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Usability of some woody plants in monitoring and reducing the Mn, Zn, Ba, and Sr concentrations in the air

Hatice COBANOGLU [1,*], Hakan SEVIK [2], Halil Baris OZEL [3] and Sezai BOZDAG [4]

[1] *Forest Engineering Department, Graduate Education Institute, Düzce University, Türkiye.*
[2] *Environmental Engineering Department, Faculty of Engineering and Architecture, Kastamonu University, Türkiye.*
[3] *Forest Engineering Department, Faculty of Forestry, Bartın University, Türkiye.*
[4] *Forest Engineering Department, Graduate Education Institute, Bartın University, Türkiye.*

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Abstract

The advancements worldwide in the last century made air pollution one of the most important problems threatening human health on a global scale. One of the most harmful components of air pollution is heavy metals. For this reason, monitoring and reducing heavy metal pollution has been one of the main research subjects in recent years. In the present study, the accumulation of Mn, Zn, Ba, and Sr, which were included in the preliminary pollutant list by ATSDR (Agency for Toxic Substances and Disease Registry) since they pose a significant threat to human health, by plant species and organ was investigated. As a result of the present study, the highest concentrations were found in the leaves. The most useful species to be utilized in monitoring the change of the concentrations of heavy metals examined here in the air and to reduce the level of pollution were found to be *Cotoneaster franchetii* and *Platycladus orientalis*.

Keywords: Heavy metal; Biomonitor; Woody plant; Karabük; Türkiye

1. Introduction

The growing population of the world brought various problems with it and the environmental pollution, one of the leading problems among them, has become one of the subjects occupying the agenda on a global scale. Particularly, air pollution became a problem threatening the ecosystem and organisms, especially humans [1-3]. Such that, it was reported that approx. 90% of the global population breathes polluted air and air pollution causes the death of 7 million individuals annually [4, 5]. Moreover, it was emphasized that, by affecting the composition of the atmosphere, air pollution has become the main factor in global climate change [6].

Air pollution has many components including particle matters, CO_2, and various volatile organic compounds [7-10]. Among these compounds, the most dangerous one for human life is heavy metals [11-14]. Some of the heavy metals such as Pb, Cr, Ni, and Hg are toxic, carcinogenic, and harmful to the organisms, especially to humans, even when at low concentrations [15-17]. It was also reported that the heavy metals, which are necessary as plant nutrition elements, might be harmful to the organisms when at high concentrations. Previous studies emphasized that the heavy metals inhaled into the human body might be more harmful and even lethal [18-21]. For this reason, it is very important to monitor and reduce the concentrations of heavy metals in the air [22].

The present study investigated the concentrations of Mn, Zn, Ba, and Sr in the organs of some plants. These elements can be very harmful, especially to human health. Among them, Mn is an element that can cause hallucinations, weakness,

* Corresponding author: Hatice COBANOGLU
Forest Engineering Department, Graduate Education Institute, Düzce University, Türkiye.

fatigue, sleeplessness, amnesia, and nerve injuries among humans. Moreover, it can also cause Parkinson's disease, lung embolism, and bronchitis [23]. Although it is involved in many vital functions in human and animal organisms, Zn which is one of the most common elements is toxic when at high concentrations [24]. Ba is an element playing a key role in the production of many products in the industry. However, Ba is one of the most dangerous heavy metals and all of its compounds are poisonous [25]. Water-soluble Sr compounds are capable of polluting the water. Some of the compounds of Sr, which are harmful to human health even when at low concentrations, may cause lung cancer [26] and very severe problems, which might result in sudden death, by accumulating in the body throughout one's life [27]. Thus, monitoring and reducing the concentrations of these elements in the air is very important for human health.

Directly monitoring the heavy metals in the air is very difficult and expensive and direct measurement methods are not used because the results are not reliable since the heavy metal concentrations in the air are not stable [28]. Instead of these methods, biomonitors that provide information about the effects of heavy metals on the ecosystem, as well as offering affordable and easy measurement, are used [29]. Plants, which are widely utilized as biomonitors, are the most effective instruments that can be used in reducing heavy metal pollution in the air [30].

In the present study, the changes in Mn, Zn, Ba, and Sr concentrations in various organs of some plants grown in Karabük, one of the provinces reported to have the highest level of air pollution in Türkiye, were determined and, thus, it was aimed to determine the most effective species and organs to be used in monitoring the concentrations of these heavy metals in the air and to reduce the heavy metal pollution.

2. Material and methods

This study was carried out using the plants collected from the city center of Karabük. Karabük is a province, where one of the largest steel and iron factories of Türkiye is located, and air pollution frequently is frequently brought to the agenda. Within the scope of this study, branch samples were collected from *Pyracantha coccinea* (Pc), *Cotoneaster franchetii* (Cf), *Platycladus orientalis* (Po), and *Euonymus japonica* (Ej) individuals grown in the city center. Collected samples were divided into organs by using no metal instrument.

The samples, which were divided into organs and labeled, were dried by keeping them under room conditions for 2 weeks without direct sunlight. Then, they were dried for 2 weeks in a drying oven at 45°C. Dried plant samples were ground into powder and tubes designed for microwave were added with 0.5g taken from dried samples. Then, the samples were added with 10 mL of 65% HNO_3. The preparations were then combusted in a microwave under 280 PSI pressure at 180 ºC for 20 minutes. After the process was completed, the tubes were taken from the microwave and left for cooling. Then, by adding deionized water, they were completed to 50 ml. After filtering through filter paper, the prepared samples were scanned at suitable wavelengths by using an ICP-OES device. The values obtained were multiplied by the dilution factor and the concentrations of elements examined here were calculated. This method is one of the techniques that are used in heavy metal analyses in recent years the most [31, 32].

The data obtained were analyzed using SPSS package software. Variance analysis was conducted, and homogeneous groups were achieved by performing Duncan's test for the groups with s statistically significant difference at the confidence level of min. 95%. The resultant data were interpreted by simplifying and tabularizing.

3. Results

The change in the concentration of Mn, which is the first element examined here, by species and organ is presented in Table 1.

Given the results presented in Table 1, the changes in Mn concentrations were statistically significant for all organs by species and all species by organs. Examining the results, it can be seen that the highest values were obtained from the leaves, whereas the lowest values were found in the woods. Such that, the Mn concentrations in woods of Cf and Ej species were found to be below the detectable limits. The highest two values found here were obtained from Po leaves and barks. Changes in Zn concentration by species and organs are presented in Table 2.

As a result of the variance analysis, the changes in Zn concentration were found to be statistically significant for all species and organs ($p<0.05$). Considering the mean values, the highest values were found in Cf among species and leaves among organs, whereas the lowest values were found in Ej and Pc among species and in woods among organs. Interestingly, the values obtained from the leaves of Cf and Po species were much higher than the others. Changes in Ba concentration by species and organs are presented in Table 3.

Table 1 Changes in Mn concentration (ppm)

Species	Organ			F Values	Average
	Leaf	Bark	Wood		
Pc	83.93 Cc	10.09 Aa	14.77 Ba	4078.057***	36.26
Cf	28.05 Aa	47.67 Bc	UL	19257.919***	37.86
Po	116.47 Cd	96.27 Bd	20.92 Ab	3169.726***	77.88
Ej	81.34 b	14.12 b	UL	67943.182***	47.73
F Values	12349.098***	2676.424***	40.553**		2.521 ns
Average	77.45 B	42.03 A	17.84 A	8.139**	

Note: Different letters show significant differences (p< 0.05). Upper case letters indicate horizontal direction, whereas lower case letters represent vertical directions. ns: not significant. * Significant at 0.05 level. ** Significant at 0.01 level. *** Significant at 0.001 level.

Table 2 Changes in Zn concentration (ppm)

Species	Organ			F Values	Average
	Leaf	Bark	Wood		
Pc	32.78 Ba	45.41 Cb	23.84 Ab	387.698***	34.01 a
Cf	130.03 Bc	50.48 Ac	UL	18151.456***	90.25 b
Po	127.75 Cb	50.30 Bc	7.99 Aa	9597.821***	62.01 ab
Ej	31.79 a	24.32 a	UL	959.878***	28.05 a
F Values	14520.717***	399.001***	4027.177***		4.284*
Average	80.58 B	42.62 A	15.92 A	8.459**	

Note: Different letters show significant differences (p< 0.05). Upper case letters indicate horizontal direction, whereas lower case letters represent vertical directions. ns: not significant. * Significant at 0.05 level. ** Significant at 0.01 level. *** Significant at 0.001 level.

Table 3 Changes in Ba concentration (ppm)

Species	Organ			F Values	Average
	Leaf	Bark	Wood		
Pc	25.61 Ba	53.14 Cd	15.74 Ab	8038.944***	31.49
Cf	76.40 Bc	39.91 Ac	UL	5961.238***	58.16
Po	119.48 Cd	37.24 Bb	11.91 Aa	39048.777***	56.21
Ej	37.65 b	21.59 a	UL	8244.287***	29.62
F Values	24657.471***	1978.796***	2047.214***		1.905 ns
Average	64.78 B	37.97 A	13.82 A	8.441**	

Note: Different letters show significant differences (p< 0.05). Upper case letters indicate horizontal direction, whereas lower case letters represent vertical directions. ns: not significant. * Significant at 0.05 level. ** Significant at 0.01 level. *** Significant at 0.001 level.

As a result of the variance analysis, the change in Ba concentration was found to be statistically significant in all species and organs ($p<0.05$). Considering the mean values, the highest Ba concentrations were found in leaves among the organs, while the lowest values were generally obtained from the woods. Such that, the Ba concentrations in woods of Cf and Ej species were found to be below the detectable limits. The highest value in this study was obtained from the leaves of Po species. Changes in Sr concentration by species and organs are presented in Table 4.

Given the results presented in Table 4, the changes in Sr concentrations were statistically significant for all species and all organs. However, despite other elements, the highest two values obtained in the present study were found in the barks of Pc and Ej species. Considering the mean values, the highest values were found in leaves and the values found in leaves and barks were in the same groups according to the results obtained from Duncan's test.

Table 4 Changes in Sr concentration (ppm)

Species	**Organ**			**F Values**	**Average**
	Leaf	Bark	Wood		
Pc	55.05 Ba	165.00 Cd	27.97 Aa	8866.515***	82.67
Cf	174.81 Bc	21.63 Aa	UL	37864.633***	98.22
Po	173.42 Cc	43.57 Ab	56.31 Bb	7535.910***	91.10
Ej	140.32 b	160.74 c	UL	67.966**	150.53
F Values	1532.991***	10707.805**	4367.614***		1.645 ns
Average	135.90 B	97.73 B	42.14 A	5.891**	

Note: Different letters show significant differences ($p < 0.05$). Upper case letters indicate horizontal direction, whereas lower case letters represent vertical directions. ns: not significant. * Significant at 0.05 level. ** Significant at 0.01 level. *** Significant at 0.001 level.

4. Discussion

As a result of the analyses, the highest Mn, Zn, and Ba concentrations were generally found in the leaves. Leaves are the organs having the highest level of contact with the air and taking the highest amount of heavy metals from the air [33]. Thus, previous studies reported that the most suitable organ to be used as biomonitors in monitoring the heavy metal pollution in the air was the leaves [34]. In corroboration with the previous studies, the highest Mn, Zn, and Ba concentrations in the present study were found in leaves in general.

The highest Sr concentrations in the present study were found in the barks. Since bark has a porous surface, the particle matters contaminated by heavy metals in the air can easily remain on them [35]. For this reason, heavy metal concentrations are found to be at very high levels in barks. Thus, the results achieved here suggest that the particle matters in the air in this region are contaminated by Sr element. The heavy metal concentrations in the air are related mainly to industrial activities [36], traffic [37], and mining activities [38]. In addition to them, it should be noted that the steel and iron industry in the region might be a source of Sr.

Heavy metals might penetrate the plant body from soil or air. Especially in the case of intake from the air, the duration of contact with air is an important factor. Wood part has no contact with the air [39]. The fact that the concentrations of all the elements examined here were found to be below the detectable threshold in Cf and Ej woods might be considered to indicate that these elements penetrate the plant body not from soil but the air in general.

The results achieved here showed that the concentrations of the elements examined here significantly change by both species and organs. Similar results were reported in previous studies carried out on this subject [40]. Intake and accumulation of heavy metals in plant bodies are shaped by mutual interaction between numerous and various factors. Many of heavy metals are also nutrient elements that are necessary for plant development. Besides that, all of the elements analyzed here were added to the primary pollutant list of ATSDR (Agency for Toxic Substances and Disease Registry) since they are toxic to living organisms when at high concentrations [41].

Toxic effects of heavy metals on plants are observed generally as growth inhibition, low biomass production, chlorosis, altered water and mineral nutrient balance, and finally plant aging [42]. This is because these elements cause stress in plants. As well as many factors including temperature, water deficiency, UV-B, diseases, pests, air pollution, etc., heavy metals can also decelerate plant growth and even cause death by creating stress in plants [43-50].

Some plants, however, can tolerate and survive high concentrations of heavy metals and accumulate them in their organs [51-52]. These plants can be very useful in reducing heavy metal pollution in air, water, and soil [53]. From the aspect of human and environmental health, determination and effective use of plants, which can accumulate the pollutant in their bodies and survive, are among the primary research subjects.

Besides that, the most useful plants to be used in monitoring and reducing heavy metal pollution should be determined regionally because plants' capacity to fulfill the functions and benefits expected from them depends on their healthy growth and development [54-59]. Plant development, as with all other phenotypic characteristics, is shaped by the mutual interaction between genetic structure [60-62] and environmental conditions [63-70]. For this reason, the optimum development conditions of each plant are related to different edaphic and climatic conditions [71-74]. Thus, since the maximum development of each plant might require different environmental conditions, their capacity to accumulate heavy metals in different parts would be at different levels.

5. Conclusion

As a result of the present study, it was determined that the concentrations of heavy metals examined here in Po and Cf leaves were at very high levels. Plants, which are capable of accumulating heavy metals in their leaves, are useful instruments to be used in reducing the heavy metal pollution in the air because leaves have the highest mass in plants. Thus, given the results achieved here, Po and Cf species can be effectively used in reducing the Mn, Zn, Ba, and Sr pollution in the air.

Although Sr, one of the elements investigated here, can be very harmful to human health, it has been ignored in studies carried out to date. The highest Sr concentration in the present study was obtained from the barks. Heavy metal concentrations found in barks are generally related to the particle matters contaminated by the heavy metals in the air. It is recommended to investigate if this Sr pollution increased because of industry, traffic, or another source.

The heavy metals studied here are of vital importance for the ecosystem, as well as human and environmental health. However, the subjects such as how efficient the heavy metals are on living organisms at which concentrations, the mechanisms playing an effective role in intake and accumulation in plant bodies, and the transfer and speciation of them after leaving the source couldn't be explained yet. For these subjects to be explained clearly, the studies examining them should be continued and diversified.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they no conflict of interest. The none of the authors have any competing interests in the manuscript.

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