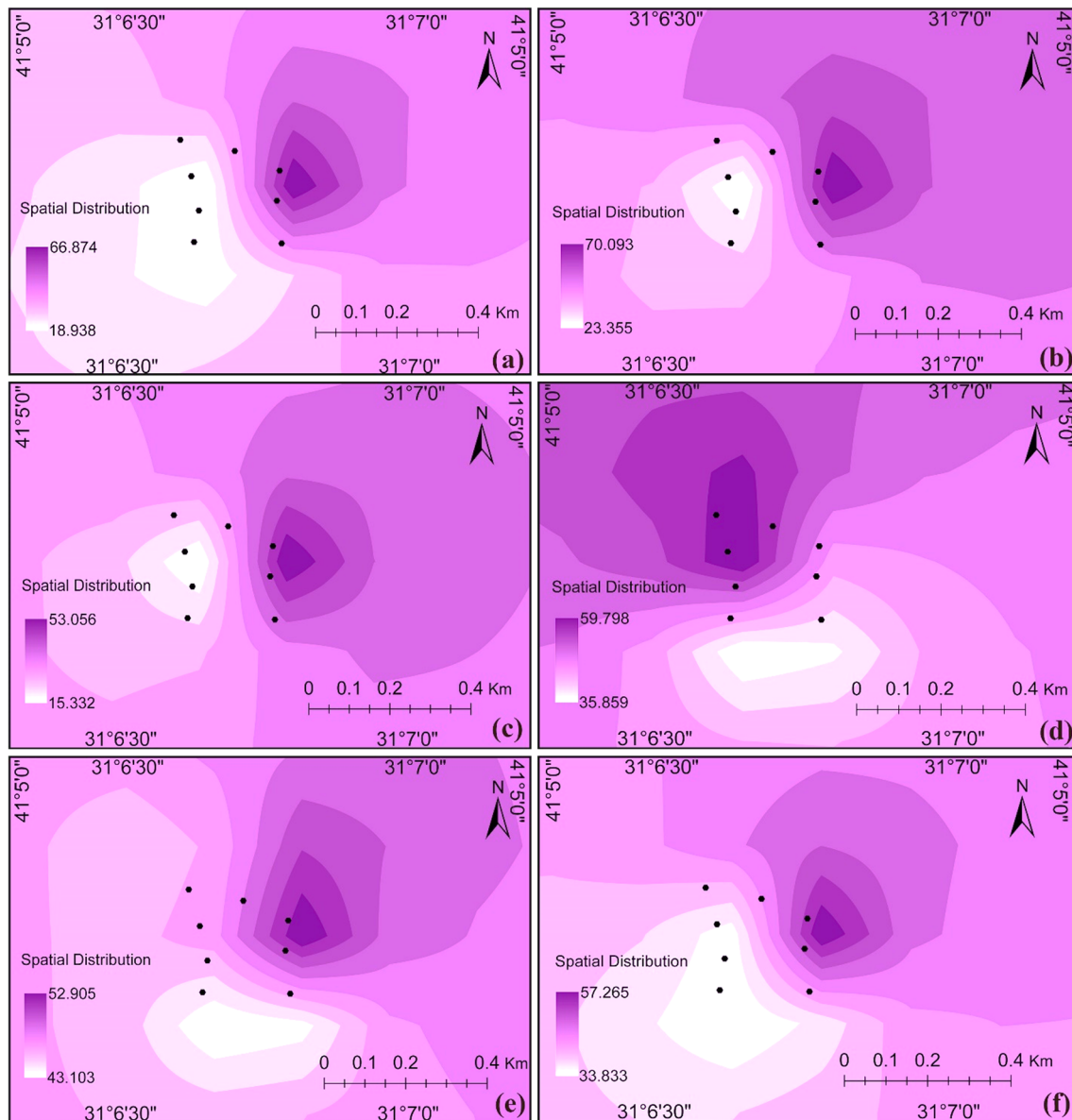


Fig. 2 The spatial distribution of Bi concentration **a** *P. pinaster*; **b** *C. arizonica*; **c** *P. orientalis*; **d** *C. atlantica*; **e** *P. menziesii*; and **f** mean accumulation

directly affected by atmospheric pollutants. The assembly in the remaining species shows that air pollutants and Bi are positively correlated. Bi accumulation shows that *P. orientalis* and *C. atlantica* do not accumulate from outside to inside, but other species get about contaminants released from the atmosphere. It is seen that the accumulation data of *C. arizonica* and *P. pinaster* reflect the atmospheric Bi deposition quite clearly compared to the others in Fig. 4.

3.2 Average data in all species

The ANOVA determined that all species' changes in Bi concentrations of average values by period were

statistically significant ($p < 0.05$). As a result of the analysis of variance, the Bi concentration in the north and east directions, according to the mean values, is not statistically significant. The period-based change is statistically significant except for 1993–1997 and 2003–2007. In general, the values obtained in the north direction are quite high. When the change of Bi concentrations in different directions periodically is examined, it is seen that the difference occasionally is statistically insignificant. The changes based on the direction are also statistically significant only in the 2003–2012 period. In these periods, the highest values were obtained in the west, and the others were in the same group due to the Duncan test result. For comparison

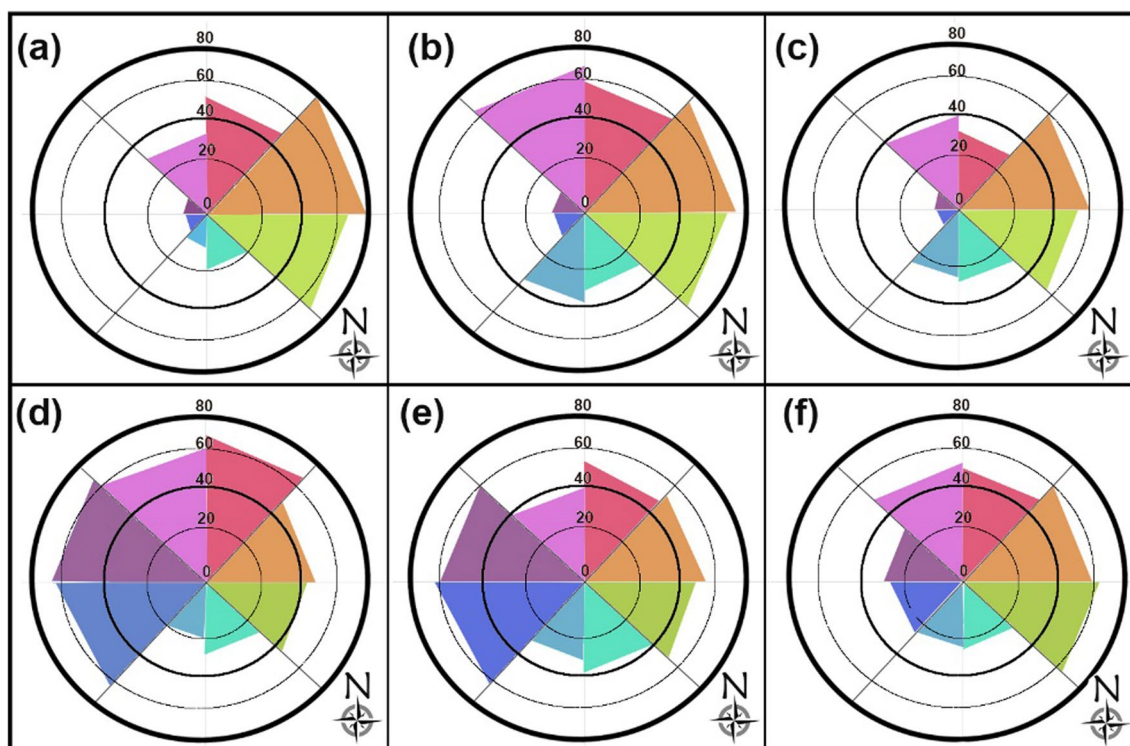


Fig. 3 The mean content of Bi concentration in each direction **a** *P. pinaster*; **b** *C. arizonica*; **c** *P. orientalis*; **d** *C. atlantica*; **e** *P. menziesii*; and **f** mean accumulation

between present and historical data, the variation of Bi concentration by years is placed in Table 3. When the data were grouped according to the four directions and years, the concentrations of Bi in the tree ring followed the order of East > North > West > South and 1988–1992 > 1998–2002 > 1983–1987 > 2003–2007 > 2008–2012 > 2013–2017 > 2018–2022, respectively.

According to the years in each species, Bi accumulation was 89 mg/kg in *P. pinaster* in 2003–2007 and 375 mg/kg in *P. orientalis* in 1983–1987. Exposure to seasonal pollutants is correlated with reduced quality of gasoline and diesel fuel with additives commonly used in traffic, industrial emissions, and fossil fuels burned in homes. Bi-accumulation data of *C. arizonica* and *P. pinaster* show an increase depending on time. The ascending–descending trend in other species could not be obtained clearly in Fig. 5.

4 Discussion

Atmospheric deposition is the principal metal source strongly correlated to airborne pollutants. The xylem tissues of trees have been influenced by long-term atmospheric pollution in cities, where higher than in rural areas due to a lack of direct proximity to emission sources. The absorption abilities of

species have been used in biomonitor studies due to physicochemical reactions and properties [38]. According to our study, the environmental concentrations, geographical distribution, transportation, and deposition of Bi in the Düzce region were investigated for Bi susceptibility on *P. pinaster*, *C. arizonica*, *P. orientalis*, *C. atlantica*, and *P. menziesii*. We focus on the influence of the accumulation in the organs examined according to the years and species have been revealed that are generally controlled by the physicochemical properties of species. Differences in accumulation levels mainly show changes in their main structures due to their reactions under stress conditions [39]. This also indicates the effect of the observed high concentrations of Bi damage on the outer and inner bark growth. The differentiation of the properties of biomass puts them in a stabilization process that is vulnerable or resistant to Bi.

Stabilization changes in species can be explained by physiological effects such as growth or shrinkage in leaves, tissues, and organs. Although adaptation is problematic in many species used in bioindicator studies, it has successfully resulted in a long time of air pollution. Kuang et al. [40] used tree barks of *Pinus massoniana* L. for atmospheric Cu, Fe, Bi, Zn, Ni, and Pb deposition in Qujiang, China. They found significant correlation elements in the outer barks at Qujiang, although

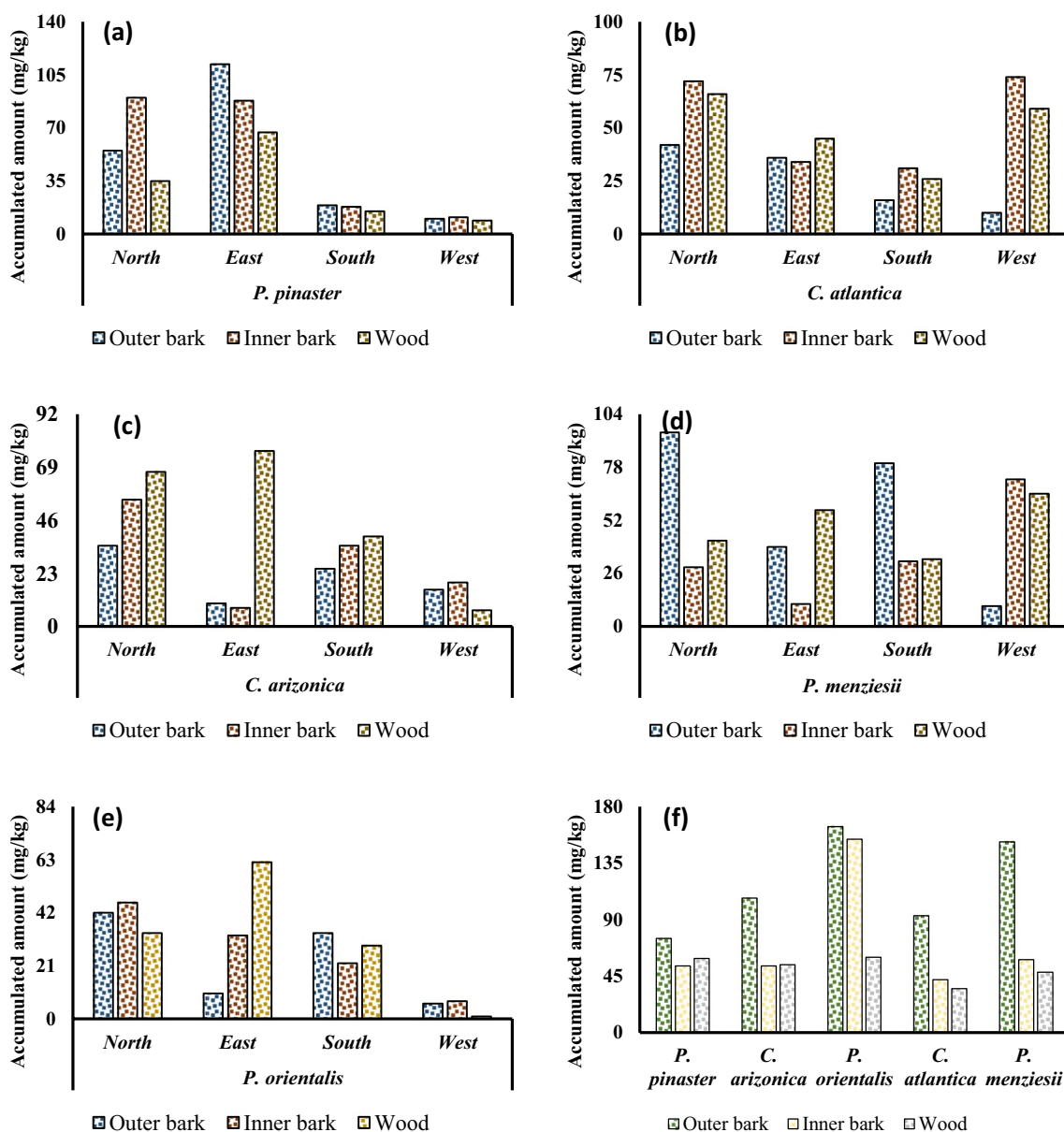


Fig. 4 Accumulation by directions **a** *P. pinaster*; **b** *C. atlantica*; **c** *C. arizonica*; **d** *P. menziesii*; **e** *P. orientalis*; **f** all species

correlation only determined Pb-Ni and Cd-Co pollution at Dinghushan. Martin et al. [41] tried to define heavy metal pollution in the eight zones of Spain by using tree cores, bark, and soil. They show that heavy metal concentrations were changed between 0.02 and 27.44 mg/kg; however, deposition of Cu element varied from 2 to 6.34 mg/kg. Xylem and barks showed differences in the amount on trees lower than our study values in Cu amount. A research carried out by Yousaf et al. [42] conducted a biomonitoring study about atmospheric Cu, Hg, Bi, Ni, Pb, and Zn concentrations in the outer and inner bark of *A. pseudoplatanus* in nine zones of

Toronto, Canada. The pollution level of these sites was compared unpolluted areas (reference point) and obtained randomly among several sites as follows: Zn (126.1 µg/kg) > Mn (94.1 µg/kg) > Pb (68.3 µg/kg) > Hg (51.7–80 µg/kg) > Cu (53.3 µg/kg) > Ni (23 µg/kg). Solgi et al. [43] studied the biomonitoring of airborne metals (Cu, Pb, and Zn) in the leaves and barks of eleven trees from 11 sampling sites. The average concentrations of Cu, Pb, and Zn were detected as 6.92–19.4, 1.2–78.6, and 15.2–44.2 mg/kg, respectively. Biomonitoring studies are usually applied to have airborne contamination in selected areas that provide well-documented disparities

Table 3 Variation of the average Bi concentration (mg/kg) for years

Years	North	East	South	West	F value
2018–2022	44 Aa	46 Aa	30 Aa	34 Aab	1.0 ns
2013–2017	47 BCab	58 Cab	32 ABa	24 Aab	4.7**
2008–2012	47 Bab	71 Cbc	23 Aa	21 Aa	20.2***
2003–2007	42 Aa	50 Aa	28 Aa	42 Aab	1.7 ns
1998–2002	63 Bb	80 Cc	26 Aa	32 Aab	26.1***
1993–1997	44 ABa	64 Babc	30 Aa	47 ABab	4.2*
1988–1992	58 Bab	56 Bab	33 Aa	57 Bb	3.1*
1983–1987	49 BCab	67 Cabc	32 ABa	28 Aab	6.3**
F value	1.7 ns	3.1**	0.4 ns	1.3 ns	

Ns, not significance, *, **, and *** indicate $p < 0.05$, $p < 0.001$, and $p < 0.001$, and Duncan's test results show that the group is located as a, b, c, etc.

in residents' health and mortality rates. Thus, several studies on tree bark and leaves show positive correlations between toxic pollutants deposition and environmental problems by several biomonitoring studies within the literature [44–46]. According to the report by Moreira et al. [47], they collected 171 tree barks to evaluate trace elements from four species in urban areas of São Paulo City. They also note that they tried to show the correlation of local atmospheric pollution between deposition on biomonitoring species and vehicular emissions. Their study demonstrated that tree barks could be useful for identifying specific emissions sources. At the same time, vehicular emission is still one of the most significant sources of airborne pollution in many cities [48–50]. Recently, research led by Cosma et al. [51] focused on how evaluating the radioactive contamination of ^{137}Cs in Romania (February 2013–July 2014) via some trees bark of spruce and oak tree aged 50–60 years and oak trees > 120 years. These results reinforce findings that the total ^{137}Cs concentrations in bark varied in several regions due to the Chernobyl nuclear bomb of May 1986. Radionuclide dispersion was accumulated on barks by wet deposition during rainfall.

Lastly, Niu et al. [52] highlight the utility of 114 tree bark as biomonitoring for atmospheric polycyclic aromatic hydrocarbons (PAHs) pollution and calculated carcinogenic and noncarcinogenic risks in rural regions of China. They reported that the accumulation of PAH is primarily from atmospheric deposition rather than root uptake. In recent work, Flett et al. [53] assessed the historical contamination of radiation biomonitoring study using *Pinus ponderosa* barks at a uranium mine area. The toxic pollutants in tree bark from mines provide airborne particulate matter, including U, Th, Pb, and As. Sut-Lohmann et al. [54] presented urban biomonitoring studies related to 25 bark samples of *Pinus sylvestris* L.

for trace metal contamination of Cottbus in Germany. The results indicated correlation among elements concentration in bark depends on locations such as mining areas, roads or highways, factories, and high traffic. Numerous biomonitoring methods for air quality status assessment and investigations to obtain detectable ranges of several metal concentrations for long exposure in biomonitor species have been reported throughout the world by Caldana et al. [55], Contardo et al. [56], Pereira et al. [57], Guarino et al. [58], and Palusci et al. [59]. As severe variability of trace metals is linked with the spatial distribution, it follows that, in the absence of mitigating factors, the wet and dry deposition will increase that act as the precipitating factors, particularly tree bark structure and porosity, provide for an understanding of inescapable environmental conditions in urban areas. However, an exciting result is a Bi value in the barks associated with coal mines, combustion processes, vehicle-related emissions, and mining activities as a potential source. This aspect is particularly true, and suitably related emission correlates with the dominating winds of the emitted particulate matter containing Bi towards the city.

5 Conclusion

In this study, the usability of *P. pinaster*, *C. arizonica*, *P. orientalis*, *C. atlantica*, and *P. menziesii* species as bioindicators in Düzce city center yielded results. The time-dependent accumulations in their growth and metabolism, where Bi levels increase due to their exposure to industry and traffic emissions in their region, explain the situation. Since the distribution of the species is suitable for its geographical and topographical features, it grows in most areas, and there is no growth problem; it is an excellent potential for application in biological monitoring studies. *P. menziesii* offers the opportunity to select distinct cultures that may exhibit a more robust response to air pollution. A complete understanding of barks (inner and outer) with the total Bi concentrations (102 mg/kg) shows a positive correlation between *P. menziesii* and anthropogenic activities due to atmospheric deposition. This study's strengths include Bi values in *P. menziesii* are relatively steady, contrasting with other species. Moreover, before administering *P. menziesii*, these visible symptoms must be reproduced in fumigation experiments with air pollutants under controlled conditions to establish well-defined dose–response relationships. Still, other events of the present work may be conducted using the other bioindicators presented in the current literature. Overall, though, the *P. menziesii* is proven suitable for assessing Bi pollution for urban designers and policymakers more in-depth research in urban air quality.

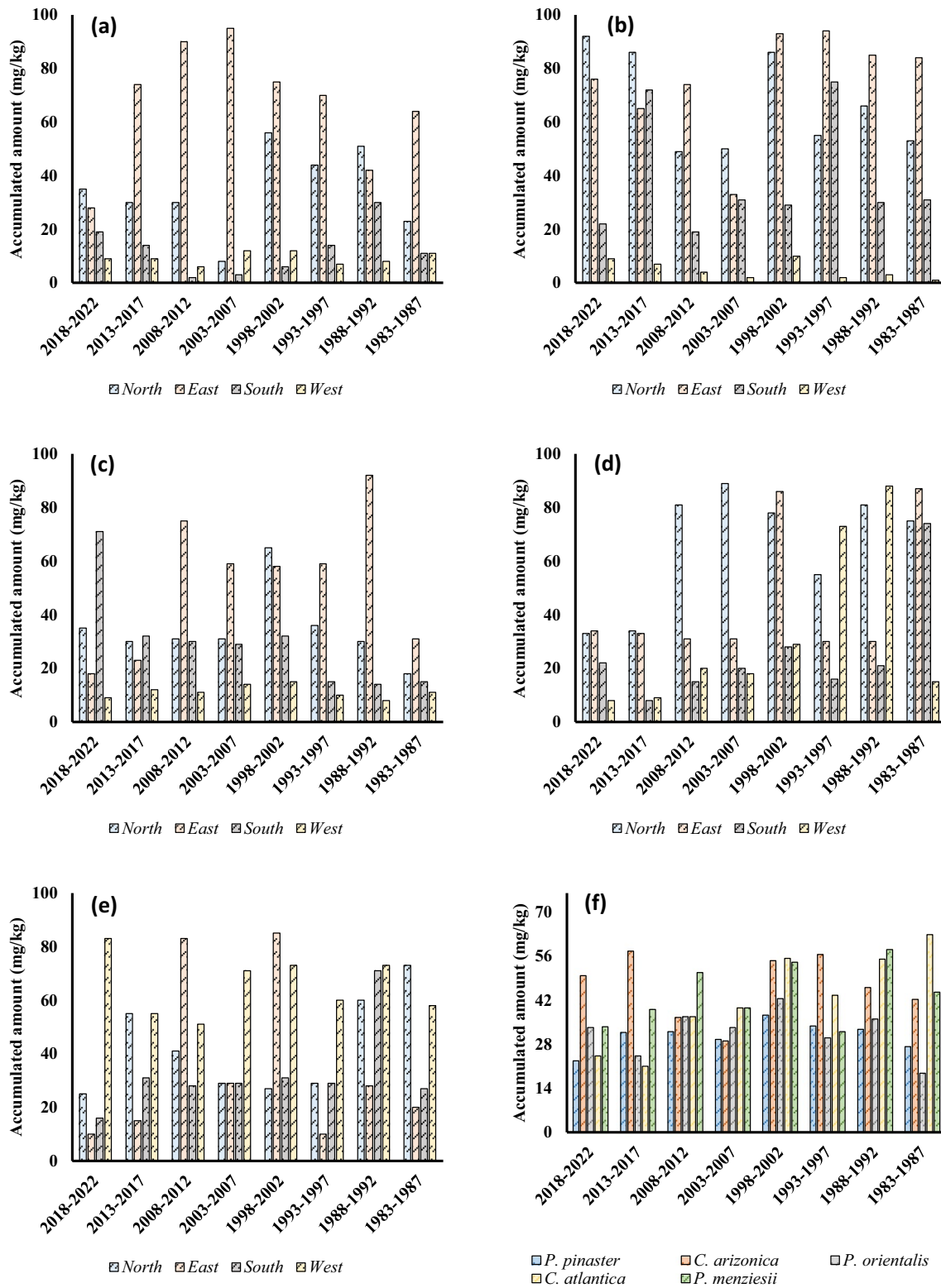


Fig. 5 Accumulation by years and directions **a** *P. pinaster*; **b** *C. atlantica*; **c** *C. arizonica*; **d** *P. menziesii*; **e** *P. orientalis*; **f** all species

Author contribution Kaan Isinkaralar: raw material collection, processing analysis, interpretation. Ozgur Isinkaralar: processing analysis, interpretation, original draft, data curation. İsmail Koç: processing analysis, interpretation, data curation. Halil Barış Özel: processing analysis, interpretation, data curation. Hakan Şevik: formal analysis, review, and editing.

Data availability The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

References

- Peng R, Liu T, Cao G (2023) Valuating multifunctionality of land use for sustainable development: framework, method, and application. *Land* 12(1):222. <https://doi.org/10.3390/land12010222>
- Selamat SN, Abd Majid N, Taib AM, Taha MR, Osman A (2023) The spatial relationship between landslide and land use activities in Langkat River Basin: a case study. *Phys Chem Earth. Parts A/B/C*, 103289. <https://doi.org/10.1016/j.pce.2022.103289>
- Isinkaralar O, Varol C, Yilmaz D (2022) Digital mapping and predicting the urban growth: integrating scenarios into cellular automata—Markov chain modeling. *Appl Geomat* 1–11. <https://doi.org/10.1007/s12518-022-00464-w>
- Bozzolan E, Holcombe EA, Pianosi F, Marchesini I, Alvioli M, Wagener T (2023) A mechanistic approach to include climate change and unplanned urban sprawl in landslide susceptibility maps. *Sci Total Environ* 858:159412. <https://doi.org/10.1016/j.scitotenv.2022.159412>
- de Jager A, Corbane C, Szabo F (2022) Recent developments in some long-term drought drivers. *Climate* 10(3):31. <https://doi.org/10.3390/cli10030031>
- Maas S, Scheifler R, Benslama M, Crini N, Lucot E, Brahmia Z, Benyacoub S, Giraudoux P (2010) Spatial distribution of heavy metal concentrations in urban, suburban and agricultural soils in a Mediterranean city of Algeria. *Environ Pollut* 158(6):2294–2301. <https://doi.org/10.1016/j.envpol.2010.02.001>
- Isinkaralar O, Varol C (2023) A cellular automata-based approach for spatio-temporal modeling of the city center as a complex system: the case of Kastamonu. *Türkiye. Cities* 132:104073. <https://doi.org/10.1016/j.cities.2022.104073>
- Hu Y, Wang D, Wei L, Zhang X, Song B (2014) Bioaccumulation of heavy metals in plant leaves from Ya'an city of the Loess Plateau, China. *Ecotoxicol Environ Saf* 110:82–88. <https://doi.org/10.1016/j.ecoenv.2014.08.021>
- Aprile A, De Bellis L (2020) Editorial for special issue “heavy metals accumulation, toxicity, and detoxification in plants.” *Int J Mol Sci* 21(11):4103. <https://doi.org/10.3390/ijms21114103>
- Ng E (2009) Policies and technical guidelines for urban planning of high-density cities—air ventilation assessment (AVA) of Hong Kong. *Build Environ* 44(7):1478–1488. <https://doi.org/10.1016/j.buildenv.2008.06.013>
- UNECE (2018) Air pollution and health - air pollution - environmental policy. <https://www.unece.org/environmental-policy/conventions/envlrtp/welcome/cross-sectoral-linkages/air-pollution-and-health.html>
- Tuohy A, Bertler N, Neff P, Edwards R, Emanuelsson D, Beers T, Mayewski P (2015) Transport and deposition of heavy metals in the Ross Sea Region. *Antarctica J Geophys Res: Atmospheres* 120(20):10–996. <https://doi.org/10.1002/2015JD023293>
- Guo G, Zhang D (2021) Source apportionment and source-specific health risk assessment of heavy metals in size-fractionated road dust from a typical mining and smelting area, Gejiu, China. *Environ Sci Pollut Res* 28:9313–9326. <https://doi.org/10.1007/s11356-020-11312-y>
- Tsai MS, Chen MH, Lin CC, Liu CY, Chen PC (2019) Children's environmental health based on birth cohort studies of Asia (2)—air pollution, pesticides, and heavy metals. *Environ Res* 179:108754. <https://doi.org/10.1016/j.envres.2019.108754>
- Zeng X, Xu X, Qin Q, Ye K, Wu W, Huo X (2019) Heavy metal exposure has adverse effects on the growth and development of preschool children. *Environ Geochem Health* 41:309–321. <https://doi.org/10.1007/s10653-018-0114-z>
- Shabanda IS, Koki IB, Low KH, Zain SM, Khor SM, Abu Bakar NK (2019) Daily exposure to toxic metals through urban road dust from industrial, commercial, heavy traffic, and residential areas in Petaling Jaya, Malaysia: a health risk assessment. *Environ Sci Pollut Res* 26:37193–37211. <https://doi.org/10.1007/s11356-019-06718-2>
- Yousefi H, Lak E, Mohammadi MJ, Shahriyari HA (2022) Carcinogenic risk assessment among children and adult due to exposure to toxic air pollutants. *Environ Sci Pollut Res* 29(16):23015–23025. <https://doi.org/10.1007/s11356-021-17300-0>
- 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. *Sci Total Environ* 619:120–126. <https://doi.org/10.1016/j.scitotenv.2017.11.075>
- Xie T, Wang M, Chen W, Uwizeyimana H (2019) Impacts of urbanization and landscape patterns on the accumulation of heavy metals in soils in residential areas in Beijing. *J Soils Sediments* 19:148–158. <https://doi.org/10.1007/s11368-018-2011-6>
- Koç İ (2021) Using *Cedrus atlantica*'s annual rings as a biomonitor in observing the changes of Ni and Co concentrations in the atmosphere. *Environ Sci Pollut Res* 28:35880–35886. <https://doi.org/10.1007/s11356-021-13272-3>
- 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 Soil Pollut* 233(7):1–13. <https://doi.org/10.1007/s11270-022-05741-3>
- Cocozza C, Ravera S, Cherubini P, Lombardi F, Marchetti M, Tognetti R (2016) Integrated biomonitoring of airborne pollutants over space and time using tree rings, bark, leaves and epiphytic lichens. *Urban For Urban Green* 17:177–191. <https://doi.org/10.1016/j.ufug.2016.04.008>
- Mukhopadhyay S, Dutta R, Das P (2020) A critical review on plant biomonitors for determination of polycyclic aromatic hydrocarbons (PAHs) in air through solvent extraction techniques. *Chemosphere* 251:126441. <https://doi.org/10.1016/j.chemosphere.2020.126441>
- Chaparro MA, Chaparro MA, Castañeda-Miranda AG, Marié DC, Gargiulo JD, Lavornia JM, Natal M, Böhnel HN (2020) Fine air pollution particles trapped by street tree barks: in situ magnetic biomonitoring. *Environ Pollut* 266:115229. <https://doi.org/10.1016/j.envpol.2020.115229>
- Isinkaralar K (2022) The large-scale period of atmospheric trace metal deposition to urban landscape trees as a biomonitor. *Biomass Convers Biorefin* 1–10. <https://doi.org/10.1007/s13399-022-02796-4>
- Esfandiari M, Hakimzadeh MA (2022) Assessment of environmental pollution of heavy metals deposited on the leaves of trees

- at Yazd bus terminals. *Environ Sci Pollut Res* 29(22):32867–32881. <https://doi.org/10.1007/s11356-021-18274-9>
27. Isinkaralar K (2022) Temporal variability of trace metal evidence in *Cupressus arizonica*, *Platanus orientalis*, and *Robinia pseudoacacia* as pollution-resistant species at an industrial site. *Water Air Soil Pollut* 233(7):1–12. <https://doi.org/10.1007/s11270-022-05743-1>
 28. Chiarantini L, Rimondi V, Benvenuti M, Beutel MW, Costagliola P, Gonnelli C, Lattanzi P, Paolieri M (2016) Black pine (*Pinus nigra*) barks as biomonitors of airborne mercury pollution. *Sci Total Environ* 569:105–113. <https://doi.org/10.1016/j.scitotenv.2016.06.029>
 29. Kousehlar M, Widom E (2019) Sources of metals in atmospheric particulate matter in Tehran, Iran: tree bark biomonitoring. *Appl Geochem* 104:71–82. <https://doi.org/10.1016/j.apgeochem.2019.03.018>
 30. Sulhan OF, Sevik H, Isinkaralar K (2022) Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye. *Environ Dev Sustain* 1–20. <https://doi.org/10.1007/s10668-022-02647-2>
 31. Istanbulu SN, Sevik H, Isinkaralar K, Isinkaralar O (2023) Spatial distribution of heavy metal contamination in road dust samples from an urban environment in Samsun, Türkiye. *Bull Environ Contam Toxicol* 110(4):78. <https://doi.org/10.1007/s00128-023-03720-w>
 32. Yayla EE, 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. *Environ Monit Assess* 194(10):687. <https://doi.org/10.1007/s10661-022-10356-6>
 33. 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 Ecol Eng* 18:75–83. <https://doi.org/10.1007/s11355-021-00483-6>
 34. Isinkaralar K, Koc I, Erdem R, Sevik H (2022) Atmospheric Cd, Cr, and Zn deposition in several landscape plants in Mersin, Türkiye. *Water Air Soil Pollut* 233(4):120. <https://doi.org/10.1007/s11270-022-05607-8>
 35. USEPA United States Environmental Protection Agency (1996) SW-846 test method 3052: microwave assisted acid digestion of siliceous and organically based matrices. <https://www.epa.gov/hw-sw846/sw-846-test-method-3052-microwave-assisted-acid-digestion-siliceous-and-organically-based> (Accessed May 15, 2021)
 36. USEPA United States Environmental Protection Agency (2013) Method 6020B (SW-846): inductively coupled plasma-mass spectrometry Rev. 2. pp 1–33. 2014. Washington, DC. <https://www.epa.gov/esam/epa-method-6020b-sw-846-inductively-coupled-plasma-mass-spectrometry> (Accessed January 21, 2022)
 37. US Environmental Protection Agency (2001) Method 200.7: trace elements in water, solids, and biosolids by inductively coupled plasma-atomic emission spectrometry. Rev. 5. EPA-821-R-01-010. USEPA, Washington, DC
 38. Miri M, Allahabadi A, Ghaffari HR, Fathabadi ZA, Raisi Z, Rezaei M, Aval MY (2016) Ecological risk assessment of heavy metal (HM) pollution in the ambient air using a new bio-indicator. *Environ Sci Pollut Res* 23:14210–14220. <https://doi.org/10.1007/s11356-016-6476-9>
 39. Monfared SH, Matinizadeh M, Shirvany A, Amiri GZ, Fard RM, Rostami F (2013) Accumulation of heavy metal in *Platanus orientalis*, *Robinia pseudoacacia* and *Fraxinus rotundifolia*. *J For Res* 24:391–395. <https://doi.org/10.1007/s11676-012-0313>
 40. Kuang YW, Zhou GY, Wen DZ, Liu SZ (2007) Heavy metals in bark of *Pinus massoniana* (Lamb.) as an indicator of atmospheric deposition near a smeltery at Qujiang. *Chin Environ Sci Pollut Res-Int* 14:270–275. <https://doi.org/10.1065/espr2006.09.344>
 41. Martin JAR, Gutiérrez C, Torrijos M, Nanos N (2018) Wood and bark of *Pinus halepensis* as archives of heavy metal pollution in the Mediterranean Region. *Environ Pollut* 239:438–447. <https://doi.org/10.1016/j.envpol.2018.04.036>
 42. Yousaf M, Mandiwana KL, Baig KS, Lu J (2020) Evaluation of *Acer rubrum* tree bark as a bioindicator of atmospheric heavy metal pollution in Toronto, Canada. *Water Air Soil Pollut* 231:1–9. <https://doi.org/10.1007/s11270-020-04758-w>
 43. Solgi E, Keramaty M, Solgi M (2020) Biomonitoring of airborne Cu, Pb, and Zn in an urban area employing a broad leaved and a conifer tree species. *J Geochem Explor* 208:106400. <https://doi.org/10.1016/j.gexplo.2019.106400>
 44. Guéguen F, Stille P, Millet M (2011) Air quality assessment by tree bark biomonitoring in urban, industrial and rural environments of the Rhine Valley: PCDD/Fs, PCBs Trace Metal Evid *Chemosphere* 85(2):195–202. <https://doi.org/10.1016/j.chemosphere.2011.06.032>
 45. Xu Y, Xiao H, Guan H, Long C (2018) Monitoring atmospheric nitrogen pollution in Guiyang (SW China) by contrasting use of *Cinnamomum Camphora* leaves, branch bark and bark as biomonitors. *Environ Pollut* 233:1037–1048. <https://doi.org/10.1016/j.envpol.2017.10.005>
 46. Karmakar D, Deb K, Padhy PK (2021) Ecophysiological responses of tree species due to air pollution for biomonitoring of environmental health in urban area. *Urban Clim* 35:100741. <https://doi.org/10.1016/j.uclim.2020.100741>
 47. Moreira TCL, de Oliveira RC, Amato LFL, Kang CM, Saldiva PHN, Saiki M (2016) Intra-urban biomonitoring: Source apportionment using tree barks to identify air pollution sources. *Environ Int* 91:271–275. <https://doi.org/10.1016/j.envint.2016.03.005>
 48. Brignole D, Drava G, Minganti V, Giordani P, Samson R, Vieira J, Pinho P, Branquinho C (2018) Chemical and magnetic analyses on tree bark as an effective tool for biomonitoring: a case study in Lisbon (Portugal). *Chemosphere* 195:508–514. <https://doi.org/10.1016/j.chemosphere.2017.12.107>
 49. Alexandrino K, Viteri F, Rybarczyk Y, Andino JEG, Zalakeviciute R (2020) Biomonitoring of metal levels in urban areas with different vehicular traffic intensity by using *Araucaria heterophylla* needles. *Ecol Indic* 117:106701. <https://doi.org/10.1016/j.ecolind.2020.106701>
 50. Isinkaralar O (2023) Bioclimatic comfort in urban planning and modeling spatial change during 2020–2100 according to climate change scenarios in Kocaeli, Türkiye. *Int J Environ Sci Technol*. <https://doi.org/10.1007/s13762-023-04992-9>
 51. Cosma C, Iurian AR, Incze R, Kovacs T, Žunić ZS (2016) The use of tree bark as long term biomonitor of ¹³⁷Cs deposition. *J Environ Radioact* 153:126–133. <https://doi.org/10.1016/j.jenvrad.2015.12.019>
 52. Niu L, Xu C, Zhou Y, Liu W (2019) Tree bark as a biomonitor for assessing the atmospheric pollution and associated human inhalation exposure risks of polycyclic aromatic hydrocarbons in rural China. *Environ Pollut* 246:398–407. <https://doi.org/10.1016/j.envpol.2018.12.019>
 53. Flett L, McLeod CL, McCarty JL, Shaulis BJ, Fain JJ, Krekeler MP (2021) Monitoring uranium mine pollution on Native American lands: insights from tree bark particulate matter on the Spokane Reservation, Washington, USA. *Environ Res* 194:110619. <https://doi.org/10.1016/j.envres.2020.110619>
 54. Sut-Lohmann M, Jonczak J, Parzych A, Šimanský V, Polláková N, Raab T (2020) Accumulation of airborne potentially toxic elements in *Pinus sylvestris* L bark collected in three Central European medium-sized cities. *Ecotoxicol Environ Safety* 200:110758. <https://doi.org/10.1016/j.ecoenv.2020.110758>
 55. Caldana CR, Hanai-Yoshida VM, Paulino TH, Baldo DA, Freitas NP, Aranha N, Vila MMDC, Balcão VM, Junior JMO (2023) Evaluation of urban tree barks as bioindicators of environmental pollution using the X-ray fluorescence technique. *Chemosphere* 312:137257. <https://doi.org/10.1016/j.chemosphere.2022.137257>

56. Contardo T, Vannini A, Sharma K, Giordani P, Loppi S (2020) Disentangling sources of trace element air pollution in complex urban areas by lichen biomonitoring. A case study in Milan (Italy). *Chemosphere* 256:127155. <https://doi.org/10.1016/j.chemosphere.2020.127155>
57. Pereira GM, da Silva Caumo SE, do Nascimento EQM, Parra YJ, de Castro Vasconcellos P (2019) Polycyclic aromatic hydrocarbons in tree barks, gaseous and particulate phase samples collected near an industrial complex in São Paulo (Brazil). *Chemosphere* 237:124499. <https://doi.org/10.1016/j.chemosphere.2019.124499>
58. Guarino F, Improta G, Triassi M, Castiglione S, Ciatelli A (2021) Air quality biomonitoring through *Olea europaea* L: the study case of “Land of pyres.” *Chemosphere* 282:131052. <https://doi.org/10.1016/j.chemosphere.2021.131052>
59. Palusci O, Monti P, Cecere C, Montazeri H, Blocken B (2022) Impact of morphological parameters on urban ventilation in compact cities: the case of the Tuscolano-Don Bosco district in Rome. *Sci Total Environ* 807:150490. <https://doi.org/10.1016/j.scitotenv.2021.150490>

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.