

SESSION E: THERMAL TECHNIQUE AND ENVIRONMENTAL PROTECTION

Monitoring of heavy metals and their movement through the environment of the city of Kragujevac

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ABSTRACT

This paper analyzes the presence, distribution and trends in concentrations of heavy metals (lead, cadmium, nickel, zinc, arsenic and chromium) in different environmental media - air, surface water and soil - in the territory of the city of Kragujevac over a three-year period (2022, 2023 and 2024). Special focus is placed on identifying the main sources of pollution, such as industrial activities, traffic and individual combustion plants. Data were collected through regular annual and monthly monitoring reports conducted by city departments and the Serbian Environmental Protection Agency (SEPA). Metal concentrations in suspended particulate matter (PM10) and sediments were analyzed at key measurement sites (Mala Vaga, Medical School). Although most parameters are within the legally permitted limits, continuous monitoring is necessary, especially in urban areas with high traffic volumes. The results for 2024 indicate the need for further integration of local environmental action plans to reduce emissions of carcinogenic metals and protect public health.

KEYWORDS

Heavy metals, Air pollution, Soil, Monitoring, Environment.

1. INTRODUCTION

Heavy metals represent one of the most significant groups of environmental pollutants due to their toxicity, persistence, and ability to accumulate in living organisms [1]. Unlike organic pollutants, heavy metals are non-biodegradable and may remain in environmental compartments for long periods, causing adverse ecological and health effects [2].

Industrialization, urbanization, increased traffic intensity, and fossil fuel combustion have considerably contributed to the release of heavy metals into the atmosphere, water bodies, and soils [3]. Urban environments are particularly vulnerable to heavy metal contamination because multiple anthropogenic sources operate simultaneously. Traffic emissions, industrial production, waste disposal, domestic heating, and atmospheric deposition contribute to elevated concentrations of toxic metals such as lead, cadmium, chromium, nickel, zinc, and arsenic [4].

The city of Kragujevac is one of the major industrial and urban centers in Serbia, characterized by intensive traffic, industrial activity, and population growth. Historical industrial development, particularly in the automotive and metal-processing sectors, has contributed to environmental pressures and potential contamination by hazardous substances. Continuous environmental monitoring is therefore essential for evaluating pollution levels, identifying pollution sources, and assessing ecological and public health risks [5].

The aim of this study was to evaluate the occurrence and distribution of selected heavy metals in air, surface water, and soil within the territory of Kragujevac during the period 2022–2024. The study also aimed to identify the dominant sources of contamination and assess temporal trends in heavy metal concentrations.

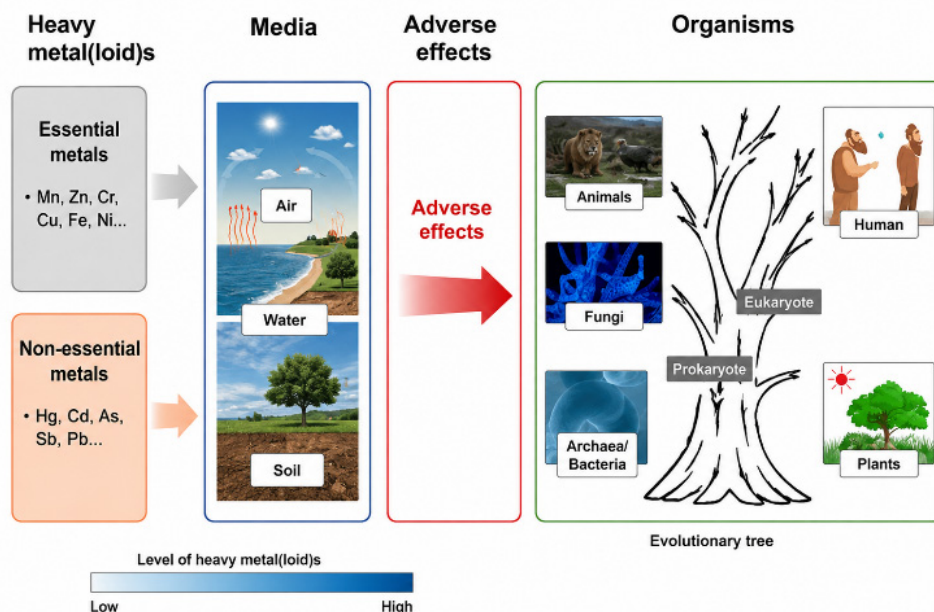


Figure 1: The cycle of heavy metals in nature

2. MATERIAL AND METHODS

2.1. Study Area

Kragujevac is located in central Serbia and represents an important administrative, industrial, and transportation center. The city is characterized by moderate continental climate conditions and a developed urban-industrial infrastructure. It is in the geographical center of the country, 145 km south of Belgrade. The city is located at an altitude of 173-220 m, with a mathematical-geographical position of + 44° 22'; +20° 56'. According to the 2022 census, there were 146.315 inhabitants, making it the fourth most populous settlement in Serbia [6].



Figure 2 a) Geographical position of Kragujevac in Serbia. b) Aerial view of the urban area of Kragujevac

2.2. Sampling and Monitoring

Environmental monitoring data were collected from official annual and monthly reports prepared by municipal environmental departments and the Serbian Environmental Protection Agency for the years 2022, 2023, and 2024 [7]. The analyzed environmental media included:

- Ambient air (PM10 suspended particles)
- Surface water and sediments
- Urban soil

Air quality monitoring was conducted at key urban locations including Mala Vaga, and the Medical School area, representing zones with intensive traffic and urban activity. In addition to the planned residential area with a large number of residential buildings, this urban area also comprises single-family housing estates equipped with individual heating units. The following heavy metals were analyzed:

- Lead (Pb)
- Cadmium (Cd)

- Nickel (Ni)
- Zinc (Zn)
- Arsenic (As)
- Chromium (Cr)

2.3 Analytical Methods

Heavy metal concentrations were determined using standard analytical procedures recommended for environmental monitoring [8]. PM₁₀ samples were collected using automatic samplers, while soil and sediment samples were collected according to standardized environmental protocols. The collected samples were subjected to laboratory analysis using atomic absorption spectrometry (AAS) and inductively coupled plasma optical emission spectrometry (ICP-OES), depending on the monitored parameter. Measured concentrations were compared with national environmental quality standards and permissible limits prescribed by Serbian environmental legislation (Official Gazette of the Republic of Serbia, 2018) [9].

3. RESULTS AND DISCUSSION

3.1 Heavy Metals in Ambient Air

The results presented in Table 1 indicate temporal variations in the concentrations of Cd, Pb, Ni and As associated with PM₁₀ particles during the monitoring period from 2022 to 2024 in the city of Kragujevac.

Table 1: Measurement results for Cd, Pb, Ni and As measurements by month for 2022

Target value for the average value of the total content of suspended particles PM ₁₀	Month and year / maximum measured value			
	5 ng/m ³	-	20 ng/m ³	6 ng/m ³
	Cd (ng/m ³)	Pb (µg/m ³)	Ni (ng/m ³)	As (ng/m ³)
2022.				
January	< 0.5	< 0.003	< 0.9	< 0.9
February	< 0.5	0.014 ± 0.003	15.0 ± 3.4	< 0.9
March	< 0.5	0.023 ± 0.005	< 0.9	< 0.9
April	< 0.5	<0.003	< 0.9	< 0.9
May	< 0.5	0.0187 ± 0.038	5.8 ± 1.3	< 0.9
June	< 0.5	0.0120 ± 0.025	4.3 ± 1.0	< 0.9
July	< 0.5	0.084 ± 0.017	16.5 ± 3.8	< 0.9
August	< 0.5	<0.003	< 0.9	< 0.9
September	< 0.5	0.050 ± 0.010	< 0.9	< 0.9
October	< 0.5	0.026 ± 0.005	1.4 ± 0.3	< 0.9
November	< 0.5	0.046 ± 0.009	< 0.9	< 0.9
December	< 0.5	<0.003	2.0 ± 0.5	< 0.9

Table 2: Measurement results for Cd, Pb, Ni and As measurements by month for 2023

Target value for the average value of the total content of suspended particles PM ₁₀	Month and year / maximum measured value			
	5 ng/m ³	-	20 ng/m ³	6 ng/m ³
	Cd (ng/m ³)	Pb (µg/m ³)	Ni (ng/m ³)	As (ng/m ³)
2023.				
January	< 0.5	0.025 ± 0.005	2.0 ± 0.5	< 0.9
February	< 0.5	0.018 ± 0.004	< 0.9	4.4
March	< 0.5	0.038 ± 0.008	10.6 ± 0.9	< 0.9
April	< 0.5	0.038 ± 0.008	10.6 ± 0.9	< 0.9
May	< 0.5	0.043 ± 0.009	< 0.9	< 0.9
June	3.8 ± 0.7	0.080 ± 0.016	9.5 ± 2.2	< 0.9
July	1.0 ± 0.2	0.025 ± 0.005	2.6 ± 0.6	< 0.9
August	1.0 ± 0.2	0.004 ± 0.001	< 0.9	< 0.9
September	3.3 ± 0.6	0.449 ± 0.092	< 0.9	< 0.9
October	< 0.5	<0.003	< 0.9	< 0.9
November	0.9 ± 0.2	0.026 ± 0.005	9.1 ± 2.1	< 0.9
December	< 0.5	<0.003	< 0.9	< 0.9

Table 3: Measurement results for Cd, Pb, Ni and As measurements by month for 2024

Target value for the average value of the total content of suspended particles PM10	Month and year / maximum measured value			
	5 ng/m ³	-	20 ng/m ³	6 ng/m ³
	Cd (ng/m ³)	Pb (µg/m ³)	Ni (ng/m ³)	As (ng/m ³)
	2024.			
January	1.5 ± 0.3	0.054 ± 0.011	2.7 ± 0.6	3.2
February	1.7 ± 0.3	0.047 ± 0.010	3.7 ± 0.9	< 0.9
March	< 0.5	0.029 ± 0.006	2.8 ± 0.6	< 0.9
April	< 0.5	<0.003	< 0.9	< 0.9
May	< 0.5	0.007 ± 0.002	3.5 ± 0.8	< 0.9
June	0.8 ± 0.1	0.068 ± 0.014	3.3 ± 0.4	< 0.9
July	3.3 ± 0.6	0.084 ± 0.017	3.0 ± 0.7	< 0.9
August	8.7 ± 1.6	0.233 ± 0.048	51.5 ± 11.7	< 0.9
September	4.5 ± 0.8	<0.003	5.5 ± 1.3	< 0.9
October	< 0.5	0.0014 ± 0.003	< 0.9	< 0.9
November	0.9 ± 0.2	0.0039 ± 0.008	11.2 ± 2.5	< 0.9
December	< 0.5	0.012 ± 0.003	< 0.9	< 0.9

Monitoring results showed the presence of heavy metals associated with PM10 particles at all investigated locations. The highest concentrations were generally observed during the winter season due to increased emissions from domestic heating and unfavorable meteorological conditions [5].

Nickel and chromium concentrations were occasionally elevated in zones influenced by traffic and industrial emissions. Seasonal variability indicates a strong influence of anthropogenic activities in combination with meteorological conditions that favor the accumulation of pollutants. Zinc was also frequently detected, mainly originating from tire wear, brake abrasion, and industrial activities [3]. Lead concentrations remained relatively low compared to historical values due to the elimination of leaded gasoline; however, its presence in airborne particles still indicates ongoing anthropogenic influence. Cadmium and arsenic concentrations were generally below prescribed limit values but require continuous observation because of their carcinogenic potential and cumulative toxic effects [10]. The obtained results indicate that traffic emissions and fossil fuel combustion remain the dominant sources of airborne heavy metals in urban areas of Kragujevac.

3.2. Heavy Metals in Soil

Soil analysis demonstrated spatial variability in heavy metals concentrations depending on land use and proximity to pollution sources [7]. Urban soils located near roads and industrial facilities showed higher concentrations of nickel, zinc, chromium, and lead compared to suburban areas [3].

Nickel and chromium exhibited the highest concentrations among the analyzed metals, which may be associated with industrial activities, atmospheric deposition, and traffic-related emissions. Zinc concentrations were also elevated in areas with intense vehicular activity [4].

Although most concentrations remained within legally permitted values, the continuous accumulation of heavy metals in urban soils may represent a long-term ecological concern because soils act as a sink for persistent pollutants [1].

3.3. Heavy Metals in Surface Water and Sediments

Heavy metals were detected in both surface water and sediment samples. Sediments generally showed higher metal concentrations due to the accumulation of contaminants over time [2].

The presence of nickel, chromium, and zinc in sediments indicates the influence of urban runoff, industrial discharge, and atmospheric deposition. Seasonal fluctuations were observed, particularly after periods of intensive precipitation when runoff increases the transport of pollutants into aquatic ecosystems.

Although the measured concentrations did not indicate severe contamination, sediments may act as secondary pollution sources through remobilization processes under changing environmental conditions [11].

3.4. Temporal Trends (2022–2024)

Comparative analysis of monitoring data revealed relatively stable trends in most heavy metal concentrations during the investigated period. Slight increases in PM10-associated metals were observed during winter months and in highly urbanized zones.

The results for 2024 suggest moderate environmental pressure associated with urban traffic and energy consumption. Continued urbanization and industrial activity may contribute to future increases in pollutant levels if adequate mitigation measures are not implemented [5].

4. ECOLOGICAL AND HEALTH IMPLICATIONS

Heavy metals may cause significant adverse effects on ecosystems and human health even at relatively low concentrations [10]. Chronic exposure to lead and cadmium may affect the nervous system, kidneys, and cardiovascular system, while nickel, chromium, and arsenic are recognized for their carcinogenic potential [5].

Airborne particulate matter containing toxic metals represents a particular risk in densely populated urban environments because inhalation exposure directly affects the respiratory system. Soil contamination may additionally contribute to pollutant transfer into plants and food chains [1].

The obtained results indicate that current pollution levels in Kragujevac do not represent critical ecological contamination; however, preventive measures and continuous environmental monitoring remain essential for sustainable urban environmental management.

5. CONCLUSIONS

This study evaluated the occurrence and distribution of heavy metals in air, soil, surface water, and sediments in the city of Kragujevac during the period 2022–2024. The main conclusions are as follows:

1. Heavy metals including Pb, Cd, Ni, Zn, As, and Cr were detected in all investigated environmental media.
2. Most measured concentrations were within legally permitted limits.
3. Elevated concentrations were periodically observed in urban zones affected by traffic and industrial activities.
4. Traffic emissions, industrial processes, domestic heating, and atmospheric deposition were identified as the dominant pollution sources.
5. Sediments and soils act as long-term reservoirs for heavy metals and may contribute to secondary contamination.
6. Continuous environmental monitoring is necessary due to the cumulative and toxic effects of heavy metals on ecosystems and human health.
7. The results highlight the importance of strengthening local environmental protection strategies and emission reduction measures.

Future studies should include expanded spatial monitoring, bioavailability assessments, and advanced ecological risk analyses to improve understanding of heavy metal behavior in urban environments.

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