ORIGINAL PAPER

STUDY OF HEAVY METAL CONTAMINATION OF PARK SOILS IN BACĂU AND BUCHAREST (ROMANIA)

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Abstract. *Urban soils, particularly those from parks and playgrounds, represent critical environments for assessing the exposure risk of children to heavy metals. This study investigated the degree of soil contamination with heavy metals in four parks located in Bacău and Bucharest (Romania). Soil samples were collected from three depths (0, 10, and 30 cm) and analyzed using the X-ray fluorescence (XRF) technique. Contamination with heavy metals was assessed through the Potential Mobility (PM), Individual Pollution Index (PI), Pollution Load Index (PLI), and the Zonal Pollution Load Index (ZPLI). The results indicated that concentrations of Cr and Pb frequently exceeded the Romanian legal thresholds for sensitive soils, with Pb levels in Morarilor Park (Bucharest) surpassing the intervention limit. In Bacău parks, moderate contamination was observed, mainly driven by Cr and Pb.*

Keywords**:** *urban soil; heavy metals; pollution indices.*

1. INTRODUCTION

Particularly in large cities, urban parks constitute vital spaces for recreation and social interaction. Given their frequent use by children, these green areas play a vital role in supporting both physical and mental health. However, in the context of rapid urbanization and escalating pollution, urban parks, especially those located in high-traffic zones, may act as reservoirs for heavy metals and other toxic substances [1, 2].

Children, in particular, are considered a vulnerable group regarding exposure to heavy metal pollution, as their behaviors increase the risk of direct contact with soil. They are more prone to putting dirty hands in their mouths, which facilitates the ingestion of contaminated soil. Moreover, children spend considerable time in playgrounds, where their intense activities can resuspend fine dust particles from polluted soil, thereby amplifying the risk of their inhalation. These particles may contain toxic metals, and human exposure can lead to adverse health outcomes such as damage to internal organs, neurological disorders, and even increased cancer risk. In conclusion, due to their active behavior and higher rates of dermal absorption, children are at substantially greater risk compared to adults [3, 4].

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Heavy metals, such as lead and cadmium, are particularly dangerous to human health. Lead is considered a carcinogenic substance and can cause severe neurological effects, especially in children, affecting their mental and physical development. Exposure to cadmium can lead to kidney disorders, lung damage, and even an increased risk of cancer. Other metals, such as arsenic and nickel, are also toxic and can cause pulmonary and dermatological diseases, being associated with cancer risks [4, 5].

In urban areas, anthropogenic activities represent the main sources of pollution. For instance, lead and other heavy metals can be released into the atmosphere through fossil fuel combustion, as well as from the wear of vehicles and construction materials [5]. In this context, the monitoring of playgrounds and other areas frequently used by children becomes a priority. This requires continuous evaluation of soil contamination levels to prevent long-term health problems, while remediation efforts and environmental protection measures can help reduce risks to children's health. Furthermore, raising the public awareness of the risks associated with heavy metal exposure and implementing effective soil pollution prevention strategies are essential measures for minimizing exposure and protecting the health of both the children and the environment [2, 6].

This paper aimed to determine the concentrations of heavy metals in park soils from Bacau and Bucharest municipalities in Romania, using X-ray fluorescence (XRF) spectrometry – a fast and non-destructive analytical technique that provides reliable data on soil multielemental contamination levels [2, 7].

2. MATERIALS AND METHODS

2.1. MATERIALS

This study presents soil quality in two major Romanian cities: Bacău and Bucharest. Soil samples were collected from four representative parks: Cancicov Park and Cathedral Park (Bacău), and Herăstrău Park and Morarilor Park (Bucharest).

The municipality of Bacău represents an urban, economic, and cultural hub of regional importance, playing a strategic role in connecting Moldova with other regions of the country. It is located in the northeast of Romania, and according to 2021 data, the city has a population of 136,087 inhabitants and covers an area of 43.1 km². The city is crossed by the Bistrița River [8].

Cancicov Park and Cathedral Park in Bacău are two emblematic green spaces that significantly contribute to improving urban quality of life through their ecological, social, and aesthetic roles. Cancicov Park, the largest park in the city, covers an area of approximately 24 hectares and is distinguished by its diverse vegetation, including mature tree species that absorb carbon dioxide and release oxygen, while also contributing to reducing temperature and urban noise. The park features well-developed infrastructure, with wide pedestrian alleys, cycling tracks, children's playgrounds, and rest areas, making it an attractive destination for residents of all ages. At the same time, Cathedral Park, located in the center of the city, offers a complete landscape with ornamental flowers, green lawns, and young trees, creating a relaxing atmosphere and enhancing the aesthetic appearance of the urban area [9].

Bucharest, the capital of Romania, is the country's largest city, with a population of over 2 million inhabitants. Herăstrău Park is the largest park in Bucharest, covering an area of approximately 110 hectares around Herăstrău Lake. Its diverse vegetation includes mature tree species such as poplars, oaks, and chestnuts, alongside landscaped areas with ornamental flowers and decorative shrubs. The park presents a wide range of infrastructure, such as walking paths, cycling tracks, playgrounds, sports fields, and restaurants.

By contrast, Morarilor Park, located in the eastern part of Bucharest, is smaller in size, covering approximately 16 hectares. Nevertheless, it stands out through its well-maintained landscape design, which includes an artificial lake and a variety of plant species, thereby supporting urban biodiversity. Its infrastructure consists of paved alleys, relaxation areas, and a modern children's playground, making it an important yet more localized green space within the city [10].

Soil samples were collected in October 2024. The geographic coordinates of each sampling location were determined using a Magellan eXplorist 310 GPS device. At each site, composite soil samples were taken from three depths: surface (0 cm), 5 cm, and 30 cm. Each composite sample weighed approximately 0.8 kg. The geographic coordinates of the sampling points are provided in Table 1.

Table 1. Geographic coordinates of the sampling points.

Sample location	Sample code	GPS Coordinates
Cancicov Park, Bacău (F)	Cancicov (F)	46°33'33.4"N, 26°54'42.3"E
Cancicov Park, Bacău (P)	Cancicov (P)	46°33'38.2"N, 26°54'36.0"E
Catedralei Park, Bacău (F)	Catedralei (F)	46°34'11.6"N, 26°54'46.9" E
Catedralei Park, Bacău (P)	Catedralei (P)	46°34'12.8"N, 26°54'46.9" E
Herăstrău Park, Bucharest (F)	Herăstrău (F)	44°28'01.9"N, 26°04'46.3" E
Herăstrău Park, Bucharest (P)	Herăstrău (P)	44°28'12.5"N, 26°04'50.5" E
Morarilor Park, Bucharest (F)	Morarilor (F)	44°26'17.9"N, 26°10'12.6" E
Morarilor Park, Bucharest (P)	Morarilor (P)	44°26'23.2"N, 26°10'19.8" E

For the analysis, soil samples were prepared at the laboratories of the INPOLDE Research Center, Faculty of Sciences and Environment, "Dunarea de Jos" University of Galati, Romania. The samples were air-dried and cleaned of stones and vegetation residues. The dried soil was ground and then sieved through a 250 µm mesh. The finely ground soil was placed into labeled capsules appropriate for X-ray fluorescence (XRF) analysis, using Mylar films to support the sample and Millipore filter paper [2, 7, 11].

2.2. METHODS

The XRF analyses were performed at the Faculty of Engineering, "Dunarea de Jos" University of Galati, using an INNOV-X System ALPHA SERIES 4000 (INNOV-X System Inc., Woburn, MA, USA) portable XRF spectrometer, specifically calibrated for soil examination. The device is equipped with a silver-anode X-ray tube with a beryllium window and a silicon PIN diode for radiation detection. Analytical quality control was performed using Certified Reference Materials (CRMs) [2]. Each soil sample was irradiated three times for 120 seconds per measurement, ensuring reproducibility and accuracy of the elemental analysis.

The pollution levels of the soil samples were assessed using indices such as the Potential Mobility index (PM) [7, 12], Individual Pollution Index (PI), Pollution Load Index (PLI), and the Zonal Pollution Load Index (ZPLI) [7, 13].

Potential Mobility (PM) is calculated by applying Equation (1) to estimate the mobility of contaminant elements in the soil depth, as well as the presence of pollution across different soil horizons, helping to identify their sources:

$$PM = \sum_{i=1}^{n} \left(\frac{c_i}{c_T}\right) D_i \quad (1)$$

where *n* represents the number of soil layers, c_i is the concentration of the target element in the soil sample at layer *i*, $c_T = \sum_{i=1}^{n} c_i$ is the sum of the concentrations from all depths, and D_i is the sampling depth in centimeters; in this study, the depths D_i are 1, 5, and 30 cm. The resulting values can range from 1, if the elements are entirely accumulated in the top centimeter of soil, to 30, if they are concentrated at 30 cm depth. Potential mobility (PM) is classified into four categories: A (PM < 5), very low; B (5 < PM < 10), moderate; C (10 < PM < 20), high; and D (PM > 20), very high [7, 12].

The Individual Pollution Index (PI) is calculated to assess the degree of anthropogenic pollution by comparing it to a background concentration. This index is used to identify which chemical elements pose the greatest threat to the soil environment. The Individual Pollution Index was calculated using Equation (2):

$$\mathrm{PI(i)} = \frac{\mathrm{c(i)_{soil}}}{\mathrm{c(i)_{background}}} \quad (2)$$

where: $\mathrm{c(i)_{soil}}$ is the concentration of the identified element „i" in the soil, and $\mathrm{c(i)_{background}}$ is the background concentration of the chemical element „i", as reported in the literature for the Earth's crust [7].

Using simple indices, such as the Individual Pollution Index (PI), complex indices can be calculated, allowing for a comprehensive assessment of metal pollution at a specific location or in a region by considering the concentration of all identified potentially toxic elements. Among these are the Pollution Load Index (PLI), defined by Equation (3) as the geometric mean of the PI values, and the Zonal Pollution Load Index (ZPLI), presented in Equation (4) as the geometric mean of the PLI values [7].

$$\mathrm{PLI(S_k)} = \left[\sqrt[n]{\mathrm{PI(1)} \times \mathrm{PI(2)} \times \ldots\ldots \times \mathrm{PI(n)}}\right]_k \quad (3)$$

$$\mathrm{ZPLI} = \sqrt[m]{\mathrm{PLI(S_1)} \times \mathrm{PLI(S_2)} \times \ldots\ldots \times \mathrm{PLI(S_m)}} \quad (4)$$

Regarding the indices in Equations (3) and (4), *k* refers to the studied sampling location, *n* is the number of heavy metals considered, and *m* is the number of sampling points. Soil contamination categories for the obtained PI, PLI, and ZPLI values can be found in previous work [7, 13].

Data processing was carried out at INPOLDE Research Center, "Dunarea de Jos" University of Galati, using Microsoft Excel 2019.

3. RESULTS AND DISCUSSION

3.1. RESULTS

Following the soil analyses, were obtained information regarding concentrations for 18 elements, among which the following were found only in certain samples: Se was detected only in Cancicov Park, near the fence at the 0 cm depth and at the playground at 30 cm depth, with the same concentration of 3 mg·kg⁻¹; Ag was identified only in the soil from Catedralei Park, at the playground at 30 cm depth, with a value of 3.8 mg·kg⁻¹; in Morarilor Park, the playground was the only location where Sn was detected at 5 cm depth (61 mg·kg⁻¹) and Hg at 30 cm depth (8 mg·kg⁻¹).

Table 2. Concentration values of minor elements identified in the soil samples.

Sample location	Depth [cm]	Minor elements [mg kg^{-1}]									
		Cr	Ni	Cu	Zn	As	Rb	Sr	Zr	Ba	Pb
Cancicov Park (F)	0	98.50	42.50	29.33	144.33	7.00	80.33	129.67	234.67	399.00	53.00
	5	127.50	41.67	38.33	168.67	9.00	89.67	141.67	219.67	362.50	61.33
	30	131.67	41.00	42.67	128.67	n.d.	83.33	154.00	245.00	310.00	69.33
Cancicov Park (P)	0	98.00	36.50	29.67	87.33	n.d.	80.00	91.33	305.33	312.00	32.67
	5	130.50	37.00	29.33	85.67	7.00	82.67	97.00	297.00	296.00	42.67
	30	112.00	n.d.	28.00	79.67	7.00	81.00	134.33	256.67	319.00	37.67
Catedralei Park (F)	0	n.d.	39.00	30.67	90.00	6.00	78.00	127.67	244.67	346.00	27.67
	5	109.00	n.d.	30.00	85.00	n.d.	80.33	130.67	257.00	342.00	34.67
	30	120.50	n.d.	35.00	94.67	n.d.	75.67	156.33	262.67	367.00	40.33
Catedralei Park (P)	0	98.50	35.00	32.00	109.00	n.d.	66.00	133.33	360.33	372.00	39.33
	5	109.50	39.00	38.33	125.33	n.d.	78.00	141.33	235.33	346.00	49.33
	30	111.67	44.50	40.33	148.33	n.d.	76.67	158.67	259.00	327.50	49.00
Herăstrău Park (F)	0	102.33	47.50	44.00	123.67	9.00	83.00	108.67	252.00	472.67	78.00
	5	120.00	46.00	41.33	112.33	10.00	87.33	112.33	264.67	377.00	63.67
	30	97.33	36.00	31.00	80.00	7.00	81.33	134.33	254.00	348.33	40.67
Herăstrău Park (P)	0	94.00	32.00	33.33	152.67	n.d.	76.00	123.67	225.00	454.00	73.00
	5	126.50	38.00	33.00	135.67	n.d.	70.00	135.33	260.00	396.67	106.00
	30	128.00	48.50	44.33	143.33	9.00	80.33	125.00	322.33	545.67	61.00
Morarilor Park (F)	0	118.33	38.00	36.67	155.33	n.d.	94.33	124.00	320.00	n.d.	87.67
	5	140.33	45.00	51.33	243.00	n.d.	92.00	144.33	264.33	432.00	149.00
	30	126.33	47.33	67.00	293.00	n.d.	95.33	107.67	278.00	429.00	145.67
Morarilor Park (P)	0	120.33	54.33	51.67	202.67	12.00	87.00	106.33	296.67	330.33	72.67
	5	131.67	65.00	42.00	166.33	8.00	91.67	103.67	286.33	440.67	77.00
	30	127.00	57.00	38.33	138.00	9.00	93.67	103.33	280.67	383.00	64.00
Average value		116.50	43.37	38.24	137.19	8.33	82.65	124.78	270.06	378.62	64.81
Maximum value		140.33	65.00	67.00	293.00	12	95.33	158.67	360.33	545.67	149.00
Minimum value		94.00	32.00	28.00	79.67	6	66.00	91.33	219.67	296.00	27.67
Standard deviation		13.56	8.03	9.12	52.20	1.67	7.56	18.59	33.37	60.95	31.87
Average value [1]		60	18	13	52	7.03	86.8	130	-	-	22.6
Normal values for sensitive areas[1]		30	20	20	100	5	-	-	-	200	20
Alert values for sensitive areas[1]		100	75	100	300	15	-	-	-	400	50
Intervention values for sensitive areas[1]		300	150	200	600	25	-	-	-	625	100
European average values[2]		94.8	37.3	17.3	68.1	11.6	86.8	130	251	400	32.6
Average values in the continental crust[3]		92	47	28	67	4.8	84	320	193	624	17

[1]Guideline values for trace elements in soils (Order no. 756/03.11.1997) [16]; [2]Salminen, 2005 [14]; [3]Rudnik and Gao, 2005 [15]; n.d.= not detected; - = not specified.

Table 2 presents the concentrations of minor elements alongside the Romanian legislative standards for sensitive soils.

Additionally, the European average concentrations, obtained from [14], were included, as well as the average values in the continental crust, as reported by Rudnik and Gao [15]. These values served as reference points for the calculations in Equations (1–4). The results obtained from the application of Equations 1–4 are summarized in Tables 3–5.

Table 3. Values of Potential Mobility (PM) for the identified elements

PM	Cr	Ni	Cu	Zn	As	Rb	Sr	Zr	Ba	Pb
Cancicov (F)	13.10	11.83	13.60	10.98	3.25	11.96	12.83	12.42	10.74	13.28
Cancicov (P)	12.07	3.01	11.68	11.50	17.50	12.00	14.28	11.05	10.60	12.18
Catedralei (F)	18.13	1.00	12.86	12.44	1.00	11.73	13.19	12.31	12.19	13.74
Catedralei (P)	12.50	13.21	12.95	13.55	-	12.49	12.92	10.89	11.13	12.76
Herăstrău (F)	11.33	10.48	10.15	9.76	10.35	11.76	12.23	11.93	11.95	8.86
Herăstrău (P)	14.29	14.15	13.81	11.89	30.00	12.53	11.85	13.87	17.55	10.14
Morarilor (F)	11.97	12.91	14.86	14.70	-	12.12	11.35	11.58	14.03	13.61
Morarilor (P)	12.11	11.85	10.69	10.21	11.10	12.32	11.89	11.75	13.09	11.13

Table 4. Values of the Individual Pollution Index (PI) for the Identified Elements

PI		Cr	Ni	Cu	Zn	As	Rb	Sr	Zr	Ba	Pb
Cancicov (F)	0	3.28	2.13	1.47	1.44	1.40	0.93	1.00	0.93	2.00	2.65
Cancicov (F)	5	4.25	2.08	1.92	1.69	1.80	1.03	1.09	0.88	1.81	3.07
Cancicov (F)	30	4.39	2.05	2.13	1.29	-	0.96	1.18	0.98	1.55	3.47
Cancicov (P)	0	3.27	1.83	1.48	0.87	-	0.92	1.70	1.22	1.56	1.63
Cancicov (P)	5	4.35	1.85	1.47	0.86	1.40	0.95	0.75	1.18	1.48	2.13
Cancicov (P)	30	3.73	-	1.40	0.80	1.40	0.93	1.03	1.02	1.60	1.88
Catedralei (F)	0	-	1.95	1.53	0.90	1.20	0.90	0.98	0.97	1.73	1.38
Catedralei (F)	5	3.63	-	1.50	0.85	-	0.93	1.01	1.02	1.71	1.73
Catedralei (F)	30	4.02	-	1.75	0.95	-	0.87	1.20	1.05	1.84	2.02
Catedralei (P)	0	3.28	1.75	1.60	1.09	-	0.76	1.03	1.44	1.86	1.97
Catedralei (P)	5	3.65	1.95	1.92	1.25	-	0.90	1.09	0.94	1.73	2.47
Catedralei (P)	30	3.72	2.23	2.02	1.48	-	0.88	1.22	1.03	1.64	2.45
Herăstrău (F)	0	3.41	2.38	2.20	1.24	1.80	0.96	0.84	1.00	2.36	3.90
Herăstrău (F)	5	4.00	2.30	2.07	1.12	2.00	1.01	0.86	1.05	1.89	3.18
Herăstrău (F)	30	3.24	1.80	1.55	0.80	1.40	0.94	1.03	1.01	1.74	2.03
Herăstrău (P)	0	3.13	1.60	1.67	1.53	-	0.88	0.95	0.90	2.27	3.65
Herăstrău (P)	5	4.22	1.90	1.65	1.36	-	0.81	1.04	1.04	1.98	5.30
Herăstrău (P)	30	4.27	2.43	2.22	1.43	1.80	0.93	0.96	1.28	2.73	3.05
Morarilor (F)	0	3.94	1.90	1.83	1.55	-	1.09	0.95	1.27	-	4.38
Morarilor (F)	5	4.68	2.25	2.57	2.43	-	1.06	0.88	1.05	2.16	7.45
Morarilor (F)	30	4.21	2.37	3.35	2.93	-	1.10	0.83	1.11	2.15	7.28
Morarilor (P)	0	4.01	2.72	2.58	2.03	2.40	1.00	0.82	1.18	1.65	3.63
Morarilor (P)	5	4.39	3.25	2.10	1.66	2.60	1.06	0.80	1.14	2.20	3.85
Morarilor (P)	30	4.23	2.85	1.92	1.38	1.80	1.08	0.79	1.12	1.92	3.20

Table 5. Values of the Pollution Load Index (PLI) and Zonal Pollution Load Index (ZPLI) for soils from the two studied cities

Sample location and depth		PLI	Sample location and depth		PLI
Cancicov (F)	0	1.58	Herăstrău (F)	0	1.77
Cancicov (F)	5	1.76	Herăstrău (F)	5	1.73
Cancicov (F)	30	1.74	Herăstrău (F)	30	1.43
Cancicov (P)	0	1.36	Herăstrău (P)	0	1.62
Cancicov (P)	5	1.44	Herăstrău (P)	5	1.76
Cancicov (P)	30	1.37	Herăstrău (P)	30	1.88
Catedralei (F)	0	1.23	Morarilor (F)	0	1.83
Catedralei (F)	5	1.38	Morarilor (F)	5	2.16
Catedralei (F)	30	1.51	Morarilor (F)	30	2.26
Catedralei (P)	0	1.51	Morarilor (P)	0	1.95
Catedralei (P)	5	1.60	Morarilor (P)	5	1.91
Catedralei (P)	30	1.80	Morarilor (P)	30	1.79
ZPLI		***1.51***	***ZPLI***		***1.83***

3.2. DISCUSSION

The concentration of major and minor soil elements in different areas varies primarily due to the characteristic mineralogy of the parent material, while contamination sources play a more significant role for minor elements.

Major elements are present in much higher concentrations, typically are found in the range of 1,000–40,000 mg·kg^{-1} [17].

In the present study, the major elements that can support proper plant development in parks will be further discussed for all the studied locations.

Iron (Fe) is one of the eight major soil elements, comprising 5% of the Earth's crust. It reduces the mobility of As, Cd, Cu, Ni, Pb, and Zn, so slightly elevated Fe concentrations in soils at Morarilor Park may be advantageous [18]. In this study, Fe ranged from 30,403 mg·kg^{-1} at Morarilor Park (30 cm) to 16,772.67 mg·kg^{-1} at Catedralei Park (0 cm).

Titanium (Ti) occurs in rocks at 0.3–1.4%, averaging 0.33%. Its low solubility and high hardness make it highly stable in soils, contributing to soil genesis studies. In the analyzed samples, concentrations ranged from 3,044.67 mg·kg^{-1} at Catedralei Park to 5,395.33 mg·kg^{-1} at Herăstrău Park. Ti sources are mainly industrial, including Ti alloys and Ti-based paint production, but they pose a minimal environmental risk [19].

Manganese (Mn), alongside Fe, is abundant in the Earth's crust, typically 350–2,000 mg·kg^{-1} (average 434 mg·kg^{-1}). In this study, Mn ranged from 461.33 mg·kg^{-1} at Cancicov Park to 693.67 mg·kg^{-1} at Herăstrău Park. Mn is widely used in steel and other alloys, pigments, ceramics, and glass, and manganese sulfate is applied in fungicides.

A. Bacău

Most of the samples, taken both near the fence, where they are typically exposed to traffic, and in the playground areas, contain high concentrations of elements considered potentially toxic. In this case, chromium (Cr), as can be seen in Table 2, concentrations reached up to four times the legal limit, often surpassing the alert threshold for sensitive soils (100 mg·kg^{-1}), while lead (Pb) exceeded the alert threshold and exhibited high mobility, posing a significant health risk.

Regarding the playgrounds, they are not significantly less polluted than the areas studied near the park fences, as can be observed in Figure 1. Even though the levels are often lower, they still exceed the normal reference values established by the Order 756/1997 [16] for sensitive soil. For example, Cr, Pb, Ni, Cu, and As are found above the standard reference values. The presence of these elements in areas frequently used by children is concerning.

Selenium (Se) was detected only in Cancicov Park, with concentrations of 3 mg kg^{-1} at both surface (near the fence) and 30 cm depth (playground). These values equal the alert threshold for sensitive areas, exceeding the normal background level of 1 mg kg^{-1} set by legislation. Although Se is an essential trace element, elevated concentrations may pose health risks, particularly for children, due to potential gastrointestinal, neurological, and developmental effects [20].

For the parks in Bacău, Ba concentrations exceeded the normal values at all locations, sometimes even surpassing the alert threshold. Recorded concentrations ranged between 309.00 mg·kg^{-1} and 357.17 mg·kg^{-1}. Barium (Ba) is used in pigments and certain brake pads [21]. In this study, Ba levels are comparable to those reported in a study on parks in Galați by Ene et al. [2].

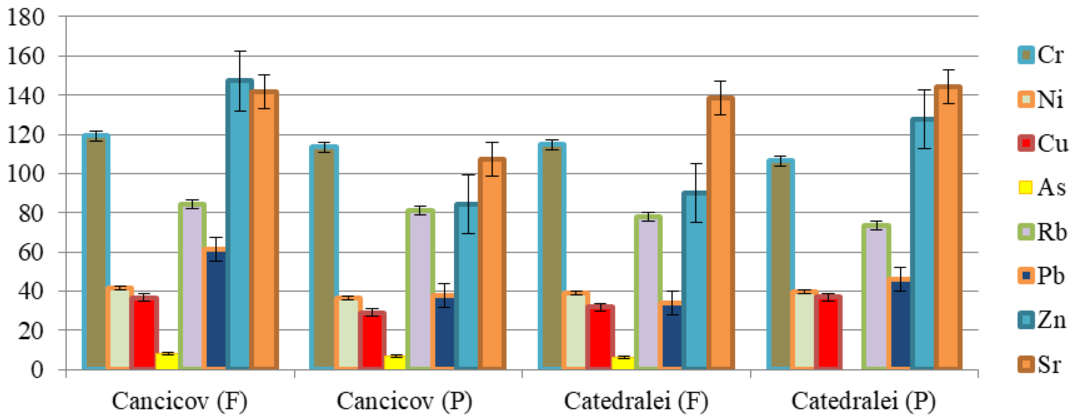

Figure 1. Graphical representation of depth-averaged minor element concentrations in soil samples collected from parks in Bacău city.

The potential mobility (PM) index was determined to assess the degree of mobility of elements identified in soil samples collected and the classification highlights both very low mobility elements due to their stability in soil such as As and Ni and high mobility elements, with greater potential for transfer and environmental impact, such as Cr, Ni, Cu, Zn, As, Rb, Sr, Ba, Pb. In general, at this location, no elements with low potential mobility (PM between 5 and 10) or very high potential mobility (PM greater than 20) were identified, as can be noticed in Table 3.

The individual pollution index (PI) indicates that chromium (Cr) is the most polluting element (PI values between 3 and 6), while most of the other elements fall within the moderate pollution range, as can be observed in Figure 2.

As can be seen in Table 5, the contamination pollution index (PLI) ranged from 1.37 to 1.70 across all locations, and anthropogenic pollution is evident. Although pollution did not reach very high levels (PLI > 6), all values indicate moderate contamination.

In the studied areas, the most likely sources are heavy traffic, followed by potential industrial contributions. Soils in the Cancicov and Catedralei parks in Bacău are moderately contaminated with heavy metals, which may pose a risk to human health, especially for children. These values are comparable to other national studies in Bacau, Iasi, Bucharest, Cluj, and Galati [1,2,22–28], highlighting a widespread issue of urban heavy metal pollution.

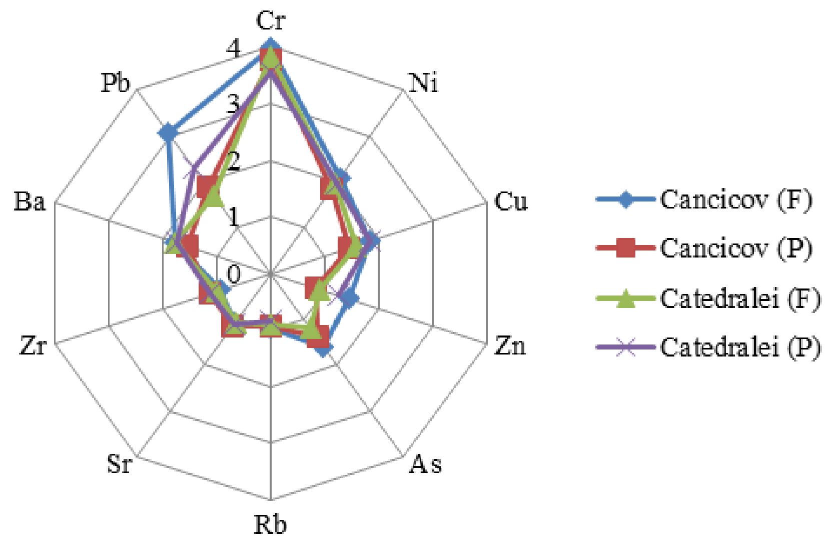

Figure 2. Graphical representation of PI values of minor elements for Bacău City.

If we consider the values from the continental crust [15], the contamination pollution index (PLI) ranges between 0.92 and 1.25. These values indicate no pollution at the Cancicov Park playground, while pollution is present at the other locations. The highest value was recorded at the Cancicov location near the fence.

B. Bucharest

Elements such as Cr, Pb, As, and Ni frequently exceeded reference and intervention thresholds, as can be observed in Figure 3, all of which are toxic and may have severe effects, particularly on children.

In Herăstrău and Morarilor Parks, Ba exceeded the intervention threshold, with concentrations ranging from 384.67 to 465.44 mg·kg^{-1}, as can be observed in Table 2. Barium affects the cardiovascular, renal, respiratory, nervous, and endocrine systems, and at high concentrations can cause neurological and metabolic disorders, and even death in severe cases [29].

Compared with national data, Cr and Pb levels in Bucharest parks, especially Cr, were significantly higher than those reported in other Romanian cities, including Bacău, Iași, Cluj, and Galați [1, 2, 22–28].

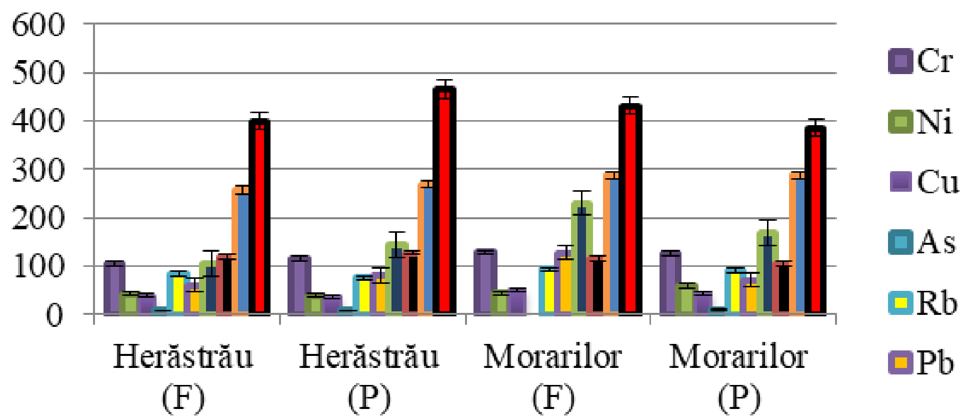

Figure 3. Graphical representation of depth-averaged minor element concentrations in soil samples collected from parks in Bucharest City.

Regarding Pb, its concentrations in soils from Bucharest were higher than those reported in all the other cities mentioned earlier, with the exception of the maximum value recorded by [28] in soils from Cișmigiu Park, Bucharest, which reached 199.8 mg·kg^{-1}. The high Pb concentration in Cișmigiu was explained by the authors through the park's diverse vegetation and complex structure, which favors the accumulation of both wet and dry atmospheric deposits in the soil. Dense vegetation prevents pollutant particles from resuspending into the air, leading to the progressive build-up of metals in the soil.

The average value of 84.86 mg kg^{-1} recorded in this work in Bucharest for Pb in soils was higher than the values found for soils from Vienna, Austria, where Pb had an average concentration of 79 mg·kg^{-1} [30]. In Vienna, elevated levels of Cd, Cu, and Pb were observed, attributed mainly to traffic emissions from a nearby highway.

In Budapest, Pb concentrations ranged from 173 to 292.8 mg·kg^{-1} [31], up to 3.7 times higher than the mean value obtained in this study for Bucharest. Average concentrations of Cr, Cu, and Ni were comparable with values reported for Budapest [31], while the mean concentration of 162 mg·kg^{-1} Zn in this study is nearly four times higher.

As can be noticed in Table 3, the potential mobility (PM) determined for Herăstrău Park was classified as follows: moderate for the elements Zn (9.76) and Pb (8.86); high for the elements Cr (11.33), Ni (10.48), Cu (10.15), As (10.35), Rb (11.76), Sr (12.23), Zr (11.93), and Ba (11.95) in the area near the fence, and high for the elements Cr, Ni, Cu, Zn, Rb, Sr, Zr, Ba, and Pb, and very high for the element As in the playground area.

The individual pollution index (PI) determined for Herăstrău Park (area near the fence) and presented in Table 4, indicated the following classification of elements: low ($PI < 1$) for Zn (30 cm), Rb (0 and 30 cm), and Sr (0 and 5 cm); moderate ($1 \leq PI < 3$) for Ni, Cu, Zn (0 and 5 cm), As, Rb (5 cm), Sr (30 cm), Zr, Ba, and Pb (30 cm); and considerable ($3 \leq PI < 6$) for Cr and Pb (0 and 5 cm).

The individual pollution index (PI) calculated for Herăstrău Park (playground area), found in Table 5, revealed the following classification of elements: low ($PI < 1$) for Rb, Sr (0 and 30 cm), and Zr (0 cm); moderate ($1 \leq PI < 3$) for Ni, Cu, Zn, As (30 cm), Sr (5 cm), Zr (5 and 30 cm), and Ba; and considerable ($3 \leq PI < 6$) for Cr and Pb. At this location, no element produced a very high pollution level ($PI \geq 6$).

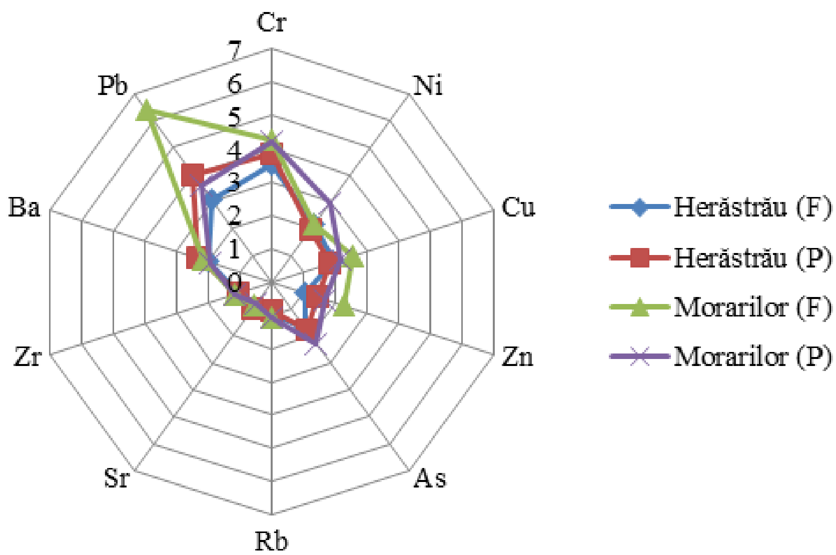

Figure 4. Graphical representation of PI values of minor elements concentrations for Bucharest City.

The playground area from Herăstrău Park showed a slightly higher cumulative pollution index (PLI = 1.75) compared to the fence area (PLI = 1.64). Arsenic (As) also displayed very high mobility in the playground soils, amplifying its toxic risk.

As can be seen in Table 2, in Morarilor Park, close to the fence, contamination was more severe. The average values for Pb (127.77 mg kg^{-1}) exceeded the intervention threshold for sensitive land, and Cr (128.33 mg·kg^{-1}) was also present at elevated levels. The playground was considerably contaminated with Cr, Ni, and Pb, though the highest PLI was recorded at the fence (2.08), exceeding even the maximum in Herăstrău (1.75). Additionally, Cu and Ni concentrations increased with depth, suggesting older and more persistent pollution.

The potential mobility (PM) determined for Morarilor Park and presented in Table 3 was classified as high for the elements Cr (11.97), Ni (12.91), Cu (14.86), Zn (14.70), Rb (12.12), Sr (11.35), Zr (11.58), Ba (14.03), and Pb (13.61) identified in the samples collected near the fence, and high for the elements Cr (12.11), Ni (11.85), Cu (10.69), Zn (10.21), As (11.10), Rb (12.32), Sr (11.89), Zr (11.75), Ba (13.09), and Pb (11.13) identified in the playground area samples.

Across both parks, the element vertical mobility values were generally high, indicating that heavy metals can be easily assimilated by plants, animals, and humans.

For Morarilor Park, the area near the fence was characterized by low pollution (PI < 1) for Sr; moderate pollution (1 ≤ PI < 3) for Ni, Cu (0 and 5 cm), Zn, Rb, Zr, and Ba (5 and 30 cm); considerable pollution (3 ≤ PI < 6) for Cr, Cu (30 cm), and Pb (0 cm); and very high pollution (PI ≥ 6) for Pb (5 and 30 cm). In the playground area**,** low PI values (PI < 1) were recorded for Sr; moderate values (1 ≤ PI < 3) for Ni (0 and 30 cm), Cu, Zn, As, Rb, Zr, and Ba; and considerable values (3 ≤ PI < 6) for Cr, Ni (5 cm), and Pb, presented in Table 4.

Considering the continental crust values reported by [15], the contamination pollution index (PLI) values presented in Table 5, for the Bucharest parks ranged from 1.01 to 1.53, indicating pollution at all the sites. The minimum value was recorded in Herăstrău Park at 30 cm depth near the fence, while the maximum was measured in Morarilor Park, also at 30 cm depth near the fence, as can be observed in Figure 5. This trend is consistent with that observed when using the background values established by legislation.

The Zonal Pollution Load Index (ZPLI), obtained for Bucharest, was 1.83, higher than the value obtained for Bacău (1.51). Since both values were greater than 1, according to the ZPLI classification (Table 5), both studies indicate anthropogenic pollution, more pronounced in Bucharest.

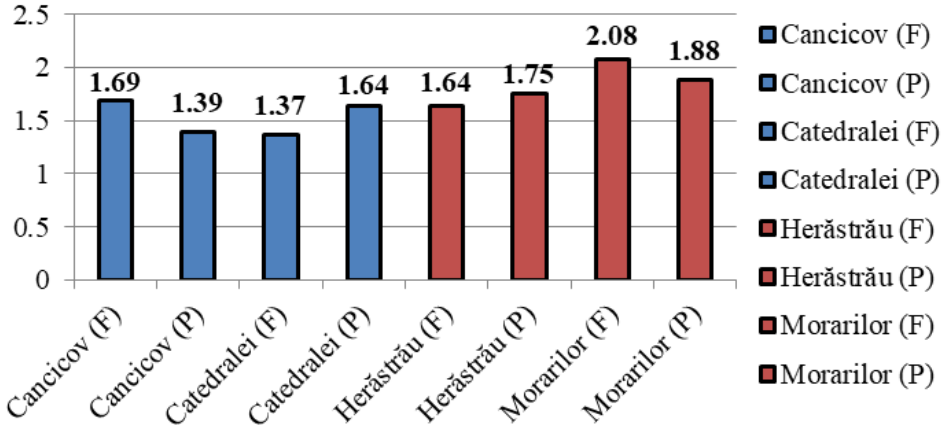

Figure 5. Graphical representation of the PLI values of minor elements concentrations in park soils from Bacău and Bucharest.

On the other hand, according to the model proposed by Ene et al. [7], which used continental crust values from Rudnik and Gao [15] as background, the zonal cumulative pollution index (ZPLI) was found to be equal to 1.28 in Bucharest and 1.06 in Bacău, indicating anthropogenic pollution in both cases. These values are comparable to those reported for an industrial steel-making area in Galați, where ZPLI reached the value 1.45 in the immediate vicinity of the steel plant facilities, and 1.20 in the surrounding industrial zone [13].

4. CONCLUSIONS

Soil samples collected from the urban parks in Bacău and Bucharest, Romania, revealed notable differences in heavy metal concentrations and pollution levels. In Bacău, concentrations of elements such as Cr, Pb, Ni, Cu, and As exceeded the standard reference values, while in Bucharest, Cr, Pb, As, and Ni frequently surpassed both the reference and intervention thresholds.

Comparisons with data from other Romanian cities and European capitals (Vienna and Budapest) showed that Bucharest exhibited higher Cr and Pb levels than other Romanian locations, with Pb and Zn concentrations comparable to or exceeding those reported in other capitals.

Assessment of pollution indices, including Potential Mobility (PM), Individual Pollution Index (PI), Pollution Load Index (PLI), and Zonal Pollution Load Index (ZPLI), indicated that the soils from Bucharest parks exhibit higher depth potential mobility of chemical elements and greater overall contamination compared to those in Bacău. PM values above 10 for most of the elements in Bucharest soils confirm a high potential mobility class, while ZPLI values above 1 in both cities indicate anthropogenic pollution, more pronounced in Bucharest.

These results underline the environmental and public health implications of heavy metal accumulation in urban green areas. Given the frequent use of these spaces by children – a particularly vulnerable group – continuous monitoring, effective remediation, and soil protection strategies are essential to minimize exposure and preserve both the health of children and the quality of the urban environment.

Our findings highlight the potential health risks associated with children’s direct contact with contaminated soils in urban recreational areas and emphasize the necessity for regular monitoring and application of appropriate remediation strategies to reduce metal exposure.

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