International Journal of Environmental Science and Technology (2022) 19:12593–12604
https://doi.org/10.1007/s13762-022-04586-x

ORIGINAL PAPER

Determination of heavy metal levels using *Betula pendula* Roth. under various soil contamination in Southern Urals, Russia

K. Isinkaralar[1] · **İ. Koç**[2] · **N. A. Kuzmina**[3] · **S. L. Menshchikov**[3] · **R. Erdem**[4] · **B. Aricak**[5]

Received: 21 January 2022 / Revised: 11 June 2022 / Accepted: 10 October 2022 / Published online: 18 October 2022

Abstract

Heavy metals are hazardous to environmental and human health. Metals contained in the solid fraction of emissions are fixed in the soil absorbing complex and tend to bioaccumulate in plants, which can be used both to diagnose the level of contamination of forest biogeocenoses and to study the laws of the processes of absorption of contaminants in the soil–plant system. The research aims to determine the degree of pollution in *Betula pendula* Roth. from emissions from Combine Magnesite (magnesite ore processing and mining plant activity area in Russia) at 1, 3, 10, and 100 km far from the emission source, which experimental plots created in the 1980s. Soil samples were collected from these sites, and 1- and 2-year-old branches and leaf specimens were collected from *B. pendula* individuals. The lead (Pb), chromium (Cr), and iron (Fe) concentrations in soil and organs of *B. pendula* by the soil depth, washing, organ type, and organ age were determined. As a result, the variations in element concentrations by organs at all the distances and distances for all the organs were significant ($p < 0.05$). Metal concentrations were higher in the subsoil and leaf collected from 2-year-old branches. These results were interpreted as the higher values in the leaves of 2-year-old branches exposed to heavy metals in the air for a longer time, and the heavy metal concentrations in the subsoil increased due to the decomposition of these leaves. The movement of heavy metals, such as Pb and Cr, in soil was minimal.

Keywords Chromium · Heavy metal · Lead · Silver birch · Soil acidity

Introduction

With the technological innovations that developed after the Industrial Revolution, the demands and needs of humans got increased and diversified. The productions made to meet these demands and need result in extracting mineral sources from underground and using them in industrial activities as raw materials (Altera et al. 2019; Gencel et al. 2021). In this process, the extraction of specific elements, which exist intensely in underground deposits and are subjected as a raw material in the production, and their release into nature resulted in air pollution (Turkyilmaz et al. 2020; Elsunousi et al. 2021), soil (Bayraktar et al. 2019a, b; Long et al. 2021), and water (Uncumusaoğlu and Mutlu 2019; Ucun Ozel et al. 2020). Besides, extracting elements from underground has been causing indirect effects on the environment and climate, resulting in some disorders in plant species such as drought (Koç 2019, 2021a; Koç et al. 2021; Koç and Nzokou 2022), cold stress (Yildiz et al. 2014; Koc and Nzokou 2018), and heavy metal contamination (Isinkaralar et al. 2022).

Editorial responsibility: Samareh Mirkia.

✉ İ. Koç
ismailkoc@duzce.edu.tr

[1] Department of Environmental Engineering, Faculty of Engineering and Architecture, Kastamonu University, 37150 Kastamonu, Turkey

[2] Forestry Vocational School, Düzce University, 81620 Düzce, Turkey

[3] Russian Academy of Sciences, Ural Branch: Institute of Botanical Garden, 620130 Yekaterinburg, Russia

[4] Department of Forestry, Programs of Forestry and Forestry Products, Arac Rafet Vergili Vocational School, Kastamonu University, 37800 Kastamonu, Turkey

[5] Forestry Department, Faculty of Forestry, Bursa Technical University, 16310 Bursa, Turkey

Among these elements, the ones threatening the health and environment the most are the heavy metals. Heavy metals such as arsenic (As), mercury (Hg), lead (Pb), and cadmium (Cd) can have severe lethal effects on living creatures, including humans, even at low concentrations. They are carcinogenic and can cause severe deformations and even death (Shahid et al. 2017; Sevik et al. 2020a). Moreover, heavy metals cannot be easily scavenged from the bodies of organisms, and they bioaccumulate. Furthermore, they are not easily broken down and cleared away in nature (Koç 2021b). Although micronutrients such as iron (Fe), zinc (Zn), chromium (Cr), manganese (Mn), copper (Cu), and nickel (Ni) are essential for plants and other living things, at higher concentrations, they might have harmful outcomes (Turkyilmaz et al. 2018). Nearly all the metals have toxic impacts on living organisms when taken at amounts higher than a specific threshold (Sevik et al. 2019a). Hence, increasing heavy metals concentrations in soil, air, and water pose a considerable risk to living organisms and ecosystems.

This study focused on the three harmful trace metals reported for humans at high concentrations, for which international regulatory implementations exist Pb, Cr, and Fe. All allowable limits are according to human toxicity data. Permissible limits were determined from the international standards set by the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO), and the maximum allowable limits of Pb in drinking water is 15 ppm (Martin and Griswold 2009), while in wastewater and agricultural soils are 0.01 and 0.1 ppm, respectively (Chiroma et al. 2014). The WHO suggested permissible levels for Cr in drinking water, wastewater, and agricultural soils are 0.55, 0.05, and 0.1 ppm, respectively (Chiroma et al. 2014). The permissible limits for Fe in drinking water and agricultural soils are 0.05 and 50,000 ppm (Chiroma et al. 2014).

Heavy metals are extracted from the deposits and careers where they exist at high amounts and then processed and used as raw materials in industrial operations. Hence, the heavy metal sources are the deposits and the industrial facilities where these ores are processed and the regions having the highest pollution levels are nearby these heavy metal sources. Besides that, heavy metals can be transported very long distances through particles and wind (Shahid et al. 2017). Because of the importance for human and environmental health, knowing how large areas the heavy metal sources affect at which level and determining their ways of spreading are vital in designing the processes to be taken. However, it is very costly and challenging to perform these measurements directly. Moreover, the effects of results obtained from the direct measurements on the ecosystem cannot be decided (Sevik et al. 2019b; Savas et al. 2021).

Plants are suitable biomonitors used in indirectly determining heavy metal pollution. Plants collect the heavy metals from the air and soil in the environment, where they grow, and the measurements made using plant organs can provide information about heavy metal pollution (Koç 2021b).

However, previous studies have commonly focused on determining heavy metal concentrations in various organs of trees grown in a similar region (Karacocuk et al. 2022), or especially heavy metal concentrations in topsoil or dust (Cetin et al. 2022). In general, heavy metal entry and accumulation in the plant body result from a complex mechanism, and this accumulation is closely related to the soil characteristics. Therefore, in order to make correct inferences, it is necessary to analyze the organ, age, and washing conditions together, as well as to evaluate the heavy metal concentrations at different depths of the soil. In addition, anthropogenic heavy metal contamination is primarily caused by traffic, industry, and mining activities (Cesur et al. 2022). As the distance to heavy metal sources increases, the level of heavy metal contamination decreases (Aricak et al. 2020). Therefore, it is vital to separately evaluate the distance to the heavy metal pollution source. However, no study has been found in the literature in which all of these factors, which are in a relationship with each other, are evaluated together. In the present study, 1- and 2-year-old branches and their leaves of 39-year-old *Betula pendula* individuals were collected in 2019, growing at 1, 3, 10, and 100 km distances from a magnesite ore processing and mining facility operating in Russia. It was aimed to determine the variations in heavy metal concentrations in these branches and leaves by distance, organ type and age, and washing status.

Materials and methods

Site description

The research was carried out in the forests of the "Satkinskoe forestry" Main Forest Management of the Chelyabinsk region, located in the northwestern part of the Chelyabinsk region, in the east it borders with the Zlatoust city district, in the north—with the Kusinsky District, in the south with the Republic of Bashkortostan. The research area, Satka city, of the Chelyabinsk region is located in 55°02′29″ N, 59°03′72″ E (Fig. 1). The Combine Magnesite of city Satka has been operating since 1901. The mining of magnesite ore is carried out by the quarrying method and through mines, and refractories are produced in rotary, tunnel, and melting furnaces. As a result, manmade waste enters the atmosphere in the form of magnesite dust, gases (carbon dioxide, sulfur dioxide, nitrogen dioxide, and hydrocarbons without volatile organic compounds). Such a huge impact is a serious obstacle to the successful existence of biological systems and humans.

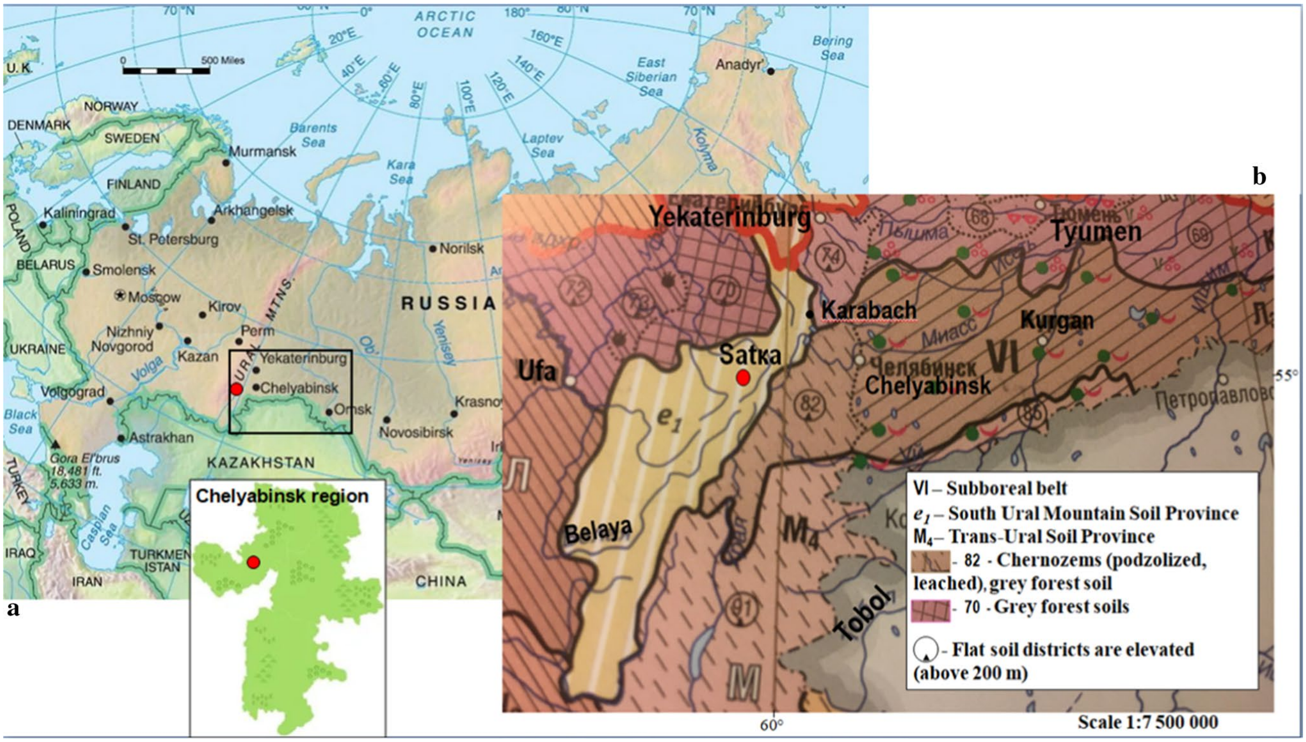

Fig. 1 Research area on the world map (**a**) and map of soil provinces of the study area (**b**) (Shoba 2011)

The forest vegetation of the Southern Urals in the Chelyabinsk province center Satka the Combine Magnesite is in danger of destruction (Fig. 1a). The experimental sites are placed at various ranges from the Combine.

The soil cover varies widely from Brown Mountain forest and sod-podzolic soils in the mountainous part to gray forest in the forest steppe and black earth in the steppe areas. In the areas of the forest steppe, a complex of rejuvenated and saline soils is also developed (Smolonogov 2001).

According to the soil map, the soils of the studied area belong to the sub-boreal geographical zone located in the central deciduous forest (Shoba 2011). Forest steppe and steppe soil-bioclimatic regions belonging to the south Ural Mountain soil province (e1), from the northwest, covers a section of the Kama Plain and from the southeast part of the Barabinsk soil plain territory of the West Siberian Plain, as shown on the map Fig. 1b (Lavrenko 1947).

The foothill alluvial–diluvial and eluvial–diluvial plains are characterized by clay and loamy, sometimes gravelly soils (70th soil district). Erosion–denudation plains are formed on eluvial–diluvial loamy gravelly bedrock (82nd soil district), as shown in Fig. 1 (Shoba 2011).

In the mountain forest (deciduous forest) zone of the mountain soil province, gray forest soils are predominant. When moving from west to east, humus content increases in these soils, the thickness of the humus horizon decreases, the second humus horizon manifests itself in the soil profile. This type of soil is characterized by changes in thermal regimes from moderate freezing (K2) to moderate long-term freezing (M4) (Figs. 1 and 2).

In the research area, according to the forestry regulations of the Satka Forestry (for 2018), on an area of 109.096 hectares, forests are classified as protective and operational and occupy zones of forest seed zoning, ordinary pine, spruce, larch, and petiolate oak. The area of land covered with forest vegetation is 98.636 thousand ha. The dominant species are pine and birch (81.2% and 58.1%) (Fig. 3a, b). The distribution of tree species by age group is uneven: Coniferous species are an average age group (38.9%—16.745 thousand soft-leaved plantings)—ripe and overripe plantings (49%—28.913 thousand ha), the share of mature plants accounts for 13.821 thousand ha or 22.8%.

According to the contamination gradient of the northeast direction under the influence of predominating winds from the emission source, the area of ES-2 is in the notable impact zone, ES-5 is in the mean impact zone when ES-4 is at the weak influence zone. These places are 1 (ES-2—strong pollution), 3 (ES-5—average pollution), and 10 (ES-4—low pollution) km far from the Combine Magnesite power plant, respectively (Fig. 2). Also, the last experimental site is located 100 km (healthy birch stand) from the emission source (Fig. 4). The birches on ESs are over 40 years old. All ESs are in similar forest conditions.

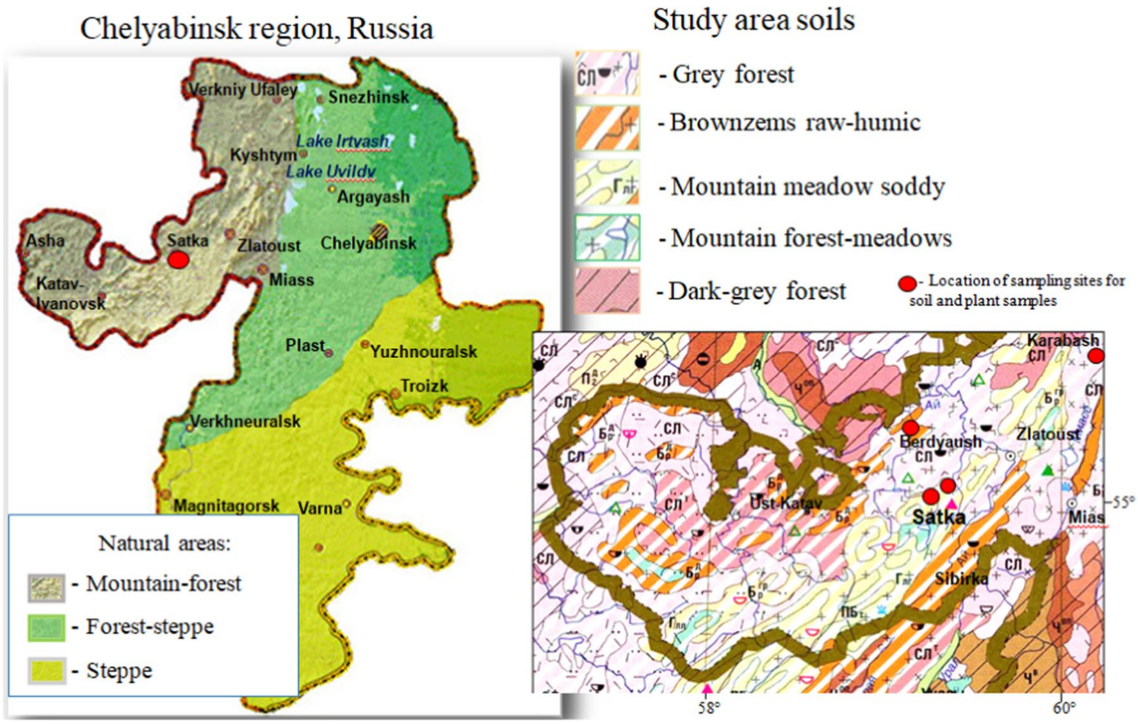

Fig. 2 Research area and characteristics of soil types

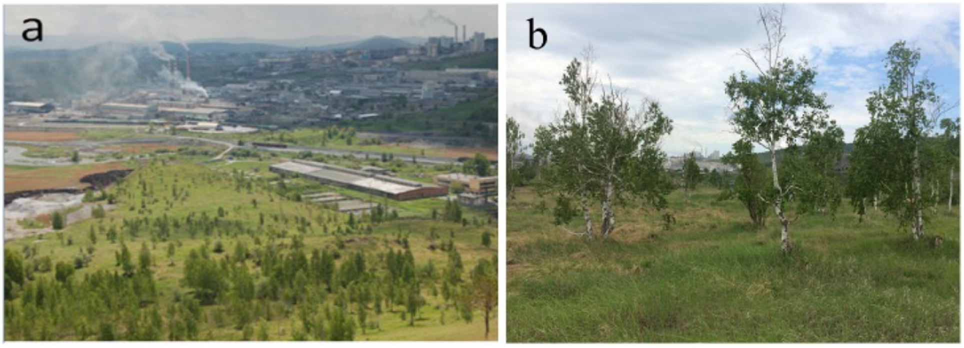

Fig. 3 Satkinsky Combine Magnesite province (**a**) and the neighboring forest (**b**)

The forest completely died near the power plant and within a 1.5–2 km radius (Fig. 4). In 1963, the highest volume of magnesite dust was 182.5–328.5 thousand tons daily basis into the atmosphere. In 1978, dust emissions declined to 70–90 tons daily basis after installing brand new electrostatic precipitators. In the last 10–15 years, the Combine Magnesite plant has significantly reduced emissions, and there is hope for reforestation of dead plantings.

Today, biochemical research generally aims to understand the ecological status of natural and artificially modified terrestrial ecosystems. In these ecosystems, woody plant species are generally used to evaluate the impact of the pollution source.

Sample collection

In autumn 2019, soil samples were taken on the simple studied plots at a 0–30 cm depth [two depts: litter layer (A0) = 0–2 cm and the root layer (AB) = 2.1–30 cm] under each model tree following GOST 17.4.4.02.84 (1984) procedure. Under laboratory conditions, soil samples were dried to an air-dry state and sifted through a sieve with pores 0.1 cm diameter. The water pH was determined on the pH meter pH-420 Aquilon following GOST 26,423–85 (1985) method. Metals were extracted from the soil with an acetate-ammonium buffer solution. Methodological guidelines for determining mobile forms of heavy metals in soils were used (Kuznetsov et al. 1992). The concentrations of Cr, Pb, Fe

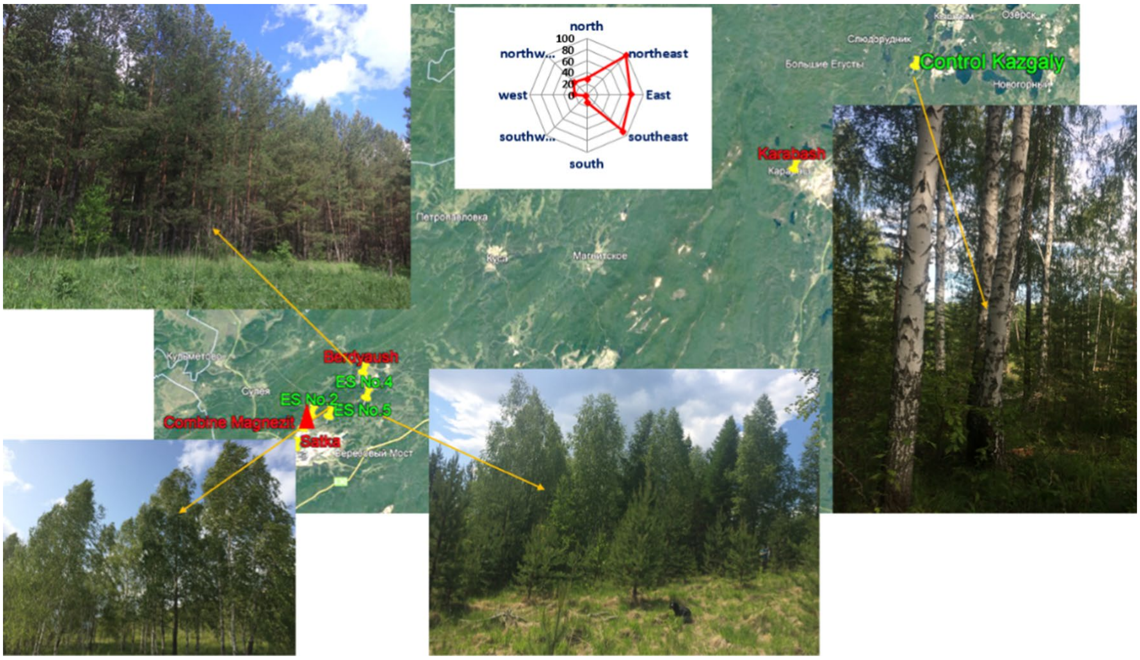

Fig. 4 Location of experimental test sites in relation to Combine Magnesite

elements were measured using a flame atomic absorption spectrophotometer (nov AA 300, Analitik Jena, Germany).

The wide distribution of the main forest-forming species—the hanging birch (*B. pendula* Roth.)—is often used in biological monitoring (Chernykh et al. 2019; Goncharova et al. 2020) to make reasonable conclusions about the state of the stand and its response to long-term pollution (Bachurina et al. 2020).

Heavy metal analyses

The branch samples collected in 2019, labeled, and then transferred to the laboratory were first classified by their organ ages. After separating the branches and leaves, all the samples were divided into two groups. Then, a group of branches and leaves were washed, and then, after thoroughly cleaning the dust residuals on these samples, they were rinsed using pure water. In order to allow branches and leaves to dry more quickly, the organs were crumbled as tiny as possible, and no instrument made of the metals tested in the current study was used in these processes.

In total, six groups were obtained using two organs (leaf and branch), two ages (1- and 2-year-old) and classified as washed and unwashed materials. These organs were placed on cardboard plates and dried for about 2 weeks under room conditions. The air-dried organs were then further dried at 45 °C in a drying oven for 15 days.

The air-dried leaf and branch samples were ground into powder using steel blenders separately, weighed at 0.5 g, and then put into flasks specially designed for microwaves. The samples were added with 10 ml 65% HNO_3 and combusted using a fume cupboard in a microwave at 180 °C for 20 min under 280 PSI pressure. Then, the flasks were taken out from the microwave to cool down and filled to 50 ml by adding deionized water. The prepared specimens were filtered using filter papers and scanned at proper wavelengths using an ICP-OES (GBC Integra XL-SDS-270) equipment (GBC Scientific Equipment Pty Ltd., Melbourne, Australia).

Statistical analyses

The obtained values from the analyses were analyzed using SPSS 22.0 statistical package software. The data were subjected to variance analysis (ANOVA) first, and then the Duncan test was conducted for the data, which were found to have significant ($p < 0.05$) in the analysis of variance. Mean values, F values obtained from ANOVA, and groups obtained from the Duncan test were interpreted by simplifying and tabulating.

Results and discussion

Change of soil pH

Analysis of soil samples taken in various zones of magnesite dusting in the litter (A0—0–2 cm) and the root layer (AB—2.1–30 cm) shows that as a result of exposure to magnesite

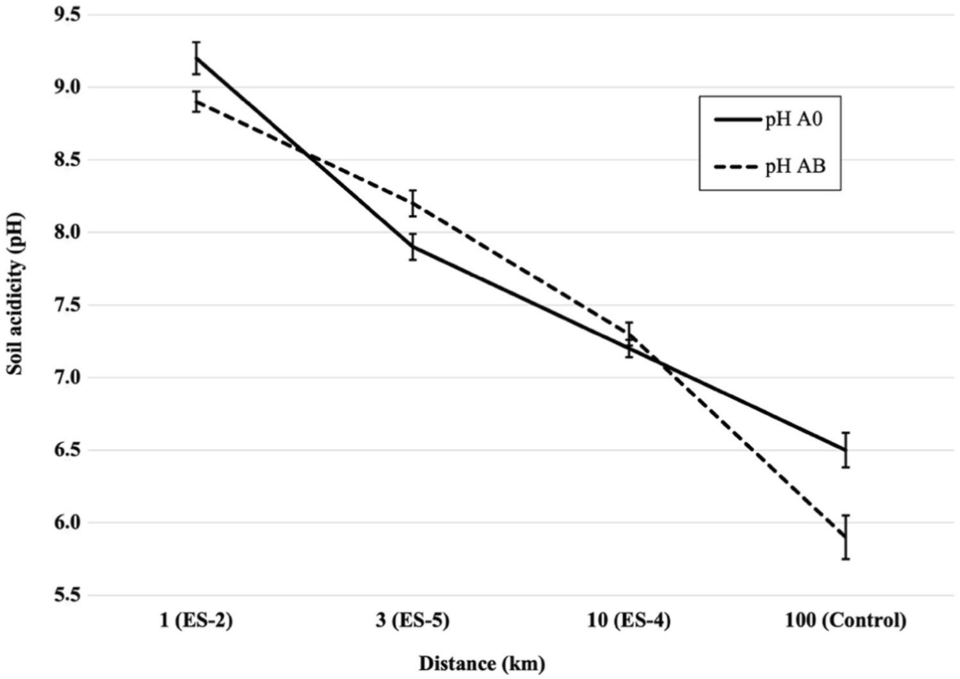

Fig. 5 Changes in the soil acidity index with distance

dust on the soil, significant shifts have occurred in it, given in Fig. 5.

The soil acidity index (water pH) is significantly higher at a distance of 1–3 km and has an alkaline reaction than at 10 and 100 km, where the soil reaction is closer to neutral and slightly acidic, respectively.

Change of Pb element in plant samples

The changes in Pb concentrations by distance for washed and unwashed samples at different ages are given in Table 1. Examining the change of Pb concentration in *B. pendula* organs by the distance, the changes by distance in all the organs and changes by organs at all distances were significant ($p < 0.001$). Given the values, except for the branches at 10 km distance, all obtained values from 2-year-old branch samples at all the distances were higher than those obtained from 1-year-old branch samples. The same also applies to the washed leaf samples. Besides that, it is difficult to state that Pb concentration changed depending on the distance.

The changes in Pb concentration by distance and depth are given in Table 2. It was found that, at both depth levels, the change of Pb concentrations in soil by the distance was not statistically significant. At different distances, the change of Pb concentration between the depths was statistically significant only for 1 and 10 km distances ($p < 0.01$). It is attention-grabbing that the Pb concentration in topsoil

Table 1 Pb concentrations (ppb) variations in organs of *Betula pendula*

Organ	Washing	Age	Distance (km)				*F* value
			1	3	10	100	
Leaf	W	1	2947.3 De	1175.4 Bc	1418.4 Cbc	890.9 Aa	206.039***
		2	7732.4 Ch	1176.6 Ac	3708.4 Bd	1387.5 Ab	1853.777***
	UW	1	1058.9 Bb	833.6 Ab	1143.8 Ba	2825.9 Ce	849.630***
		2	3741.6 Bf	611.8 Aa	3925.7 Ce	668.2 Aa	1835.724***
Branch	W	1	1571.9 Bc	537.7 Aa	1605.5 BCc	1650.3 Cbc	658.772***
		2	2012.9 Bd	1170.1 Ac	1011.0 Aa	6384.1 Cf	450.412***
	UW	1	830.2 Aa	1260.5 Bc	1234.2 Bab	1672.4 Cc	105.176***
		2	5871.3 Dg	3649.3 Bd	4080.4 Ce	2396.6 Ad	251.144***
F value			1511.657***	1131.205***	366.546 ***	415.636 ***	

According to Duncan's test results, the capital letters represent the statistical differences between horizontal direction while lowercase letters represent vertical direction. ns = not significant. *** = significant at 0.001 level. W = Washed UW = Unwashed. *** = $p < 0.0001$

Table 2 Pb concentrations (ppb) variations in soil

Depth	Distance (km)				*F* value
	1	3	10	100	
Topsoil	6.62 b	7.43	3.40 a	14.42	3.337 ns
Subsoil	1.39 a	0.76	3.86 b	1.67	1.064 ns
F value	32.861**	1.654 ns	36.675**	6.272 ns	

According to Duncan's test results, the lowercase letters represent the statistical differences between topsoil and subsoil within each distance. ns = not significant. ** = $p \le 0.01$

Table 4 Cr concentration (ppb) variations in soil

Depth	Distance (km)				*F* value
	1	3	10	100	
Topsoil	5.91 bC	2.55 A	0.76 A	1.91 B	44.370***
Subsoil	2.50 a	1.67	0.66	2.24	2.234 ns
F-value	13.438*	3.872 ns	0.102 ns	2.243 ns	

According to Duncan's test results, the capital letters represent the statistical differences between distances in each soil depth, while lowercase letters represent the differences between soil depths within each distance. ns = not significant. * = $p \le 0.05$. *** = $p < 0.0001$

at a 1 km distance was much greater than the concentration in the subsoil.

The changes in Cr concentrations between washed and unwashed *B. pendula* organ samples at different ages by distance are presented in Table 3. The variations in Cr concentrations in *B. pendula* organs by all the organs at all distances and by all the distances in all organs were statistically notable ($p < 0.001$). It was determined that Cr concentration changed in reverse proportion to the distance when examining the unwashed branches values. Moreover, the highest concentrations were obtained from the 2-year-old branches obtained from the shortest distances, and these values were higher when compared to the Cr concentrations obtained from other organs.

The changes in Cr concentrations by distance and depth are given in Table 4. It was determined that the variation of Cr concentration by distance was significant only in the topsoil ($p < 0.001$) and, among the depth levels, the difference was found to be significant only between the distances that are close to each other ($p < 0.05$). Among all the values, the highest Cr concentration was found in the topsoil at the shortest distance.

The changes of Fe concentration in the organs of *B. pendula* by age, washing, and distance are given in Table 5. As in Pb and Cr, the changes in Fe concentrations in *B. pendula* organs by all the organs at all distances and by all the distances in all organs were significant ($p < 0.001$). In general, the lowest Fe concentrations were observed at the longest distances in many organs. Fe concentration changed in reverse proportion to the distance in many organs. The highest concentrations were obtained from the 2-year-old branches, especially at short distances (1 and 3 km).

The changes in Fe concentrations by distance and depth are given in Table 6. The variations in Fe concentration by distance were statistically significant at both depth levels. As a result of the Duncan test, the values obtained from subsoil at 10 and 100 km distances were in the first group, the values obtained from 3 km distance were in both groups, and the values obtained from 1 km distance were in the second group. In the topsoil, the values obtained from 10 and 100 km distances were in the first group and the values obtained from 1 and 3 km distances were in the second group. Accordingly, it can be stated that Fe concentrations changed in reverse proportion to distance. Depending on the depth level, only the change at 100 km distance was statistically notable ($p < 0.05$).

Table 3 Cr concentration (ppb) variations in *Betula pendula* organs

Organ	Washing	Age	Distance (km)				*F* value
			1	3	10	100	
Leaf	W	1	112.0 Aa	674.1 Dbc	519.6 Cc	316.3 Bc	104.727***
		2	363.8 Ab	1562.8 Bf	1572.1 Bg	1511.4 Bg	483.600***
	UW	1	1586.1 Dg	786.6 Ccd	651.7 Bd	163.5 Aab	1517.953***
		2	1413.6 Df	584.0 Bab	327.7 Ab	890.0 Ce	986.952***
Branch	W	1	1154.7 Dd	471.6 Ba	237.8 Aa	1072.6 Cf	11,297.702***
		2	549.6 Ac	864.3 Cd	761.8 Be	552.5 Ad	57.571***
	UW	1	1268.8 Ce	1215.8 Ce	531.0 Bc	204.0 Ab	85.276***
		2	11,938.1 Dh	3321.6 Cg	941.6 Bf	143.3 Aa	8960.428***
F value			12,977.184***	353.841 ***	527.301***	743.690 ***	

According to Duncan's test results, the capital letters represent the statistical differences between horizontal direction while lowercase letters represent vertical direction. ns = not significant. *** = significant at 0.001 level. W = Washed UW = Unwashed. *** = $p < 0.0001$

Table 5 Fe concentration (ppm) variations in organs of *Betula pendula*

Organ	Washing	Age	Distance (km)				*F* value
			1	3	10	100	
Leaf	W	1	95.5 De	65.1 Ce	25.1 Ba	20.0 Aa	840.289***
		2	292.4 Bh	59.4 Ae	64.7 Af	61.1 Ae	1561.030***
	UW	1	28.6 Ba	32.4 Cc	49.9 Dd	22.34 Ab	1513.615***
		2	123.8 Cf	25.3 Ab	61.8 Be	23.6 Ab	5271.089***
Branch	W	1	68.4 Cc	10.6 Aa	27.3 Bb	132.9 Df	18,816.726***
		2	83.0 Cd	32.7 Ac	89.2 Dh	37.5 Bc	616.505***
	UW	1	44.8 Ab	48.7 Bd	47.4 Bc	43.9 Ad	10.934***
		2	254.4 Bg	502.5 Cf	69.2 Ag	61.7 Ae	4539.913***
F value			1758.427***	5700.66***	1692.240 ***	2326.247***	

According to Duncan's test results, the capital letters represent the statistical differences between horizontal direction while lowercase letters represent vertical direction. ns = not significant. *** = significant at 0.001 level. W = Washed UW = Unwashed. *** = $p < 0.0001$

Table 6 Fe concentration (ppm) variations in soil

Depth	Distance (km)				*F* value
	1	3	10	100	
Topsoil	39.45 B	31.82 B	4.72 A	5.65 aA	26.044***
Subsoil	78.00 B	30.97 AB	4.91 A	25.26 bA	3.954*
F value	2.227 ns	0.009 ns	0.087 ns	10.453*	

According to Duncan's test results, the capital letters represent the statistical differences between distances in each soil depth, while lowercase letters represent the differences between soil depths within each distance. ns = not significant. * = $p \leq 0.05$. *** = $p < 0.0001$

The changes in Fe concentration by distance were statistically significant at both depth levels. As a result of the Duncan test, the values obtained from subsoil at 10 and 100 km distances were in the first group, the values obtained from 3 km distance were in both groups, and the values obtained from 1 km distance were in the second group. In the topsoil, the values obtained from 10 and 100 km distances were in the first group and the values obtained from 1 and 3 km distances were in the second group. Accordingly, it can be stated that Fe concentrations changed in reverse proportion to distance. Depending on the depth level, only the change at 100 km distance was statistically notable ($p < 0.05$).

The pH intervals of the soil corresponding to successful growth are as follows: for ordinary pine—at least 5.0; optimum 5.0–6.2 and maximum 7.5; for hanging birch—5.5; 5.8–7.5 and 8.5, respectively (Francová et al. 2017).

High soil pH values at a distance of 1 to 3 km are explained by emissions of highly alkaline magnesite dust into the atmosphere. Caustic magnesite dust has a pH (water) = 10. It has been established that the soil pH in the upper root horizons, as a rule, is two to three units higher than the background level at a distance of up to 3 km in the direction of the main emission drift—to the northeast, east (ES-2, ES-5) from the Combine Magnesite (Fig. 5):

- At a distance of 1 and 3 km (ES-2 and ES-5), soil pH has an alkaline and slightly alkaline reaction—A_0—9.2, AB—8.9 and in A_0—7.9, AB—8.2, respectively.
- At 10 km (ES-4) the reaction of the soil solution is close to neutral—A0 – 7.2 and in the root layer AB – 7.3.
- Outside the source of contamination 100 km (Control), the soils are mostly slightly acidic—A0 – 6.5 and AB – 5.9.

It is known that with an alkaline reaction of the environment (pH above 8), the mobility in the soil decreases, and hence the availability of most heavy metals (Fe, Mn, Co, Cd, Pb, Zn, Ni, and some others) to plants. Earlier, we carried out an analysis of the content of exchangeable cations in the soil, which showed a significant increase in exchangeable magnesium, which can cause a deterioration in the water-physical properties of the soil—it becomes viscous, structureless (the phenomenon of alkalinity). An increase in the content of exchangeable magnesium in relation to calcium up the soil profile, as well as a comparison of this indicator with background indicators, indicates the technogenic nature of this process. Outside the focus of pollution in soils, exchangeable calcium is several times more than magnesium (Kuzmina and Menshchikov 2015).

With an alkaline reaction in the soil, the mobility and, consequently, the availability of iron, manganese, phosphorus, and cobalt to plants decreases, and if the pH exceeds 9.0, the root system of most plants experiences toxicosis and plants die (Menshikov et al. 2016).

The current study determined the changes in Cr, Pb, and Fe elements concentrations in *B. pendula*'s organs and soil by the distance to the source, "processing and mining of magnesite ore." The results suggested that the changes in concentrations in *B. pendula* by organs and distances were statistically significant for all distances and all organs, respectively.

The values obtained from 2-year-old organs of *B. pendula* were greater than those obtained from 1-year-old organs in this study. Heavy metal entry into the plant body occurs in 3 ways. Heavy metals can accumulate in plant organs by being absorbed by the roots, through the air via the leaves, and directly entering the stem parts (Chen et al. 2021; Cesur et al. 2022). Two-year-old leaves are formed earlier than 1-year-old leaves and are more exposed to heavy metals in the air, and heavy metal concentrations in these leaves are higher if heavy metal pollution in the air is high (Turkyilmaz et al. 2018). When leaves with high heavy metal concentrations fall into the soil and decompose, it also increases the concentration of heavy metal in the topsoil (Cetin et al. 2022). Therefore, the current study results prove that the heavy metal pollution in the air is at a high level.

Among heavy metals, Pb has a specific importance. Pb, an element extensively used in agricultural and industrial actions and thus observed very frequently, is a heavy metal that spreads the atmosphere in metal or compound form and is poisonous in any case. Besides being a crucial metal for humans for long years, Pb is among the leading metals causing environmental pollution (Ucun Ozel et al. 2019; Sevik et al. 2019a).

Previous studies showed that the Pb concentrations in plants near the mining areas are at very high levels. In a study carried out nearby the mining area in Nigeria's Ebonyi state's Ishiagu region, Pb concentrations in *Cassava* leaf specimens ranged between 0.21 and 0.51 mg/kg and higher than the standards set by WHO (Ajiwe et al. 2018). In a study carried out in a restored coal mining area of Huainan coalfield, China, Pb concentration was reported to be 43.6 mg/kg (in *Broussonetia papyrifera* leaves) (Niu et al. 2017). Especially the herbal and animal foods grow in mining areas (Chen et al. 2020; Stefanowicz et al. 2020), high traffic zones (Sevik et al. 2019a; Aricak et al. 2020), areas near the city centers (Turkyilmaz et al. 2019; Cesur et al. 2021), and industrial regions (Bi et al. 2018; Islam et al. 2020) causing pollution might be higher than the normal levels (França et al. 2017; Shahid et al. 2017).

At the end of this study, it was concluded that, especially in unwashed branches, Cr concentrations changed in reverse proportion to distance. The highest concentrations were obtained from 2-year-old unwashed branch samples, and these values were much higher than Cr concentrations found in other organs. These results suggest that Cr concentration increased because of the mining zone and was transported by particle materials. Previous studies reported that the air metals in the air stick to and pollute the particles. Because of the settlement of these particles on tree organs, the heavy metal contaminations in these organs increased (Koç 2021b; Isinkaralar et al. 2022). The retention of particle materials becomes easier on the rough surfaces of plants such as bark, and the high concentrations of heavy metals in these organs explain the contamination of particles by heavy metals (Sevik et al. 2020b; Savas et al. 2021).

It was determined that, in many organs, Fe concentrations changed in reverse proportion to the distance, and the highest values were obtained from 2-year-old organs taken from short distances (1 and 3 km). As explained before, many studies reported that heavy metal pollutions at the points near the heavy metal sources were at higher levels (Aricak et al. 2019; Wang et al. 2020). The higher concentrations of Fe and Cr in 2-year-old organs might be explained by these organs prolonged exposure to air metal. Hence, previous studies suggest that the heavy metal accumulation in plant organs occurs through a complex mechanism that has not been explained yet, and the span of exposure to the pollution of heavy metal is one of these factors (Alaqouri et al. 2020a; Cetin et al. 2020).

The heavy metals accumulation in plants may originate from soil or air (Shahid et al. 2017), though the heavy metal mobility in soil is at a more limited level. The results showed that the changes in Pb and subsoil Cr concentrations at different depth levels by the distance were not statistically significant. The difference between the depth levels was statistically significant only at 1 and 10 km distances for Pb and 1 km for Cr. For both elements, the concentrations in topsoil at a 1 km distance were much higher than in subsoil. This finding might suggest that heavy metals cannot be transported to long distances in soil. Thus, it was determined in previous studies that heavy metal concentrations in soil were at very high levels at locations, which are close to heavy metal sources, such as city centers, industrial areas, and traffic, but these concentrations remarkably decreased at relatively close locations (Hou et al. 2017; Alsbou and Al-Khashman 2018; Barsova et al. 2019; Zhang et al. 2019).

Heavy metals penetrate the plant organism via leaves and roots. Nevertheless, it is hard to distinguish whether the heavy metals in plant organs originate from soil or the atmosphere because the pathways of intake from soil and air might be synchronous. Hence, leaves are considered the most proper body part for tracing the contamination of heavy metals in the air. Leaves are the most affected plant organs by heavy metal contamination, and they can accumulate heavy metals in the air into their bodies through air intake via stomata during photosynthesis (Shadid et al. 2017; Alaqouri et al. 2020a, b; Cetin et al. 2020). These results claim that the transportation of heavy metals in soil is minimal, and they can be transported to longer distances through the air.

It is challenging to watch heavy metal contamination in the air. After the particles in the atmosphere adhere to the leaf surfaces, they enter the leaf structure and can accumulate on the plant leaves. Various factors affect the entry and accumulation of heavy metals in the air into the plant body. The diffusion of heavy metals in the atmosphere and their entry into the plant body is a very complex mechanism (Aricak et al. 2020). Heavy metal accumulation potential of plants grown in a similar environment also varies depending on many factors such as plant type, organ structure, metal properties, heavy metal exposure time, and amount of particulate matter (Turkyilmaz et al. 2020; Cesur et al. 2022). In addition, environmental situations, especially air humidity and precipitation, also significantly affect heavy metal entry into the plant (Cetin et al. 2020).

Apart from these factors, the entry of heavy metals into the plant body may differ depending on several factors, because the growth performance of plants, such as anatomical, morphological, and phenotypic characteristics, can affect heavy metal entry into the plant body. The plant phenotypic characteristics also emerge due to the interaction of genetic structure (Hrivnák et al. 2017) and environmental situations (Canturk and Kulac 2021; Varol et al. 2022). Therefore, external factors such as climatic and edaphic factors that significantly affect plant metabolism (Kravkaz Kuscu et al. 2018; Yigit et al. 2021) and stress level (Ozel et al. 2021) interfere with plant growth, plant metabolism, and therefore heavy metal affects the accumulation (Key and Kulac 2022).

Consequently, the change of heavy metal concentration in plants results from a complex mechanism in which numerous factors interact. However, this mechanism has not been fully resolved. Information on the uptake of heavy metals from aboveground organs is minimal (Shahid et al. 2017; Ghoma et al. 2022).

Conclusion

Heavy metals are pollutants that are very dangerous for human and environmental health. Thus, it is crucial to track the air metal contamination in urban regions and the areas, which are heavy metal sources, such as industrial facilities and high traffic density. In the present study, the changes in concentrations of Fe, Cr, and Pb elements, which are among the most dangerous heavy metals to living things and environmental health, by distance were determined using soil and *B. pendula* organs taken around a mineral deposit. The results achieved here revealed that the mobility of heavy metals in the soil is generally minimal, and especially Pb and Cr concentrations can be transported in a short distance, but these elements can be conveyed by air to longer distances. It was determined that especially the particle materials were contaminated by Cr. In this case, it is a necessity to take precautions to prevent the transportation of heavy metals by air to far distances. Among these precautions, using tall and densely planted trees is one of the most effective methods of preventing heavy metal sources. These trees might be very effective in reducing pollution by preventing the spread of heavy metals and decreasing the intake of them from air and soil.

Heavy metals are not only elements that can threaten the health of living things, especially humans, but also small amounts of essential elements for the development of many living things. Heavy metals threaten living things only when they exceed certain limits. Therefore, it is crucial to determine these limits with future studies to be carried out. In the few studies carried out to date, it has been tried to determine the limits where heavy metals pose a threat, especially for foodstuffs and soils. However, an internationally valid standardization could not be established. With the comprehensive studies to be done, this standardization should be established primarily for nutrients and soils. In addition, it is recommended to establish a similar standardization for biomonitors, which are indicators of heavy metal pollution in the air.

Acknowledgements The work was carried out as part of the state assignment of the Botanical Garden of the Ural Branch of the Russian Academy of Sciences and Kastamonu University, Faculty of Forestry and Faculty of Architecture and Engineering.

Authors Contributions All authors contributed to the study conception and design. Material preparation and data collection were performed by N.A.K. and S.L.M. The analysis performed by K.I. and R.E. The first draft of the manuscript was written by K.I., İ.K. and B.A., and all authors commented on the previous version of the manuscript. All authors read and approved the final manuscript.

Funding Not applicable.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Not applicable.

Consent for publish Not applicable.

References

Ajiwe VIE, Chukwujindu KC, Chukwujindu CN (2018) Heavy metals concentration in Cassava tubers and leaves from a Galena Mining Area in Ishiagu, IVO LGA of Ebonyi State Nigeria. J Appl Chem 11(3):54–58

Alaqouri HAA, Genc CO, Aricak B, Kuzmina N, Menshikov S, Cetin M (2020) The possibility of using scots pine needles as biomonitor in determination of heavy metal accumulation. Environ Sci Pollut Res 27(16):20273–20280

Alaqouri HAA, Ozer Genc C, Aricak B, Kuzmina N, Menshikov S, Cetin M (2022) The possibility of using scots pine (*Pinus sylvestris* L.) needles as biomonitor in the determination of heavy metal accumulation. Appl Ecol Environ Res 18(2):3713–3727

Alsbou EME, Al-Khashman OA (2018) Heavy metal concentrations in roadside soil and street dust from Petra region. Jordan Environ Monit Assess 190(1):48

Altera AZA, Bayraktar OY, Soylemez H (2019) Investigation of the effects of modified bitumen on asphalt concrete performance by industrial waste. KUJES 5(2):93–100

Aricak 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. Appl Ecol Environ Res 17(3):6723–6734

Aricak 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. Pol J Environ Stud 29(2):1051–1057

Bachurina AV, Zalesov SV (2020) Bioindication method application to assess environment quality of industrial cities in the Urals. For Bul 24(3):11–17. https://doi.org/10.18698/2542-1468-2020-3-11-17

Barsova N, Yakimenko O, Tolpeshta I, Motuzova G (2019) Current state and dynamics of heavy metal soil pollution in Russian Federation—A review. Environ Pollut 249:200–207

Bayraktar OY, Saglam-Citoglu G, Belgin CM, Cetin S, Cetin M (2019a) Investigation of effect of brick dust and silica fume on the properties of portland cement mortar. Fresenius Environ Bull 28(11):7823–7832

Bayraktar OY, Saglam-Citoglu G, Belgin CM, Cetin M (2019b) Investigation of the mechanical properties of marble dust and silica fume substituted portland cement samples under high temperature effect. Fresenius Environ Bull 28(5):3865–3875

Bi C, Zhou Y, Chen Z, Jia J, Bao X (2018) Heavy metals and lead isotopes in soils, road dust and leafy vegetables and health risks via vegetable consumption in the industrial areas of Shanghai, China. Sci Total Environ 619:1349–1357

Canturk U, Kulaç Ş (2021) The effects of climate change scenarios on Tilia ssp. in Turkey. Environ Monit Assess 193:771. https://doi.org/10.1007/s10661-021-09546-5

Cesur A, Zeren Cetin I, Abo Aisha AES, Alrabiti OBM, Aljama AMO, Jawed AA, Cetin M, Sevik H, Ozel HB (2021) The usability of *Cupressus arizonica* annual rings in monitoring the changes in heavy metal concentration in air. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-13166-4

Cesur A, Zeren Cetin I, Cetin M, Sevik H, Ozel HB (2022) The use of *Cupressus arizonica* as a biomonitor of Li, Fe, and Cr pollution in Kastamonu. Water Air Soil Pollut 233:193. https://doi.org/10.1007/s11270-022-05667-w

Cetin M, Sevik H, Cobanoglu O (2020) Ca, Cu, and Li in washed and unwashed specimens of needles, bark, and branches of the blue spruce (*Picea pungens*) in the city of Ankara. Environ Sci Pollut Res 27(17):21816–21825

Cetin M, Aljama AMO, Alrabiti OBM, Adiguzel F, Sevik H, Zeren Cetin I (2022) Determination and mapping of regional change of Pb and Cr pollution in Ankara city center. Water Air Soil Pollut 233:163. https://doi.org/10.1007/s11270-022-05638-1

Chen W, Peng L, Hu K, Zhang Z, Peng C, Teng C, Zhou K (2020) Spectroscopic response of soil organic matter in mining area to Pb/Cd heavy metal interaction: a mirror of coherent structural variation. J Hazard Mater 393:122425

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. Elem Sci Anth 9(1):00075

Chernykh VL, Chernykh LV, Chernykh DV (2019) Mathematical models of productivity of stands of pine, spruce, birch, aspen and Linden of the Mountain Urals. Forests of Eurasia-Serbian forests: Materials of the XVIII International conference of young scientists dedicated to academician Professor Zhark Miletich (1891–1968) Belgrade. Forest faculty of the University of Belgrade, Serbia, pp 75–82

Chiroma TM, Ebewel RO, Hymore F (2014) Comparative assessment of heavy metal levels in soil, vegetables and urban grey waste water used for irrigation in Yola and Kano. Int Ref J Eng Sc 3(2):01–09

Elsunousi AAM, Sevik H, Cetin M, Ozel HB, Ucun Ozel H (2021) Periodical and regional change of particulate matter and CO_2 concentration in Misurata. Environ Monit Assess 193(11):1–15. https://doi.org/10.1007/s10661-021-09478-0

França FC, Albuuerque AM, Almeida AC, Silveira PB, Crescêncio Filho A, Hazin CA, Honorato EV (2017) Heavy metals deposited in the culture of lettuce (*Lactuca sativa* L.) by the influence of vehicular traffic in Pernambuco. Brazil Food Chem 215:171–176

Francová A, Chrastný V, Šilleroá H, Vítková M, Kocourková J, Komárek M (2017) Evaluating the suitability of different environmental samples tracing atmospheric pollution in industrial areas. Environ Pollut 220:286–297

Gencel O, Bayraktar OY, Kaplan G, Benli A, Martínez-Barrera G, Brostow W, Tek M, Bodur B (2021) Characteristics of hemp fibre reinforced foam concretes with fly ash and Taguchi optimization. Constr Build Mater 294:123607

Ghoma W, Sevik H, Isinkaralar K (2022) Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke. Air Qual Atmos Health 15:415–424. https://doi.org/10.1007/s11869-021-01146-z

Goncharova IA, Skripalschikova LN, Barchenkov AP, Shushpanov AS (2020) Understory vegetation cover components assessment in anthropogenically disturbed birch stands of Krasnoyarsk forest-steppe. Russ J For Sci 1:75–87. https://doi.org/10.37482/0536-1036-2020-1-75-87

GOST 17.4.4.02.84 (1984) Soils methods of sampling and preparation of samples for chemical, bacteriological, helminthological analysis. Publishing House of Standards

GOST 26423–85 (1985) Methods for determining the specific electrical conductivity, pH and dense residue of water extract. Publishing House of Standards

Hou D, O'Connor D, Nathanail P, Tian L, Ma Y (2017) Integrated GIS and multivariate statistical analysis for regional scale assessment of heavy metal soil contamination: a critical review. Environ Pollut 231:1188–1200

Hrivnák M, Paule L, Krajmerová D, Kulaç Ş, Şevik H, Turna İ, Tvauri I, Gömöry D (2017) Genetic variation in Tertiary relics: the case of eastern-Mediterranean *Abies* (Pinaceae). Ecol Evol 7(23):10018–10030

Isinkaralar K, Koc I, Erdem R, Sevik H (2022) Atmospheric deposition in several landscape plants in Mersin, Türkiye. Water Air Soil Pollut 233:120. https://doi.org/10.1007/s11270-022-05607-8

Islam MS, Proshad R, Asadul Haque M, Hoque MF, Hossin MS, Islam Sarker MN (2020) Assessment of heavy metals in foods around the industrial areas: health hazard inference in Bangladesh. Geocarto Int 35(3):280–295

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. Landsc Ecol Eng 18:75–83. https://doi.org/10.1007/s11355-021-00483-6

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 Qual Atmos Health 1–11

Koç İ (2021a) Examining seed germination rate and seedlings gas exchange performances of some Turkish red pine provenances under water stress. DUBITED 9(3):48–60

Koç İ (2021b) 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

Koç İ, Nzokou P (2022) Do various conifers respond differently to water stress? A comparative study of white pine, concolor and balsam fir. KUOFD 22(1):1–16

Koç İ, Nzokou P, Cregg B (2021) 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 For. https://doi.org/10.1007/s11056-021-09894-7

Koc I, Nzokou P (2018) Effects of water stress and cold treatments in the germination of two conifers (*Pinus nigra* and *Pinus brutia*) species from Turkey. HortScience 53(9):259–259

Koç İ (2019) Conifers Response to water stress: physiological response and effects on nutrient use physiology. Dissertation, Michigan State University.

Kravkaz Kuscu IS, Cetin M, Yigit N, Savaci G, Sevik H (2018) Relationship between enzyme activity (urease-catalase) and nutrient element in soil use. Pol J Environ Stud 27(5):2107–2112

Kuzmina N, Menshchikov S (2015) Influence of aerotechnogenic emissions of magnesite production on the chemical composition of snow water and soil in dynamics. Proc Orenburg State Agrar Univ 6(56):192–196

Kuznetsov AM, Fesyun AP, Samokhvalov SG, Makhon'ka EP, (1992) Methodical instructions for the determination of heavy metals in agricultural soils and crop production. TsINAO, Moscow, pp 13–24

Lavrenko EM (1947) Geobotanical zoning of the USSR. Publishing House of the USSR Academy of Sciences, Russia

Long Z, Huang Y, Zhang W, Shi Z, Yu D, Chen Y, Liu C, Wang R (2021) Effect of different industrial activities on soil heavy metal pollution, ecological risk, and health risk. Environ Monit Assess 193(1):1–12

Martin S, Griswold W (2009) Human health effects of heavy metals. Environ Sci Tech 15:1–6

Menshikov SL, Zavyalov KE, Kuzmina NA, Mokhnachev PE, Tepordei IC (2016) Distribution of trees experienced cultures *Betula pendula* Roth. on steps of thickness and level of pollution of the soil in a zone of action of emissions of Magnezit combine. Prog Nat Sci 10:84–89

Niu S, Gao L, Zhao J (2017) Heavy metals in the soils and plants from a typical restored coal-mining area of Huainan coalfield, China. Environ Monit Assess 189(10):1–12

Ozel HB, Cetin M, Sevik H, Varol T, Isik B, Yaman B (2021) The effects of base station as an electromagnetic radiation source on flower and cone yield and germination percentage in *Pinus brutia* Ten. Biol Futura 72:359–365

Savas DS, 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. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-14826-1

Sevik H, Cetin M, Ozturk A, Ozel HB, Pinar B (2019a) Changes in Pb, Cr and Cu concentrations in some bioindicators depending on traffic density on the basis of species and organs. Appl Ecol Environ Res 17(6):12843–12857

Sevik H, Cetin M, Ozel HB, Pinar B (2019b) Determining toxic metal concentration changes in landscaping plants based on some factors. Air Qual Atmos 12(8):983–991

Sevik H, Cetin M, Ozel HU, Ozel HB, Mossi MMM, Cetin IZ (2020a) Determination of Pb and Mg accumulation in some of the landscape plants in shrub forms. Environ Sci Pollut Res 27(2):2423–2431

Sevik H, Cetin M, Ozel HB, Akarsu H, Cetin IZ (2020) Analyzing of usability of tree-rings as biomonitors for monitoring heavy metal accumulation in the atmosphere in urban area: a case study of cedar tree (*Cedrus* sp.). Environ Monit Assess 192(1):1–11

Shahid M, Dumat C, Khalid S, Schreck E, Xiong T, Niazi NK (2017) Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake. J Hazard Mater 325:36–58

Shoba SA (2011) National Atlas of soils of the Russian Federation. Astrel Publishing, Moscow

Smolonogov EP (2001) Integrated zoning of the Urals. Forests of the Urals and the economy in them. UGLTU

Stefanowicz AM, Kapusta P, Zubek S, Stanek M, Woch MW (2020) Soil organic matter prevails over heavy metal pollution and vegetation as a factor shaping soil microbial communities at historical Zn–Pb mining sites. Chemosphere 240:124922

Turkyilmaz A, Sevik H, Cetin M (2018) The use of perennial needles as biomonitors for recently accumulated heavy metals. Landsc Ecol Eng 14(1):115–120

Turkyilmaz A, Sevik H, Isinkaralar K, Cetin M (2019) Use of tree rings as a bioindicator to observe atmospheric heavy metal deposition. Environ Sci Pollut Res 26(5):5122–5130

Turkyilmaz A, Cetin M, Sevik H, Isinkaralar K, Saleh EAA (2020) Variation of heavy metal accumulation in certain landscaping plants due to traffic density. Environ Dev Sustain 22(3):2385–2398

Ucun Ozel H, Ozel HB, Cetin M, Sevik H, Gemici BT, Varol T (2019) Base alteration of some heavy metal concentrations on local and seasonal in Bartin River. Environ Monit Assess 191(9):594

Ucun Ozel H, Gemici BT, Gemici E, Ozel HB, Cetin M, Sevik H (2020) Application of artificial neural networks to predict the heavy metal contamination in the Bartin River. Environ Sci Pollut Res 1–18.

Uncumusaoğlu AA, Mutlu E (2019) Evaluating spatial and temporal variation in Tuzaklı pond water using multivariate statistical analysis. Pol J Environ Stud 28(5):1–14

Varol T, Cetin M, Ozel HB, Sevik H, Zeren Cetin I (2022) The effects of climate change scenarios on *Carpinus betulus* and *Carpinus orientalis* in Europe. Water Air Soil Pollut 233:45. https://doi.org/10.1007/s11270-022-05516-w

Wang Y, Duan X, Wang L (2020) Spatial distribution and source analysis of heavy metals in soils influenced by industrial enterprise distribution: Case study in Jiangsu Province. Sci Total Environ 710:134953

Yigit N, Mutevelli Z, Sevik H, Onat SM, Ozel HB, Cetin M, Olgun C (2021) Identification of some fiber characteristics in *Rosa* sp. and *Nerium oleander* L. wood grown under different ecological conditions. BioResources 16(3):5862–5874

Yildiz D, Nzokou P, Deligoz A, Koc I, Genc M (2014) Chemical and physiological responses of four Turkish red pine (*Pinus brutia* Ten) provenances to cold temperature treatments. Eur J For Res 133(5):809–818

Zhang Q, Yu R, Fu S, Wu Z, Chen HY, Liu H (2019) Spatial heterogeneity of heavy metal contamination in soils and plants in Hefei. China Sci Rep 9(1):1–8